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REPORT OF THE SUPERINTENDENT

OF THE

U. S. COAST AND GEODETIC SURVEY

SHOWING

THE PROGRESS OF THE WORK

DURING THE

FISCAL YEAR ENDING WITH

JUNE, 1880.

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Annual Report of the Superintendent of the Coast Survey

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LETTER

OF THE

SECRETARY OF THE TREASURY,

TRANSMITTING

Report of the Superintendent of the Coast and Geodetic Survey, for the year ending June 30, 1880.

DECEMBER 21, 1880.—Ordered to lie on the table and be printed.

TREASURY DEPARTMENT, *December* 17, 1880.

SIR: In accordance with section 4690, United States Revised Statutes, I have the honor to transmit herewith, for the information of the Senate, a report addressed to this department by Carlile P. Patterson, Superintendent of the United States Coast and Geodetic Survey, showing the progress made in that work during the year ending June 30, 1880, and also an engraved sketch illustrating the general advance in the operations of the survey.

Very respectfully,

JOHN SHERMAN,
Secretary.

HON. WILLIAM A. WHEELER,
Vice-President of the United States, President of the Senate.

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ABSTRACT OF CONTENTS OF REPORT.

CONTENTS OF APPENDICES.

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ALPHABETICAL INDEX.

C.

D.

E.

F.

I.

J.

K.

N.

O.

P.

Q.

R.

S.

REPORT.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, D. C., December 16, 1880.

SIR: I have the honor to transmit herewith a detailed report showing the progress made in the work of the United States Coast and Geodetic Survey during the year ending June 30, 1880.

The system pursued during the year in carrying forward the operations of the Survey has been, as heretofore, designed to secure uniform development in the different classes of work. With limited appropriations the progress in each branch can be made to correspond, but, as before stated, the cost of individual results is increased by limitation in means. The drawing and engraving of charts must be kept even with the progress of work in the field and afloat, else in many cases results would become obsolete by changes in shore lines, depths, and channel courses. In order to furnish points for the topography and hydrography, the triangulation must be duly advanced, and the requisite computations must be made in the office before triangulation points can be available for such uses. The same is true of other branches of the service. Moreover, the scope of the Survey has been enlarged by the necessity for geodetic work in the interior. Geological surveys in progress in most of the States now demand precise determinations of position for the correction of State maps, and this requirement has been met as far as appropriations would allow.

In submitting estimates for the ensuing fiscal year the attention of the department was called to these facts, and suggestions were repeated for prosecuting the work on the basis most conducive to economy.

Soundings in the Gulf of Mexico and Caribbean Sea have developed new and interesting facts in regard to the physical formation of the basins of those waters and the flow of the Gulf Stream. That work will be noticed under the head of Section VI in the body of this report.

Near the close of the fiscal year a party was sent to the coast of Alaska to make surveys and examinations of the shores of that Territory, and in particular to gain information in regard to the variation of the compass. This party has instructions to extend its work along the coast to Point Barrow, in the Arctic Ocean, the most northern point of land of the American continent. It is confidently expected that the results will greatly improve the charts and sailing directions now depended on for navigating the waters adjacent to that Territory.

The constantly growing importance to the country, of the triangulation of the States, the measurement of the arc of the parallel of thirty-nine degrees between the Atlantic and the Pacific coasts, and early arrangements for measuring an arc on the meridian of ninety-nine degrees west of Greenwich (the longest available meridian arc on the American continent), require increased facilities to meet the urgent needs of our wondrously developing territory. In the several States geological and other surveys are now in progress in accordance with their increasing industries, all demanding accurate maps that can be obtained only by triangulation conducted under one system. The whole, when completed, will form true bases for maps of the several States as well as for the whole country. For want of appropriations sufficient to keep pace in geodetic work, these geological surveys and other developments in the States are much in advance of the triangulation, and this relation between public work and local requirements is greatly to the disadvantage of the States. From State authorities applications are frequent to advance the triangulation more rapidly in order to meet urgent wants, but the appropriations have been insufficient to meet such requisitions.

In Great Britain and Ireland, with an aggregate area less than one-half the State of Texas, there are now employed on the topography alone twenty-two hundred persons, and in Hindostan

(India), containing but one-half the area of this country, there are at present employed fifty-seven hundred persons on triangulation and topography alone; but the largest number ever employed at any one time on the triangulation and topography of the Coast and Geodetic Survey has been less than four hundred. It is therefore apparent that the amounts appropriated are inadequate for prosecuting in this country the class of work deemed requisite by enlightened people of other nations.

The measurement of the largest possible meridian arc on the North American continent is imperatively demanded, not only by the science of the day, but by every material interest of the States through which it will pass. This meridian is the ninety-ninth west from Greenwich, and, fortunately for the purpose, passes through the States of Texas, Kansas, Nebraska, Indian Territory, and the Territory of Dakota, including twenty-three degrees of latitude = thirteen hundred and eighty geographical and nearly sixteen hundred statute miles, and so lies that it can be extended through the British possessions on the north and Mexico on the south, with a possible length of over 50° = three thousand geographical or nearly thirty-five hundred statute miles. Striking, as this meridian arc does, through the middle of the arc of the thirty-ninth parallel, the two will form the grandest work of the kind that can be attempted by any single government, and will be the most valuable contribution yet made to our knowledge of the form of the earth.

I dwell on this subject with urgency on account of its importance, and because of the length of time necessary for the completion of the work under the most favorable auspices. Hence, it should be continued with steady energy and sufficient means.

The investigation of the "Gulf Stream" and the laws controlling its action progresses slowly for want of funds. But this problem involves researches in regard to the circulation of nearly the whole North Atlantic Ocean, including the Caribbean Sea and Gulf of Mexico, for its due solution. Only one small steamer can, with our present appropriation, be employed on this work, and for but one-half the year. Thus, it is evident that progress must be slow in the collection of facts of every character relating to the physical condition of so vast an area.

The facts obtained during the past three years tend greatly to modify the views formerly entertained in regard to the Gulf Stream, notably in reference to the quantity of water passing into the Caribbean between Cuba and San Domingo, and the development of the plateau off Charleston over which the stream runs. No conclusions even of a general nature can be arrived at until all the waters of the Gulf Stream are traced from their sources throughout their circulation, and the whole of the sea bottom over which the stream flows can be developed. To accomplish these results within any reasonable time would require the use of not less than three steamers to be employed during at least nine months in each year. For a due advance in this important problem, probably the most important to the commercial world of all ocean problems, nothing less can be asked. To illustrate the importance of the deep-sea soundings with reference to this investigation, it may be stated that during the past year, in a portion of the Gulf Stream flowing through the Caribbean Sea, where a depth of not more than one thousand fathoms was expected, an actual depth of thirty-four hundred and fifty fathoms or nearly twenty-one thousand feet was found, and along our southern Atlantic coast, in a locality where a depth of not less than one thousand fathoms was expected, a depth of but two hundred and seventy fathoms was found.

The necessity for the rapid prosecution of this important work is most urgent at present on account of the benefits that may be expected to accrue to commerce, not only along our own coasts, but between this country and Europe.

Part III of Mr. William Ferrel's Meteorological Researches for the Coast Pilot has been in progress during the year. This will contain a thorough investigation of the hypsometrical formula, especially with reference to the effect of temperature and barometric gradients; and also the discussion of various observations obtained for verifying the principal constant of the formula. A set of tables in English measure will be given, based upon the most recent and convenient formula, and with constants derived from Regnault's determinations of the densities of mercury and air, and the constant of expansibility of air by heat. Mr. Ferrel has made a full discussion of the six years' observations of tides at Pulpit Cove, coast of Maine, by the harmonic analysis, and also designed a tide-computing machine that promises to save the immense labor involved in the computations for predicted tides.

The following synopsis of the field and office operations of the year ending June 30, 1880, corresponds in character with items included in the detailed estimates submitted for the work of the fiscal year ending June 30, 1882. As heretofore, the work done will be recapitulated in geographical order, beginning with the coast of Maine and closing with the coast of Alaska and points in the geodetic survey. My annual report will show in detail the prosecution of topography at the head of Frenchman's Bay, coast of Maine; hydrography of Union River and Morgan's Bay; also, of Blue Hill Bay and of the southeastern approaches to Mount Desert Island; soundings in Frenchman's Bay and Flanders Bay; development of the vicinity of Johnston's Rock in Casco Bay, and of outer Green Island Ledge; soundings on Morris Rock near the coast of New Hampshire; tidal observations at North Haven in Penobscot entrance; triangulation for the geodetic connection in Northern New Hampshire; reconnaissance for geodetic work in Vermont; triangulation in that State; magnetic declination, dip, and intensity determined at Eastport and Bangor, Me.; at Portsmouth and Hanover, N. H.; at Cambridge and Nantucket, Mass.; at Rutland, Vt.; at Halifax (Nova Scotia); and at Quebec and Montreal, in Canada; examination and securing marks at stations of the primary triangulation along the shores of Buzzard's Bay and Martha's Vineyard Sound; and tidal observations at Providence, R. I.; sea currents observed at stations between Nantucket and the entrance of Delaware Bay; tidal observations at the Block Island Breakwater; ground marks renewed at stations of the primary triangulation in New York, Connecticut, and Delaware; topography and hydrography of the coast of Long Island eastward of Rockaway, N. Y.; detailed survey of the shores of Hudson River below West Point; magnetic declination, dip, and intensity determined at Rouse's Point and at Albany, N. Y., at Sandy Hook, N. J., and at Hartford, Conn.; reconnaissance for geodetic work in Northern New York; pendulum observations at Brooklyn, N. Y., and at stations in Pennsylvania; tidal observations at Sandy Hook; coast topography of the vicinity of Cape May; geodetic operations in Northern New Jersey; determinations of latitude at stations along the northern boundary of Pennsylvania; triangulation of the Delaware River from League Island downward to Tonkin's Island; life-saving stations determined in position on the coast of Delaware, Maryland, and Virginia; geodetic operations continued west of the Blue Ridge in West Virginia; hydrographic survey of Patapsco River, Md., from Lazaretto Point to Hawkins' Point; special hydrographic examination of the vicinity of oyster beds in Chesapeake Bay; deep-sea soundings, dredgings, and records of temperature on sections across the Gulf Stream at intervals between George's Bank and Charleston, S. C.; magnetic declination, dip, and intensity determined at Beaufort, N. C.; hydrography of the coast of North Carolina from Ocracoke Inlet to Cape Lookout, and from Barren Inlet to New Inlet; magnetic declination, dip, and intensity determined at Charleston, S. C.; astronomical observations and exchange of telegraphic signals there for determining the longitude of Atlanta, Ga.; determination of the latitude of Atlanta; magnetic declination, dip, and intensity determined at Jacksonville, Saint Augustine, Enterprise, Eau Gallie, Saint Lucie, and Fort Jupiter, Fla.; hydrography of Charlotte Harbor and approaches, Fla.; astronomical observations and exchange of telegraphic signals at New Orleans for determining longitude at Baton Rouge, La.; observations for latitude at the last-named station; topography of the vicinity, and measurement of base line; magnetic declination, dip, and intensity determined at New Orleans, and line of levels from that city upward to Fort Adams; triangulation of the Mississippi River from Donaldsonville upward to Baton Rouge, and from Bayou Sara upward to stations above Milliken's Bend; topography of the vicinity of Donaldsonville, Baton Rouge, and Grand Gulf; soundings in the Mississippi at Grand Gulf; and lines of level from the last-named point upward to Milliken's Bend; secondary base lines measured at Lum's Point and Lake Providence; hydrography of the coast of Texas southward and westward of Matagorda Island; triangulation of the southern part of Laguna Madre and adjacent coast of Texas; magnetic declination, dip, and intensity at Tortugas, Alacran Reef, Cay Arenas, Vera Cruz, Coatzacoalcos, Lagunas, Campeche, and Progressa, in the Gulf of Mexico; deep-sea soundings, dredgings, and record of temperatures in the eastern part of the Caribbean Sea and adjacent waters; detailed survey of San Nicolas Island off the coast of California; hydrography of that vicinity, and soundings near San Clemente Island and Santa Barbara Island; also along the coast south of San Luis Obispo and north of Point Sal; tidal observations inside of San Francisco Bay, at Saucelito; geodetic operations at primary stations on Mount Lola and Round Top for extending the main triangulation eastward across the State oı California; reconnaissance from the same points for additional stations to the southward; development of topographical peculiarities in the region adjacent to Fallen Leaf Lake, Eastern California; triangulation and topography between Walalla and Point Arena, and coast hydrography between Point Arena and Bodega Head; topography of the shores of Columbia River, Oreg., extended from Kalama to Columbia City; reconnaissance for connecting the survey of that river with Puget Sound; soundings in the southern part, and topography of the shores of Puget Sound in the vicinity of Hammersley's Inlet; triangulation of the shores of that inlet; astronomical and magnetic observations at points between Chilkaht and Sitka, and tidal observations commenced at Kadiak, coast of Alaska; tidal observations at Mazatlan, west coast of Mexico, and at the entrance of the harbor of Honolulu, Sandwich Islands; measurement of base line near Louisville, and triangulation for the geodetic survey of Kentucky; similar work extended westward to Nashville, Tenn., from the Lebanon base line and stations occupied northward and eastward of Lebanon; longitude determined by exchange of telegraphic signals at Louisville, Ky., and Nashville, Tenn., and observations for latitude at Louisville; geodetic levels run from Athens in Ohio, to Mitchell in Indiana; triangulation continued in the last-named State, and in Wisconsin; reconnaissance for geodetic work westward of Jefferson City, Mo., and eastward from stations in Colorado; and stations occupied for the geodetic connection eastward from points in Nevada.

Progress commensurate with that of the field work has been made in the course of the fiscal year in the Coast and Geodetic Survey Office. Details comprise the reduction and discussion of all observations, including the arrangement for publication of the records and results; the drawing of hydrographic charts from the original note books; reductions to various scales of original topographical and hydrographic maps for publication; the engraving, electrotyping, printing, photolithographing, and issue of the same, and maintenance of instruments used in the survey. Tide tables of the principal ports of the United States for the year 1881 have been computed and published; the drawings of sixty-three charts have been in progress, and of this number twenty-five have been completed, including ten charts for publication by photolithography; fourteen small harbor charts were also drawn for the Alaska Coast Pilot. Six copper-plate engravings of charts have been begun; one hundred and sixty-eight engraved plates have received additions, and twenty plates have been finished.

An aggregate of twenty-seven thousand eight hundred and sixty-six copies of charts has been issued to sale agents and others; upwards of four hundred copies of the Annual Reports and one thousand and ninety-two copies of the Coast Pilot have been distributed, including the several subdivisions descriptive of the coast between Eastport and New York; and a third volume of the work is now in hand for publication.

ESTIMATES IN DETAIL.

The estimates for continuing work in the eastern division of the Coast and Geodetic Survey during the year ending June 30, 1882, are intended to provide for the following progress:

FIELD WORK.—To continue the topography of the coast of Maine east of Mount Desert; to determine heights at geodetic points between Boston and the Saint Croix, and coefficient of refraction; to complete the hydrography between Penobscot Bay and Narraguagus Bay, and continue soundings in the coast approaches eastward of Petit Manan Island; to continue a topographical and hydrographic survey of Portsmouth Harbor, and make such additional triangulation as may be requisite for that and other surveys on the eastern coast; to continue the triangulation of New Hampshire, determine the position of new light-houses between Eastport, Me., and New York; to continue the triangulation of Vermont; to continue soundings along the coast of Maine, and other offshore hydrography between Cape Cod and Manan, and make special examination for the sailing lines for charts; to continue the observations of sea and tidal currents in the Gulf of Maine; to continue tidal observations and to make such astronomical and magnetic observations as may be required; to continue the survey of the Connecticut River from its mouth to Hartford; to make such examinations as may be required in New York Harbor, and such surveys in its vicinity as may be necessary, including the continuation of the topographical and hydrographic survey of the south coast of Long Island; to make, along this part of the coast, observations on tides and currents; to continue the plane-table survey of the west shore of Hudson River above Haverstraw; to continue triangulation between Hudson River and the north end of Lake Champlain, and between Lake Champlain and Lake Ontario; to make the requisite astronomical observations; to continue the topographical and hydrographic surveys of the coast of New Jersey; to continue the triangulation of New Jersey and Pennsylvania; to connect the Atlantic coast triangulation with that of Chesapeake Bay near the boundary line between Maryland and Virginia; to complete the detailed survey of James River, Va., including the hydrography; and continue the plane-table survey of the Potomac River; to continue westward the main triangulation from the Atlanta base to the Mississippi River, at or near Memphis, including astronomical and magnetic observations; to continue the supplementary hydrography between Cape Henlopen and Cape Henry, and the tidal observations, including also such as may be required in Chesapeake Bay; to continue westward the triangulation in West Virginia along the thirty-ninth parallel; to measure base lines of verification and determine azimuths for the coast triangulation south of Cape Lookout; to make the astronomical and magnetic observations requisite; to continue the offshore hydrography between Cape Henry and Cape Fear; to complete the hydrography of Pamplico Sound and its rivers; to sound the entrance to Cape Fear River; to continue the topographical and hydrographic survey of rivers on the coast of South Carolina and Georgia; to determine azimuths for the triangulation of the coast of South Carolina and Georgia; to continue the detailed survey of sea islands and water passages north and south of Savannah River entrance and make tidal observations; to continue the offshore hydrography between Cape Fear and the Saint John's River, Fla.; to continue southward from Cape Malabar, near latitude 28° north, the triangulation, topography, and hydrography of the eastern coast of Florida, including Indian River; to continue the triangulation, topography, and hydrography of Saint John's River; to make the requisite astronomical observations; to continue hydrography off the eastern coast of Florida from Cape Cañaveral to the southward; to continue soundings and observations for deep-sea temperatures, currents, and dredgings in such parts of the Gulf Stream northward of the latitude and eastward of the meridian of Cape Florida as may be deemed advisable, and also in the Caribbean Sea; and within the same limits such as may be considered advantageous in conjunction with the United States Commission on Fish and Fisheries; to continue the astronomical and magnetic observations requisite throughout the Gulf of Mexico; to complete the hydrography of Charlotte Harbor, Fla., and continue the triangulation, topography, and hydrography of the western coast of Florida between Cedar Keys and Tampa Bay, and between Tampa Bay and Charlotte Harbor; to continue the same classes of work to the southward of Charlotte Harbor; to run lines of soundings and dredging and make observations of sea temperatures in the Gulf of Mexico, and develop the hydrography of the Gulf coast included in field operations; to connect the trigonometrical survey of the Mississippi River at New Orleans with that of Lake Borgne, Lake Pontchartrain, and Maurepas; to continue the triangulation, topography, and hydrography of the Mississippi River above New Orleans to the head of ship navigation; to determine geographical positions and make the astronomical and magnetic observations requisite; to extend the triangulation, topography, and hydrography of the coast of Louisiana westward of the Mississippi Delta, and continue the hydrography of the Gulf of Mexico between the mouths of the Mississippi and Galveston, Tex.; to continue the triangulation, topography, and hydrography of the coast of Texas westward between Sabine Pass and Galveston, and between Corpus Christi and the Rio Grande; to measure a base line of verification and make the astronomical and magnetic observations requisite between Sabine Pass and the Rio Grande; to continue the hydrography of the approaches to the coast of Texas; and triangulation across the States of Ohio, Indiana, Illinois, Missouri, and Kansas to connect the surveys of the Atlantic and Pacific coasts, and continue triangulation in Kentucky, Tennessee, and Wisconsin to furnish points for State surveys; to continue the determination of the positions of new light-houses and life-saving stations along the coast between New York and the Rio Grande; to continue field work for the verification of data for the Coast Pilot; to continue the organized system of magnetic observations required for a complete magnetic survey, and to run lines of levels connecting points in the main triangulation with the sea level.

OFFICE WORK.—To continue the deduction of results by computation from the field operations along the Atlantic and Gulf coasts, and in connection with interior geodetic surveys, including astronomical, geographic, magnetic, hypsometric, and tidal work; to advance the publication of the Coast Pilot for the Atlantic and Gulf coasts, and to complete tidal predictions for the year 1882 for those coasts; to continue the publication of topographical and hydrographic maps and charts and reductions thereof, and to plot the hydrographic surveys; to continue the drawings of sailing chart A, Cape Sable to Cape Hatteras, and of No. 1 and No. 2, Cape Sable to Sandy Hook and Nantucket to Cape Hatteras; to continue the drawing and engraving of the general chart of the Atlantic coast from Quoddy Head to Cape Cod; to begin the drawing and engraving of coast chart No. 2, Machias Bay to Prospect Harbor, and to continue that of coast chart No. 3, Frenchman's and Blue Hill Bays; to finish the engraving of the harbor charts of Frenchman's Bay and Somes' Sound, Blue Hill and Union River Bays, and approaches to Blue Hill Bay and Eggemoggin Reach, and the engraving of the chart of Carver's Harbor; to begin the drawing of the chart of Burnt Coat Harbor; to continue the drawing of the coast chart of Great South Bay, Fire Island, and Long Beaches (new edition); to begin the engraving of the new edition of the chart of Hudson River from Haverstraw to Poughkeepsie, and the drawing and engraving of new topography for coast chart No. 23, Absecom Inlet to Cape May; to commence the drawings of new hydrography for coast charts Nos. 24 and 25, Delaware Bay and River; to begin the drawing of the chart of James River from City Point to Richmond, and to complete the engraving of the charts of James River, Nos. 1, 2, and 3, from Newport News to City Point; to continue the drawing of sailing chart B, from Cape Hatteras to Key West, and the drawings of sailing charts Nos. 3 and 4, Cape Hatteras to Mosquito Inlet, and Mosquito Inlet to Key West; to continue the drawing and engraving of coast chart No. 45, Cape Hatteras to Ocracoke Inlet; to continue the drawings of coast charts Nos. 46, 47, 48, and 49, Ocracoke Inlet to Cape Lookout, Cape Lookout to Bogue Inlet, Bogue Inlet to New Topsail Inlet, and New Topsail Inlet to Cape Clear, and to begin the engraving of these charts; to continue the drawing and engraving of coast chart No. 50, Cape Fear River and approaches; to begin the drawing of the new edition of the chart of Cape Fear River; to complete the drawing and to commence the engraving of coast chart No. 51, part of Long Bay, including Little River Inlet; to complete the drawing and engraving of coast chart No. 52, Winyah Bay, Cape Romain, &c.; to finish the engraving of coast chart No. 53, Winyah Bay to Long Island; to complete the drawing of general coast chart from Saint Mary's River to Cape Cañaveral, and to continue that of Saint John's River south of Jacksonville; to continue the drawing and engraving of the general chart of the coast from Cape Cañaveral to Cape Florida, and to begin the drawing of the chart of Cape Cañaveral Shoals; to commence the drawing and engraving of the general chart of the coast from Key West to Tampa Bay, and to continue the drawing and engraving of the general coast chart from Tampa Bay to Cape San Blas; to complete the engraving of the coast chart, Charlotte Harbor; to begin the drawings of coast charts Nos. 76 and 78, Sarasota Bay and Bayport to Anclote Keys; to continue the engraving of the coast chart, Chassahowitzka River to Cedar Keys; to begin the engraving of the chart of Saint Mark's River (new edition), and the drawing of the chart of Crooked River; to complete the engraving of the coast charts, Apalachee Bay and Apalachee Bay to Apalachicola Bay; to continue the engraving of coast chart, Saint Joseph's Bay to Saint Andrews Bay, and to complete that of coast chart, Saint Andrews Bay to Choctawhatchee Inlet; to begin the drawing of the harbor chart, Saint Andrews Bay; to complete the engraving of the general chart of the coast, Cape San Blas to Mississippi Passes; to continue the drawing and to begin the engraving of general chart of the coast, Mobile Bay to Atchafalaya Bay; to continue the drawing and engraving of coast chart No. 92, Chandeleur and Breton Sounds, and to complete the engraving of coast chart No. 93, approaches to Mississippi Delta; to begin the drawing of coast chart No. 96, Barataria Bay, &c., and to continue the engraving of coast chart No. 99, Point au Fer to Cote Blanche, including Atchafalaya Bay; to commence the drawing and engraving of the general chart of the coast, Atchafalaya Bay to Galveston; to finish the engraving of coast chart No. 108, Pass Cavallo and San Antonio Bays, and to continue that of coast chart No. 109, Aransas and Copano Bays; to continue the drawing and engraving of the general chart of the coast, Galveston to the Rio Grande, and to commence that of coast chart No. 112, Rio Grande, Brazos Santiago, and part of Laguna Madre; for material for drawing, engraving, map printing, for electrotyping and photographing, and for instruments and apparatus.

Total for the Eastern Division, including the Atlantic and Gulf coasts, and involving work in thirty-two States and three Territories, will require $371,000.

For the continuation of the resurvey of Delaware Bay and River, $10,000.

The estimates for continuing work in the Western Division of the Coast and Geodetic Survey of the United States are intended to provide for the following progress:

FIELD WORK.—To make the requisite observations for latitude, longitude, azimuth, and the magnetic elements at stations along the Pacific coast of the United States; to continue offshore soundings along the coast of California, Oregon, and Washington Territory, and tidal observations at San Francisco and such other localities as may be necessary; to continue the main coast triangulation from Monterey Bay to the southward, and from Point Concepcion to the northward, and from San Pedro toward San Diego; to continue the main triangulation of the coast from San Pedro to Point Concepcion; from Cape Mendocino to the northward; from Columbia River north to Puget Sound, and south up the Willamette Valley; to continue the main triangulation through the Sacramento and San Joaquin Valleys, and measure base lines in the Western Division of the survey; to continue the coast triangulation and topography from Newport, Los Angeles County, Cal., towards San Diego; to continue the tertiary triangulation and topography from Point Buchon toward San Simeon, and hydrography between San Diego and Monterey Bay; to develop hydrographic changes in San Francisco Bay and its approaches; to continue triangulation across the States of California, Nevada, Colorado, and the Territory of Utah, along the thirty-ninth parallel, to connect the survey of the Pacific coast with that of the Atlantic, and furnish points for the survey of the States named; to complete the secondary and tertiary triangulation and topography of the coast between Bodega Bay and Point Arena; to continue soundings between Cape Mendocino and the Klamath River; and between Cape Sebastian and Point Orford; to observe currents along the coast and take soundings and temperature observations in the California branch of the Kuro Siwo current; and execute such other hydrographic work as local demands may require; to continue tidal and current observations at the Golden Gate, and observations on ocean currents along the coast of California; to continue the triangulation, topography, and hydrography of the Columbia River; to complete the detailed survey between Cape Sebastian and Crescent City and offshore hydrography at Crescent City Reef; to measure a base line and continue the triangulation of the Strait of Fuca, and the topography and hydrography of Puget Sound and the adjacent waters; to continue the reconnaissance survey of the coast and islands of Alaska, with observations of the tides and currents and the requisite astronomical and magnetic observations; to continue field work for description of the coast and verification of the Coast Pilot of the coasts of California, Oregon, Washington Territory, and Alaska Territory; to continue the organized system of magnetic observations required for a complete magnetic survey; and to run lines of levels connecting points in the main triangulation with the sea level.

OFFICE WORK.—To make computations of the field observations, including astronomical, geodetic, magnetic, and tidal work; to continue the compilation of the Coast Pilot of the coasts of California, Oregon, Washington Territory, and Alaska Territory; to prepare tidal predictions for the year 1882; to continue the publication of topographic and hydrographic maps and charts and the reductions thereof, and to plot the hydrographic surveys; to continue the drawing and engraving of the general chart of the coast, San Diego to Santa Monica; to continue the engraving of the general chart of the coast, Point Vincent to Point Concepcion; to continue the drawing and to begin the engraving of the general chart of the coast, Point Concepcion to San Luis Obispo; to begin the drawing of the chart of Wilmington Harbor, and to complete the engraving of the chart of San Luis Obispo Bay and approaches, and the engraving of the chart of San Francisco Bay entrance (new edition); to continue the drawing and to begin the engraving of the general chart of the coast, Point Reyes to Mendocino City; to continue the drawing and engraving of the general chart of the coast, Point Arena to Cape Mendocino; to begin the drawings and engravings of charts of the harbors of Puget Sound; for materials for drawing, engraving, and map printing, for electrotyping and photographing, and for instruments and apparatus.

Total for the Western Division, including the Pacific coasts, and involving work in four States and eight Territories, will require $246,000.

For repairs and maintenance of the complement of vessels used in the Coast and Geodetic Survey will require $44,000.

For continuing the publication of observations made in the progress of the Coast and Geodetic Survey will require $8,000.

For general expenses of all the work, rent, fuel, for transportation of instruments, maps, and charts, miscellaneous office expenses, and for the purchase of books, maps, and charts will require $30,900.

MISSISSIPPI RIVER SURVEY.

For the uses of the Mississippi River Commission, the survey of that river was of necessity adapted to the physical features to be traversed in a limited period of time. To that end small triangles were laid out so as to avoid expense and delay in cutting lines for sight, and in general the bends of the river were followed with triangle sides forming parts of quadrilaterals. At the same time advantage was taken of openings or clearings back of the levees. Shortening the sides to a range of between one and three miles made it requisite to measure base lines at short intervals in the triangulation. It will be noticed under the head of Section VIII in this report that five lines were measured in the course of the season, and these corresponding in length with the average of the triangle sides, their lengths are assured with an accuracy ordinarily varying between $\frac{1}{5000}$ and $\frac{1}{10000}$ of the distances between the stations.

To keep in perfect check the direction of the triangulation, astronomical azimuths were measured in connection with each of the base lines; and at well-distributed stations along the course of the Mississippi provision was made, in advance, for determining astronomical latitudes and telegraphic longitudes.

In the calculations, if the records of a station show *angles of repetition*, whatever may be the conditions between resulting angles, the conditions are satisfied in the Computing Division by simple adjustment. But if the record contains *directions*, they are treated in the ordinary way, quadrilaterals or other figures being adjusted by the method of least squares, figure after figure. This involves generally four equations for any one case. Next the triangle sides are computed, starting from one of the measured base lines. On reaching the next base of course a small discrepancy appears between the computed and measured length. So also when computation of the latitudes, longitudes, and azimuths is carried over the triangulation, a small difference is found between the computed and observed azimuth as each base line is reached. The computer then selects from the quadrilaterals and other figures treated, the triangles that are best conditioned in regard to shape, between the two base lines; establishes two conditional equations, and by one of these he brings into accord the lengths of the base lines; by the other the two astronomical azimuths. Experience has shown that two equations of this kind should go together, else the adjustment may bring into accord base-lengths at the expense of the direction of the triangulation. At the same time the conditions of the sums of the angles of each triangle are kept, so that the number of equations may rise to forty, fifty, or more, but their solution presents no particular difficulty.

The triangles and positions being recomputed, the base lines and azimuths as well as the angles of the principal triangles will be found in accord, and the latter will satisfy their theoretical values. The secondary and subordinate points of the triangulation are next computed upon the basis of the preceding adjusted values. This process supposes differences of local deflections of the plumb line in azimuth to be small in comparison with errors in observation, or else the triangulation is made to conform to the astronomical azimuth.

Should the number of conditions between any two base lines become inconveniently great, the computations may be started from both base lines and join about midway between them, adopting in that case a mean length and mean azimuth for the junction line, and finally making two adjustments, one from each base to the junction.

The geodetic latitudes and longitudes are those adopted for the triangulation between Mobile and New Orleans. When the work on the Mississippi is completed it will have the support of all astronomical latitudes and all telegraphic longitudes measured in that region. Though the distance in a general line between Memphis and the Passes is about five hundred miles, the apparently slender series of triangles will have considerable strength. As to latitude and longitude, the series will be correctly located, and so also in respect of direction. The length will be true, and in the extension to Saint Louis, the river triangulation will be powerfully supported by junction with the transcontinental arc of the parallel, along which geodetic work has been extended east and west of that city.

ASTRONOMICAL VISION.

Prof. S. P. Langley, director of the Allegheny Observatory, near Pittsburgh, Pa., having occasion to visit Europe in December, 1878, made at my request on Mount Etna (Sicily) some observations relative to astronomical vision, for comparison with others taken within the Territories of the United States. The telescope used was furnished from the United States Naval Observatory by the Superintendent, Admiral John Rodgers, U. S. N., and in addition the instrumental outfit included only a spectroscope from the Allegheny Observatory, provided with a Rutherfurd speculum metal grating of seventeen thousand two hundred and ninety-six lines to the inch, and with collimating and observing telescopes of 1.1 inch aperture. Although banditti do not infest the region around Mount Etna as they do the western end of Sicily, it was deemed advisable by the American minister at Rome, Hon. George P. Marsh, that the observer should be provided with an escort. On his application to the prefect of Catania, a native guide and two soldiers were assigned to accompany Professor Langley.

The observing station has an elevation of about forty-two hundred feet, the hut occupied being on the southeastern side of the mountain. The telescope used has a full aperture of three and a quarter inches, but in experimenting the aperture was reduced, and the following is an abstract of the results, taken from the report of Professor Langley. Respecting Polaris he thus records:

Polaris.—The companion (position previously unknown) recognized with 1.6 inch aperture.

Rigel.—The companion steadily seen with 1.6 inch aperture; not seen with 1.4 inch.

β Leporis.—Companion (magnitude 11) seen with full aperture.

Aldebaran.—Companion (magnitude 11.2) an easy object with full aperture.

θ Orionis.—Fifth star in Trapezium seen when nebula was about 40° high. Full aperture.

ι Orionis.—Third star (magnitude 11) seen with full aperture, in moonlight.

Star pr. δ Orionis.—Magnitude 11, seen with full aperture.

"The observations for stars included many others, but this short list is selected as fairly typical, with the remark that while observing the wind was an almost constant obstacle to steady vision. Considering the distinctness with which stars of the 11th and 11.2 magnitude were observed under unfavorable circumstances, and in moonlight, we shall probably be justified in stating the limit for an aperture employed and *an ordinary eye* at this altitude on Etna, to lie near the 11.5 magnitude of the Bedford Catalogue, or the 10.2 magnitude of Struve."

At any station in America Professor Langley has been able to see only six stars in *Pleiades*, but, even while the moon was shining, he readily recognized nine, from the station at Casa del Bosco, on Etna. His report of observations at that station is quite full in detail. After noting that under an apparently clear sky the definition was less clear than that in previous observations, he thus concludes:

"Upon the whole, though the ideal station where atmospheric tremor does not exist, and the astronomer pursues his observations in an even, transparent sky, is not to be found on any part of the earth's surface yet examined, we find within our own territory, in the dry and elevated tablelands of Colorado and New Mexico or California, every condition which experience points out as favorable, united in a degree which no part of the earth, so far as we can judge, surpasses."

PART II.

The progress made in the Coast and Geodetic Survey in the course of the fiscal year ending June 30, 1880, will be stated in detail in the abstracts which follow. In geographical order going south on the Atlantic coast of the United States and north on the Pacific coast, notice will be taken of the operations in each locality, and in accordance with that arrangement the work done will be stated as usual in tabular form in Appendix No. 1.

As heretofore, brief mention will be made of the work done in the office in a concluding chapter of this report. In details pertaining to the condition of vessels used in the survey, and repairs and outfits, I have had the intelligent and ready assistance of Commander Edward P. Lull, U. S. N., hydrographic inspector. All the hydrographic sheets received within the year have been examined as heretofore by that able officer, in advance of being drawn and engraved as charts.

Lieut. H. E. Nichols, U. S. N., remained on duty in the office of the hydrographic inspector until June, 1880, when he was assigned for service afloat to the charge of the hydrographic party in the steamer Hassler, as will be further mentioned in this report under the head of Section X. He was replaced by Lieut. C. T. Hutchins, U. S. N., an officer well informed in practical hydrography and earnest in the application of his knowledge in details.

Many calls for information, chiefly in regard to nautical distances, are made from year to year, and in order to meet them in future a general table of ocean distances has been taken in hand for compilation. To meet another class of inquiries a table showing the depths that can be carried over the bars of the harbors of the United States is also in preparation.

The Light-House Board from the outset has annually referred the printed lists of lights for the correctio ı of geographical positions, and thus the results found in the Computing Division of the Survey avail as precise determinations accumulate. As heretofore, Assistant Charles A. Schott furnished corrections for the list referred in the course of the fiscal year. Assistant J. S. Bradford revised the list in regard to the orthography of proper names, and checked the bearings of aids to navigation by his own observations previously recorded for the Atlantic Coast Pilot.

Within the year, Lieut. Commander Charles D. Sigsbee, U. S. N., completed his description of the methods used for deep-sea sounding and dredging while he was in charge of the hydrographic party in the Coast and Geodetic Survey steamer Blake. His work has been published with illustrations, and has been much called for as containing the best exposition of the processes followed in deep-sea researches at the present time. To my regret the edition printed has been quite inadequate to meet the demand for the work.

SECTION I.

MAINE, NEW HAMPSHIRE, VERMONT, MASSACHUSETTS, AND RHODE ISLAND.—(SKETCHES NOS. 3, 4, AND 5.)

Topography of Frenchman's Bay, Me.—In previous seasons the plane-table survey of the shores of Frenchman's Bay was well advanced in the direction of the headwaters. For the extension of the work, Assistant H. G. Ogden took the field, and resumed operations on the 22d of July, 1879. Between that date and the close of October the detailed survey was advanced from Ash Point, in Flanders Bay, northward and westward into Franklin Bay, a few miles above the Narrows. Waukeag Neck appears on the plane-table sheet and the surface details of the northwest part of Frenchman's Bay, corresponding to the limit reached by the party in mapping the east shore of Franklin Bay. Further westward Mr. Ogden filled in details requisite for completing the topographical survey of Skilling's River. The villages of Sullivan, East Sullivan, West Sullivan, and Hancock, with part of Crabtree Neck, are shown on the map.

The additional points of triangulation needed at the headwaters of Frenchman's Bay were furnished in August and September by Subassistant W. I. Vinal. Twenty-two positions were determined for the use of the plane-table party, and all requisite data were supplied for prosecuting the hydrography of the waters within the limits of field operations. The statistics of the topography are:

Shore line surveyed, miles	50½
Creeks and ponds, miles	10
Roads, miles	40½
Area of topography, square miles	21

Hydrography of Frenchman's Bay, Flanders Bay, and of the approaches to Blue Hill Bay, Me.—With his party in the steamer Endeavor, Lieut. J. F. Moser, U. S. N., Assistant in the Coast and Geodetic Survey, left New York on the 1st of July, 1879, and after a run of two days was at Portland, Me. Before proceeding farther eastward, search was made for a rock in Casco Bay, the existence of which was made known by Master E. W. Johnson, of the light-house tender Iris. The rock was found and its vicinity developed by soundings. On the 25th of July all the particulars in regard to it were published from the office as a Notice to Mariners.

Soundings were commenced in the approaches to Blue Hill Bay on the 7th of July. As heretofore, all means were taken for procuring information in regard to sunken ledges. The lines were run with great care, and close examination was made if the depth or character of the bottom changed. In the difficult and tedious hydrography of Blue Hill Bay the party was engaged until the 19th of September. That site of work is open to the sea and has many sunken ledges with deep water around them.

For the hydrography of Frenchman's Bay, Assistant Ogden furnished a tracing from the plane-table sheet. The space sounded was between Crabtree Neck and Stave Island. East of Waukeag Neck, Flanders Bay was sounded. In this quarter the hydrography was completed on the 18th of October, 1879. The steamer then proceeded to Portsmouth, N. H., and in that vicinity Moore's Ledge was developed. The shoalest part gave a depth of about eight feet, but the ledge lies well inshore and out of the usual track of vessels.

Lieutenant Moser was assisted in the work here noticed by Masters J. B. Murdock, A. C. Dillingham, and F. E. Greene, U. S. N. The steamer Endeavor reached New York on the 26th of October, and was refitted for service which will be referred to under the head of Section IV. The statistics of work done by the party on the coast of Maine are:

Miles run in sounding	920
Angles measured	11,476
Number of soundings	35,743

Topography of Ellsworth and vicinity, coast of Maine.—Between the 9th of July, 1879, and November 24, of the same year, the topographical survey of the vicinity of Ellsworth, Me., was continued by Assistant A. W. Longfellow. Of the two sheets taken into the field one contained the previously traced shore-line survey of Union River and Bay. On the other had been traced the shores of Jordan's River. Mr. Longfellow extended on the first-mentioned sheet the survey of Union River to the northward and mapped the town of Ellsworth with its wharf lines and streets. The party was employed in that work until the 2d of September, when the instruments were transferred to West Trenton. There the topographical survey was carried from Oak Point to the west bank of Jordan's River, where a junction was made with a previous survey of Assistant Ogden in the middle of October. Assistant Longfellow continued the detailed survey of both sides of Jordan's River until the work was stopped by repeated falls of snow. The statistics are:

Shore line surveyed (high water), miles	9
Shore line surveyed (low water), miles	3½
Streams and ponds, miles	19½
Roads, miles	47
Area of topography, square miles	20½

In the coming season the topographical survey will be continued in the vicinity of Lamoine, and at the upper branches of Frenchman's Bay.

Hydrography of the middle part of Blue Hill Bay, Me.—The hydrographic party of Lieut. Uriel Sebree, U. S. N., Assistant in the Coast and Geodetic Survey, reached Blue Hill Bay in the schooner Silliman on the 15th of July, 1879, and prosecuted soundings until the close of September. Two projections were filled comprising the waters of the main body of the bay, in which lines of soundings were run about an eighth of a mile apart, crossed by others about the same distance asunder. Where shoals or ledges were found or suspected additional lines were run for developing the character of the bottom.

Two tidal stations were occupied while soundings were in progress, and as usual the results of the gauges were checked by simultaneous observations. By a short series of observations the current in the bay at maximum was found to be a little more than one knot.

Lieutenant Sebree was assisted in this section by Ensigns J. W. Stewart and J. C. Colwell, U. S. N., and in the latter part of the working season by Lieut. Perry Garst, U. S. N. The last-named officer has since been assigned to conduct a hydrographic party in the waters of Puget Sound in Section XI.

To the report of Lieutenant Sebree was appended a list of the dangers to navigation in the waters in which his work was prosecuted, together with mention of suitable anchorages and sailing directions. The work done is represented by the following statistics:

Miles run in sounding	387
Angles measured	4, 511
Number of soundings	16, 648

The tides were recorded by upwards of four thousand observations. Thirty-eight signals were erected for hydrographic purposes, and forty-nine positions were occupied on shore for adjusting the soundings.

Hydrography east and west of Mount Desert Island, coast of Maine.—With four projections, Lieut. Commander C. M. Chester, U. S. N., Assistant in the Coast and Geodetic Survey, reached Southwest Harbor at the end of May, 1879, with his party in the steamer A. D. Bache. The hydrography of the vicinity of Mount Desert Island was immediately resumed and steadily prosecuted until the middle of October, and soon after the four sheets were returned to the office with data sufficient to fill them with soundings. In the southeastern approach to Mount Desert Island the work done joins outside with two hydrographic sheets which were completed by other parties in previous years. The second hydrographic sheet of Lieutenant-Commander Chester represents soundings made in the development of what is known as Goose Cove, an indentation of the main coast north of Bartlett's Island. The third sheet represents the hydrography of Union River Bay to the northward and westward of Mount Desert, and the fourth continues the hydrography of the same quarter to the westward of Long Island. In the course of the season the party in the steamer erected one hundred and sixty-five signals, and occupied a hundred and seventy-one stations on shore for verifying the courses of the lines of soundings. Forty-five specimens of bottom were procured and carefully marked with notes of the localities from which they were taken.

Lieutenant-Commander Chester was ably assisted by Master T. G. C. Salter, U. S. N., and by Ensigns Henry Morrell, H. F. Reich, and Charles H. Amsden, U. S. N.

The aggregate statistics of the four hydrographic sheets are:

Miles run in sounding	966
Angles measured	13, 206
Number of soundings	43, 009

As usual, the tides were recorded in each of the localities while soundings were in progress. At the close of the season in this section the steamer Bache was laid up for repairs.

Tidal observations.—The series commenced in January, 1870, at North Haven, on the coast of Maine, has been continued to the present time by Mr. J. G. Spaulding. By the skill and attention of the observer the record of observations has been sent in nearly perfect. The self-registering guage is of the best construction, and is provided with means for heating to protect the action of the apparatus from ice in winter. From the beginning a careful series of meteorological observations has been recorded. When occasional short stoppages were needful for the adjustment or repairs of the tide guage, frequent staff readings were taken and entered to preserve the continuity of the register.

Geodetic operations.—Prof. E. T. Quimby took the field in the middle of July, 1879, for continuing the work of triangulation in the northern part of New Hampshire. Mount Moriah, in Coos County, was first occupied. That summit was reached after traversing a course of seven miles through a heavy growth of timber. Observations were made both for horizontal and vertical angles upon eight outlying stations, two of which are in the State of Maine. On account of the wild nature of the country only a limited number of tertiary or subsidiary points could be observed on, but the directions of many summits were recorded approximately. The erection of definite signals in that region would have entailed much labor and expense. As many of the summits were unknown to Professor Quimby, an eye sketch was taken and marked with numbers, to give means for identifying the mountains in future for mapping that region. Observations at Mount Moriah were completed on the 12th of September. After removing the camp and instruments from the summit of the mountain, a reconnaissance was made at the expense of the State for the remainder of Northern New Hampshire. The geodetic observations are represented by the following statistics in the field report:

Horizontal angles measured	104
Vertical angles	15
Number of observations	3,604

Mr. Walter Aiken, resident at Franklin Falls, N. H., and chiefly interested in the tenure of the summit of Mount Washington, while projecting the erection of a tower for general observations by tourists, obligingly arranged for its construction over the point used by observers of the survey in geodetic measurements. The foundation was so made that instruments may be isolated from the main tower. For this great advantage, the additional outlay for which was considerable, Mr. Aiken generously declined any remuneration.

Geodetic operations.—For continuing the triangulation in Vermont, Prof. V. G. Barbour took the field on the 1st of July, 1879, and after consultation with Assistant Richard D. Cutts erected signals at several points visible from the primary stations which have already been occupied. In August the reconnaissance was continued in the vicinity of Brandon, and subsequently near Goshen and Bethel, in which places additional points were selected so as to be in view from adjacent stations of the primary work. For the triangulation north of Killington, Professor Barbour set up signals on hills at Landon, Goshen, Rochester, and Colton. Proceeding northward other points were examined, and when suitable for geodetic connection signals were set up for perfecting the scheme of triangulation. All the points selected are carefully described in the report on field work.

While Assistant Cutts was at Killington and engaged in the measurement of horizontal angles, Professor Barbour visited that station and employed ten days in practice with the theodolite, observing, as weather permitted, between the 9th and 18th of September, 1879. The remainder of the season was passed in opening lines when requisite to render the stations intervisible. Fourteen in all were selected and described in the record.

Primary triangulation.—In the scheme of geodetic operations for connecting the survey of Lake Champlain with the primary triangulation of the coast of New England, Killington Peak, near Rutland, Vt., was indicated, and at the opening of the fiscal year that station was occupied by Assistant Richard D. Cutts. It connects directly with several primary points of the Coast and Geodetic Survey, and with numerous positions which will be used by Prof. V. G. Barbour for triangulation on account of the geological survey of Vermont. Assistant Cutts left Washington late in June, 1879, and in the course of a few days traced out a sled road for transporting instruments and equipage to the summit of Killington. At the same time he suggested the desirability for public uses of a wagon road to enable citizens and sojourners at Rutland to enjoy the magnificent view from Killington Peak. The citizens responded promptly, subscribed a sum sufficient for the work, and, although hands were scarce and the ground very rough, the road to the summit was practicable for wheeled vehicles on the 14th of July.

Meanwhile, Mr. C. H. Sinclair, aid in the party, had adjusted the signal on Mount Equinox to the southward and westward of Killington, and stationed heliotropers at Prospect Mountain and Blueberry Hill to the northward and westward. Northeast of Killington the summit of Mount Washington was seen on favorable days at a distance of about eighty-eight miles.

The plan of work, as laid out in advance, was to connect with and verify the New Hampshire triangulation; to commence observations for the Vermont series, assisted by Professor Barbour, and to take measures for connecting Lake Champlain with the main triangulation. In pursuance of the general scheme, heliotropers were stationed at Mount Mansfield, Mount Washington, and Gunstock Mountain. When arrangements were complete for the measurement of horizontal angles at Killington, the triangles meeting there as a septagon covered an area of ten thousand six hundred square miles.

The reconnaissance of the southern part of Vermont by Professor Barbour resulted in the selection of many points in sight of Killington, and hence it was desirable that the signals at all such stations should be promptly erected so as to be observed on by Assistant Cutts. This was done to avoid the necessity of reoccupying that station (forty-two hundred and thirty-nine feet high) in the field operations of Professor Barbour. After placing the signals he joined Mr. Cutts and assisted in the observations at Killington for the practice needful with field instruments.

As triangulation advanced in the State of New Hampshire, Professor Quimby selected and observed upon stations in the Green Mountains, and these are included in the scheme laid out by Assistant Cutts. Intermediate points in Vermont, selected by the observer in New Hampshire, will be embraced in the series of triangles laid out by Professor Barbour.

At Killington observations with the theodolite were commenced on the 24th of July, and were completed on the 27th of September. The journal shows that on twenty-four mornings and eighteen afternoons no observations could be recorded. Amongst other obstacles to progress the field report mentions the fog or low clouds present at the high summit generally in the morning. Assistant Cutts remarks: "They frequently hang on during the day, while fifteen hundred or two thousand feet below the summit it is all sunshine."

An unusual number of stations were observed on from Killington Peak. Of these, eleven were primary points at distances varying between fifty and seventy miles, the longest line (88.54 miles) being that to Mount Washington. Eleven signals of the Vermont series were also observed on, and seven subsidiary directions were measured on objects in Rutland and in the Adirondacks. The statistics are thus given in the field report:

Directions observed	29
Number of pointings	1,320
Stations for differences of altitude	13
Zenith distances	255

Before leaving the field in September, 1879, Assistant Cutts arranged with Professor Barbour for reconnaissance to the northward of the present site of work, and under direction the professor visited and marked "Bigelow" as a station. In the latter part of December he visited and carefully examined a number of elevations in Vermont and New York, and carefully reported on the availability of the positions for purposes of triangulation.

Early in June of the present year (1880) Assistant Cutts again took the field and occupied a primary station to the northward of Killington. At the close of the fiscal year the prospects were good for success in his field operations. The station referred to is upwards of four thousand feet high.

Magnetic observations.—The plan of operations for the year included a careful study in regard to points at which magnetic observations would most effectively supplement our previous knowledge respecting the variation of the compass, and magnetic dip and intensity along the coast of New England and the Middle States. In accordance with that view all positions occupied in recent years have been selected in advance. Fourteen additional points were designated in the prospective operations of the season, and as heretofore Subassistant J. B. Baylor was assigned to make the observations. Before taking the field the instruments were tested at the station on Capitol Hill. The stations were occupied in the order in which they were reached in going northward and eastward, but for the sake of convenience the usual geographical order will be observed in mentioning the work. In general each station was occupied on two consecutive days. Two sets of observations for azimuth were recorded at the same place, one set in the morning and one in the afternoon. For the dip of the magnetic needle two sets of observations were made each day, and for the declination one set was recorded daily. Deflections and oscillations were observed by one series of observations daily at each of the stations.

Mr. Baylor took the field early in July. In this section he determined the magnetic declination, dip, and intensity in August at Eastport and Bangor, Me.; at Portsmouth, N. H.; and at Cambridge and Nantucket, Mass. In October the magnetic elements were determined by the same observer at Hanover, N. H., and at Rutland, Vt., on his return from Canada. Proceeding beyond the northeastern boundary in September, Mr. Baylor occupied a station at Halifax in Nova Scotia, and in the same month determined the magnetic elements at Quebec and Montreal in Canada. Other points occupied in the course of the season will be mentioned under the head of Section II in this report.

By the courtesy of the United States consul at Halifax, Mr. Baylor was much aided in arrangements for observing at that place. Admiral Inglefield, of the Royal Navy, took special interest in the observations, and assigned a depository in his own quarters for the safe keeping of the instruments when they were not in use.

The mayor of Quebec was equally obliging when the object sought was brought to his notice by our consul, Maj. John N. Wasson.

At Montreal all needful facilities were accorded by the mayor at the instance of our consul-general, Hon. John Quincy Smith.

Preservation of station marks.—Assistant F. H. Gerdes took the field in July, 1879, and by the close of October personally examined a number of positions at which ground marks had been placed when the points were occupied for the primary triangulation of the coast between Cape Cod and New York. Two of the hills occupied in former years with the theodolite have been so washed by storms as to obliterate the ground marks, but at all others the cones were identified. Fourteen stations were found from the office descriptions. These at the outset of the survey were occupied without the necessity of clearing lines of sight, but all are now sequestered in woods or surrounded by a dense growth of bushes. All the copper bolts were found in place at Falmouth station, on Cape Cod peninsula; at Pine Hill, near Pocasset, Mass.; at Sampson's Hill and Prospect Hill on Martha's Vineyard; and at Spencer Hill and Broad Hill near Point Judith, R. I. The other stations visited being in Section II will be referred to under that head. In that section and also in Section III Mr. Gerdes determined in position several of the recently established life-saving stations. From data thus gained the stations are marked on the engraved coast charts.

Tidal observations.—The self-registering tide gauge lent to the city authorities of Providence, R. I., in 1872 is still kept in operation by the local engineers for the adjustment of surveys which are yet in progress. Records have been received at the office representing six years of the series, and these have yielded valuable results. The final discussion will be made when the series is complete, for developing the law which governs the tides in Narragansett Bay.

SECTION II.

CONNECTICUT, NEW YORK, NEW JERSEY, PENNSYLVANIA, AND DELAWARE.—(SKETCHES NOS. 5, 6, AND 7.)

Sea currents.—In previous reports the successful progress made in determining the character of sea currents off the coast of New England has been recorded. As therein stated, the observations were conducted on board a vessel anchored in positions at which a knowledge of the character of the currents was desirable, the depths being in some cases upwards of one hundred fathoms. The satisfactory issue of observations previously made suggested that the methods adopted should be applied in the sea approaches of New York Bay, and arrangements were made accordingly.

Lieut. S. M. Ackley, U. S. N., Assistant in the Coast and Geodetic Survey, with his party in the schooner Eagre, and provided with the means for observing and recording currents at sea, proceeded on the 6th of August, 1879, and occupied a station about thirty-seven miles south of Martha's Vineyard. The record at that position was continued during thirty-six hours, in which interval it was observed that the current swung entirely around the compass. To the southward of Montauk

Point, and distant forty-six miles, the same result was found on the 21st of that month by observations continued for twenty-seven hours; and also at a third station to the southward and westward off Fire Island beach, where the currents were observed on the last day of August and during a period of twenty-six hours. To the southward and eastward of the last-mentioned position a station was occupied in ninety-nine fathoms during twenty-three hours on the 1st of September. There the current was noticed as vibrating between south, east, and west, as was also found at a fifth station in twenty-nine fathoms off the coast of New Jersey, about forty-eight miles southeast of Absecon Inlet. For the work here under notice the weather was very unfavorable previous to the close of August, but was less so in the following month.

After closing the observations off the coast of New Jersey, Lieutenant Ackley returned to New York, and after refitting the schooner Eagre sailed to the Gulf of Mexico for service, of which further mention will be made in Section IX of this report. He was assisted in both sections by Lieut. H. T. Monahon, U. S. N., Master Frank E. Sawyer, U. S. N., and Ensign Warner H. Nostrand, U. S. N.

Rock off Sakonnet Point, R. I.—With his party in the schooner Silliman, Lieut. Uriel Sebree, U. S. N., Assistant in the Coast and Geodetic Survey, reached Newport on the 11th of October. Bad weather coming on immediately after that date deferred the intended search for a rock off Sakonnet Point, but the vicinity was carefully examined, and soundings were completed by the 2d of November, 1879. The rock was found very nearly in its reported position, and has on it at one point only eight feet at mean low water, but the general depth is twelve feet on the ledge, which is about seventy-five yards long and thirty yards wide. All particulars in regard to this danger to navigation were published in a Notice to Mariners on the 15th of November.

Preservation of station marks.—As already mentioned under the head of Section I, Assistant F. H. Gerdes passed the summer and autumn of 1879 in examining the ground marks placed in former years at the primary stations when they were occupied with the theodolite for the triangulation eastward of New York. In this section he visited Beacon Hill on Block Island; Whiteman's Hill and Watch Hill station in Connecticut; and Osborn, Terry, and Shinnicock in New York. At all, the marks were found undisturbed, and where it seemed desirable additional marks were set for identification in future. The station mark at Buttermilk Hill, near Tarrytown on the Hudson, was examined in October and made secure by suitable points of reference.

In this section Mr. Gerdes visited the life-saving stations at Watch Hill on the coast of Connecticut and at Short Beach on the coast of Long Island, N. Y. Both were determined in position and marked on the topographical sheet of the vicinity. With as little delay as possible the positions of the life-saving stations are marked on the engraved plates of the coast charts.

Tidal observations.—As stated in my last annual report, Mr. C. H. Van Orden made a series of observations at several places on the shores of Buzzard's Bay. In the middle of July, 1879, he established a self registering tide gauge at the Block Island breakwater, and instructed the observer, Mr. J. M. Conley, by whom the record was kept up until the 1st of December.

Topography and hydrography of Hempstead Bay, Long Island, N. Y.—From positions near Far Rockaway the detailed survey of the south side of Long Island has been extended eastward eight miles and inland about four miles from the shore line. Within the limits just described Assistant J. W. Donn traced the shores of Hempstead Bay, including its numerous islands and the adjacent water passages. In reference to the vicinity, the following remarks are made in the field report:

"A very marked change has taken place in the bay of Far Rockaway, and apparently caused by the closing of the small inlet near life-saving station No. 34. The bay in consequence became very shallow, and near the small inlet was entirely bare at half tide. Excepting at high tide, even light-draft boats could not pass from Far Rockaway to Hempstead Bay. The beach from Far Rockaway to East Rockaway Inlet is rapidly receding, and the conditions that existed during the survey of 1845 are apparently about to be repeated. At that time there was no outlying beach or island between East Rockaway Inlet and Far Rockaway."

Assistant Charles Junken co-operated in the prosecution of plane-table work and hydrography. Because of the necessity of sounding at high water, boat work was practicable only three or four hours in the course of the day. At other intervals the topography was advanced, and the unusua freedom from high wind and rains so favored the work that Mr. Donn's projections were completed in detail by the 10th of October, 1879. The following are statistics of the field work:

Shore line surveyed, miles	227$\frac{1}{4}$
Roads and streets, miles	45
Area of topography, square miles	33$\frac{3}{4}$
Miles run in sounding	123
Angles measured	2,453
Number of soundings	17,358

As heretofore, Assistant Donn used the schooner Scoresby for transportation.

Tidal observations.—The self-registering tide gauge, started in October, 1875, at the depot of the New Jersey Southern Railroad on Sandy Hook, has been kept in operation by Mr. J. W. Banford. Generally the curves obtained are good, but as the water is often rough there has been considerable friction and wear of the working parts of the tidal apparatus. Frequent repairs have been necessary, but considering the impediments due to the exposure of the station to the effect of storms the record has been well maintained.

Topography of Hudson River, N. Y.—The detailed plane-table survey of the east bank of the Hudson was extended in the course of the season ending with November, 1879, by Assistant H. L. Whiting to points about two miles above Cold Spring. In reviewing the character of the field work above Croton, Mr. Whiting thus remarks:

"Back of Verplank's Point, and along the central part of the region mapped by the party, the country is broken and irregular, and the numerous copses and rows of shade trees made the determination of contour slow and difficult."

Throughout, the detached hills and knolls are represented by the usual signs and contour curves, and these, although the larger features of the Highlands, form striking details on the map.

The extension of this survey northward has necessitated the erection and determination of signals, many of which were placed on the highest peaks of the Highlands. All the trigonometrical stations were identified, and subsidiary points were determined with special care. Difficulties of unusual character are presented by the surface features, but these are admirably delineated on the topographical sheets. The statistics of work done in the present season are:

Shore line surveyed, miles	14
Creeks and ponds, miles	39
Roads, miles	66
Area of topography, square miles	10$\frac{1}{2}$

Assistant Whiting was aided in the work here noticed by Mr. W. C. Hodgkins.

Magnetic observations.—Under the head of Section I, mention has been made of the plan of operations adopted at the outset of the fiscal year for gaining data in regard to the distribution of magnetism along the coast of New England.

In this section, and after closing his operations in Section I and in Canada, Subassistant J. B. Baylor occupied a station at Rouse's Point, N. Y., in September, 1879, and there determined the magnetic declination, dip, and intensity. As usual, the operations were repeated on two consecutive days, and two sets of observations for azimuth were recorded at the same station.

At Albany similar series of observations were made in October. On his way northward at the outset of the season in July, Mr. Baylor determined the magnetic elements at Sandy Hook, N. J., and at Hartford, Conn. Fourteen stations in all were occupied in the course of the season for work in northern sections. Later in the fiscal year determinations were made at points near the southern seaboard, as will be stated under the heads of Sections IV, V, and VI.

Before taking the field the magnetic instruments were carefully tested by observing with them at the standard magnetic station on Capitol Hill, Washington, D. C., and after the return of Mr. Baylor in October the observations were repeated there.

Reconnaissance west of Lake Champlain.—In July, Assistant S. C. McCorkle conferred with Assistant Cutts, at Rutland, Vt., and then visited Prospect Mountain, one of the primary points in the vicinity of Lake Champlain. That station has a height of twenty-three hundred and sixty feet, and nearly due north of it is Mount Marcy, a summit about fifty-four hundred feet high. The length of the line joining them is upwards of fifty miles. Proceeding westward from this line as a base, Mr. McCorkle passed on to Lake Ontario, and at intervals selected points for continuing a system of triangulation. His reports contain information in regard to the topography of the wild region through which he passed. Assistant McCorkle traveled alone and relied only for help in climbing mountains or trees on the inhabitants of the cabins nearest to the place of ascent. The project was extended westward to Oswego, but on account of many hindrances the intervisibility of some of the points remains uncertain. In another season the scheme of triangulation will be perfected.

Before entering upon the reconnaissance, Mr. McCorkle had a personal conference with the director of the New York State survey, Mr. James T. Gardner, who communicated notes respecting the region. The printed reports of the survey by Mr. Verplanck Colvin were also found useful in traversing the country westward of the line selected as a base for joining with the primary triangulation of New England. The reconnaissance was closed at the end of October, 1879.

Pennsylvania and New York boundary line.—For the determination of additional points desired by the Joint Commission on the New York and Pennsylvania boundary, Assistant Edwin Smith resumed field work at Waverly, N. Y., on the 25th of August, 1879. There an observing station was occupied and connected by measurement with a monument which stands a few hundred feet east of the sixtieth milestone of the boundary. For the latitude of the station at Waverly, twenty pairs of stars were observed during four nights closing with the 2d of September, and fifty-two observations were recorded.

At Little Meadows a station was located midway between the thirty-ninth and fortieth milestones, and fifty observations were made between the 3d and 7th of September. Next day the party moved to Lawrenceville and occupied a station a few feet north of the ninetieth milestone. In observing the same stars for latitude, forty-nine observations were recorded by the middle of the month.

At Austinburgh the position chosen was a few feet south of the old fifth-latitude stone of the year 1787, which is between the one hundred and ninth and one hundred and tenth milestones of the boundary. During three nights fifty-eight observations were made for latitude on twenty stars. Near Shongo, in Genesee Valley, a station was occupied adjacent to the one hundred and twenty-ninth milestone, and, using the same list of stars, fifty-eight observations were recorded for the determination of latitude. On the 23d of September the party moved to Ceres and made the same number of observations during three nights. In Tuna Valley a position was chosen near Limestone, and after the close of cloudy weather the instrument was set up a few feet north of the old seventh-latitude station of 1787, which is between the one hundred and sixty-seventh and one hundred and sixty-eighth milestones of the boundary. With duly selected pairs of stars sixty-three observations were made for latitude, and on the nights of September 30 and October 1 one hundred and sixty observations were taken to determine the angular value of one revolution of the micrometer screw of meridian telescope No. 13.

At Corydon the instrument was set up a few feet north of the one hundred and eighty-fourth milestone, and the latitude of the place was ascertained by sixty-two observations recorded during two nights of the first week of October.

The last station occupied by Assistant Smith was at Sugar Grove, nearly midway between the two hundred and third and two hundred and fourth milestones, where fifty-nine observations were recorded for latitude, and work was closed on the night of the 10th of October.

At the nine stations an aggregate of five hundred and nine observations were recorded for latitude on thirty-one pairs of stars. The field computation gives as the mean probable error of one observation on a pair of stars $\pm 0''.33$, a result that would be considered good from records of observations with either of the large zenith telescopes.

In turning over the reductions of his observations along the forty-second parallel Assistant Smith thus remarks: "They show a surprising degree of accuracy in the survey of the line by Rittenhouse in 1787. His party must have cut their way through the woods. The line was run with a compass, and the instruments used to determine latitudes must have been inferior in construction, as compared with those now employed." Of the nine latitude stations of 1787, Mr.

Smith's results show that at five the error in position was less than one second. At Tuna Valley the error was about four seconds; and at Genesee Valley somewhat less than two and a half seconds. At the two other stations occupied the error found was less than one second and a half.

Assistant Smith was aided in the field by Mr. F. H. Parsons.

The work was specially facilitated by the personal co-operation of Mr. C. M. Gere, a member of the Pennsylvania Commission. Having previously passed along the boundary, that gentleman preceded the party of Mr. Smith, and set up piers and floors at all the stations. The difficulties, delays, and expense thus avoided were very considerable. Mr. Gere, by reason of weather suitable for the astronomical work, was unable to keep more than one station ahead of the observer. Including the time needful in the transfer and adjustment of instruments at the nine stations, all the work was accomplished in forty-four days.

Geodetic operations in New Jersey.—In May, 1879, Prof. Edward A. Bowser readjusted the signals at Mount Rose, Pickles, Mount Olive, and Bald Hill, and then resumed the measurement of horizontal angles at Mount Horeb, where he had closed for the season at the end of October in the preceding year. By the transfer of a heliotrope from one to another of the outlying stations, the work at Horeb Station was successfully continued. Early in July a tripod was built at Mount Olive, and that station was occupied with the theodolite in the latter part of the month after the completion of angular measurements at Mount Horeb. At intervals in August and September reconnaissance was extended northward and two points of the Blue Mountain ridge were added to the scheme of triangulation. One of these (High Point) is near the northwestern corner of the State, and adjacent to the New York boundary line. In that quarter the scheme was perfected by the selection of a third point to the eastward and not far from the State boundary.

From Mount Horeb six primary signals were observed upon, and as many subsidiary points. At Mount Olive angular measurements were recorded on five outlying primary stations, and on six subsidiary objects. The statistics of the field work are:

Stations occupied	2
Angles measured	20
Number of observations	399

The triangulation was closed for the season on the 19th of September, 1879.

Triangulation of the Delaware River below Philadelphia.—After the completion of the special survey of the Delaware at Philadelphia, of which mention was made in my last annual report, the triangulation of the river was extended below the city, and as far as Chester, by Assistant R. M. Bache. His party was employed in that service during the autumn of 1879.

In prosecuting this work along the Delaware, all the difficulties incident to the occupation of the banks by structures put up in recent years were encountered. Seven platform signals from forty to fifty feet high were found necessary to bring into view the points needful for defining shore lines the directions and relations of which have been sensibly changed in the march of improvement. One point only of the original triangulation of this part of the Delaware could be identified, and with that the work here under notice was only connected. In addition to a system of quadrilaterals restricted to points along the water lines, four stations were occupied at distances averaging a mile and a half from the banks. These positions will serve future uses in topographical surveying, and for such purposes the triangulation is ample, as will be seen by the following synopsis of statistics:

Stations occupied	23
Angles measured	125
Points determined	62
Number of observations	11,484

Pendulum observations.—The pendulum operations instituted for ascertaining vertical attraction near the Allegheny Mountains, and commenced in 1878 by Assistant C. S. Peirce at Allegheny Observatory, have been completed by occupying a station at Ebensburg in Cambria County, Pennsylvania, and a station at York in the same State. In careful determinations of the difference of longitude between Ebensburg and Allegheny, Assistant Peirce was aided by an observer who acted at the last-named place under the supervision of Prof. S. P. Langley, director of the Observatory.

For the purposes of the pendulum experiments, time was telegraphed daily, and thus the observations made for time at Ebensburg were supplemented. The latitude of the station there was determined by observations with a sextant. At that station Mr. Peirce was aided by Messrs. Henry Farquhar and Marcus Baker. The first-named aid made the observations at York under the supervision of Assistant Peirce.

At both of the stations in Pennsylvania extensive series of observations were recorded for the purpose of studying the statical and dynamical flexure of variously modified pendulum supports, and the influence of these modifications upon the period of oscillation of the pendulum. The results will be given hereafter in a separate paper by Assistant Peirce. In the course of the season experiments were made by substituting for the ordinary knife edge of the pendulum small steel cylinders. This method, proposed in a previous report by Assistant Peirce, had been independently recommended by M. Yvon Villerceau, but the trials made by Mr. Peirce proved that the friction was increased by that method of swinging the pendulum.

The measurement of the acceleration of gravity made by Assistant Peirce at Paris, France, revealed a disagreement with the measures obtained by Borda and Biot. For the investigation of the discrepancy, Mr. Peirce again visited Paris, with the sanction of the honorable Secretary of the Treasury, and by theoretical and experimental studies demonstrated from principles not known in their times that the results obtained by the two celebrated physicists were subject to certain very large corrections. These, when properly applied, brought their results into perfect accord with results already reported by Assistant Peirce, who read a memoir upon the subject before the Academy of Science of the Institute of France. The paper was printed in the Comptes Rendus for the 14th of June, 1880, and on its reference to a committee the conclusions of Assistant Peirce received the approval of the Academy.

Operations for the comparison of the meter with a wave length of light have been provisionally completed, yet certain parts of the work require verification—in particular the comparison of decimeters with the meter has been only partly made. In connection with this subject Assistant Peirce has published, with my approval, in the American Journal of Mathematics, a memoir upon certain apparitions which appear in diffraction spectra. These were shown to be consequences of eccentricity in the screw used in ruling the diffraction plates. By another observer the subject was treated in a paper presented to the American Association for the Advancement of Science at their last meeting in Boston.

Geodetic operations in Pennsylvania.—Prof. Lewis M. Haupt at the opening of the fiscal year employed his field party in the erection of signals and in examining and permanently marking the stations to be observed on in the course of the season. Near Reading, in Berks County, a station was occupied, and from it angular measurements were made on three points previously occupied to the northward.

To the southward and westward four other positions were completed in angular measurements so as to extend the work through Lancaster County to the immediate vicinity of the Susquehanna River. At Rawlinsville, in the lower part of the last-named county, a junction was made with stations of the coast triangulation near the head of Chesapeake Bay. From the records of the field work which closed in September, 1879, the Computing Division of the office has added five additional entries in the register of geographical positions.

In July the weather was unfavorable, but was much more satifactory in August and September. The statistics of the work are:

Stations occupied	4
Signals observed on	24
Directions to subsidiary objects	133
Number of observations	3,010

The field report of Professor Haupt was accompanied by complete descriptions of the stations, sketches of the horizon at each, record of the results of observed angles, and topographical sketches of the sites occupied by the theodolite.

Topography of Cape May, N. J.—This work was taken up at the opening of the fiscal year by Assistant C. M. Bache, who remained in the field until the 20th of November.

About the cape the topographical features are in close detail. The vicinity of Sea Grove was mapped; also Cape Island, the intervening roads, and the vicinity of Cold Spring Inlet. In the same direction the survey was pushed two miles farther to the northward and eastward. Special care was taken to secure accuracy throughout, and in order to meet the requirements of public interests which have rapidly developed in this quarter the map was promptly published by photo-lithography.

In moving from place to place as the work advanced, Assistant Bache used the barge which has long been in service on this coast. The statistics of the plane-table survey are:

Shore line surveyed, miles	119
Roads, miles	48
Area of topography, square miles	15¼

SECTION III.

MARYLAND, VIRGINIA, AND WEST VIRGINIA.—(SKETCHES NOS. 7, 8, AND 10.)

Life-saving stations.—Before taking up duty which has been mentioned under preceding heads, Assistant F. H. Gerdes passed along the coasts of Delaware, Maryland, and Virginia, and determined the positions of three life-saving stations. These have been recently established, one at Rehoboth Beach, one at Ocean City, and the third at Pope's Island, on the coast of Virginia. Good observations were recorded at each of the stations, and their places are carefully marked on the plane-table sheets. As heretofore, the positions will be inserted on the engraved charts.

While Mr. Gerdes was on the coast of Delaware, in July, he made thorough inquiry in regard to the point near Lewes at which the Transit of Venus was observed in the year 1769. The site probably occupied was in that year an open common, but the ground is now laid out in gardens attached to the dwellings of residents, and a church has been erected within the century, and near the church there is a burial-ground. As late as 1842 tradition pointed to this locality as the place at which the Transit was observed, but no one now living at Lewes was able to give definite information in regard to the spot occupied by the observer.

Assistant Gerdes kept the field until the middle of October, engaged in service in other sections.

Hydrographic reconnaissance of Chincoteague Inlet and approaches.—In the vicinity of the boundary line between Maryland and Virginia, a careful hydrographic examination was made by Mr. J. W. Parsons during a week in the latter part of November, 1879. Serial lines of soundings were run across the bar. Descriptive notes of the seaward approaches and positions of buoys, with correct courses for entering the inlet, make parts of the record, and in it attention is called to the excellent shelter afforded during easterly gales or head winds by what is locally known as "Chincoteague anchorage," which is a short distance northeast of the bar, and under the southern side of the extensive Chincoteague Shoals.

The channel leading across Chincoteague Bar was found to be nearly as it was thirty years ago, an apparent permanence that may be due to the closing in that interval of Green Run Inlet, which was formerly a much-used thoroughfare at the northern end of Chincoteague Island.

Mr. Parsons, on his return to the office, embodied his notes and observations in the manuscript of the third volume of the Atlantic Coast Pilot.

Soundings in Patapsco River, Md.—At the request of Mr. N. H. Hutton, engineer to the Harbor Board of Baltimore, the Patapsco was sounded in February last between Lazaretto Point and Hawkins' Point. This work was done by Assistant Charles Junken, aided by Messrs. P. A. Welker and G. F. Bird, and rests on the triangulation made in previous surveys. Five additional points were occupied, after the erection of signals by the party. The shore line of the river was then traced by means of the plane table. Stormy weather interrupted the field operations, but the requisite details were completed by the end of February.

Early in March Mr. Junken returned to the office and there completed the chart of his survey. In April the sheet was transmitted to Mr. Hutton, after the completion of a tracing for deposit in the archives of the Survey. The map represents eight miles of shore line. A synopsis of hydrographic statistics appended to the report shows:

Miles run in soundings	118
Angles measured	843
Number of soundings	7,680

Magnetic observations.—At the standard observatory on Capitol Hill, where observations for magnetic declination, dip, and intensity have been repeated yearly, the customary series was recorded on the 12th, 14th, and 17th of June, 1880.

Assistant Charles A. Schott has usually made the observations in person, but this year they were recorded under his immediate direction by Subassistant J. B. Baylor, mention of whom will be found as concerned in magnetic observations in all the sections of the Atlantic coast. After his return from the south, in April last, he tested, at the Washington station, the instruments used at various places along the coast.

Special hydrographic operations.—Early in July, 1879, Master Francis Winslow, U. S. N., Assistant in the Coast and Geodetic Survey, again reached Crisfield, Md., with his party, in the schooner Palinurus. He had previously developed the positions and areas of oyster beds in Tangier Sound and Pocomoke Sound, and in continuing researches the beds in the Nanticoke and Little Annemessex Rivers and in Hooper's Strait and Kedge's Strait were surveyed. The intercourse of Master Winslow last year with persons engaged in the oyster trade enabled that officer to prepare a list of questions for collecting all the information possible in regard to the subject. Printed copies of queries were judiciously distributed, and many have been returned with answers showing that the questions were not new in the minds of the persons to whom the lists were sent. Much information has been gathered in that way in the course of the year.

In connection with his surveys Master Winslow gave much attention to the determination of temperatures in the water over oyster beds, and also recorded observations for ascertaining the density.

Before leaving the section, hurdles were placed on the beds in Tangier Sound and Pocomoke Sound, but most of these could not be found later in the month. (Three only remained; the others were doubtless taken away by those who coveted the rope by which all the hurdles were moored.) Thirteen sections were run across the sounds for the determination of densities.

Master Winslow conferred freely with Prof. W. K. Brookes, of the Johns Hopkins University, and interchanged views and suggestions in regard to the object of the researches.

The work afloat was suspended by the detachment from service of Master Winslow in December, 1879. The judicious arrangement of details made by that officer for continuing the investigations will greatly facilitate the prosecution of the work hereafter. Until the 10th of December, Master Winslow was assisted by Master H. H. Barroll, U. S. N.

Survey of James River, Va.—In previous years the detailed survey of James River had been advanced to stations above City Point by Assistant J. W. Donn with a party working in the schooner Scoresby. The work was resumed in December, 1879, and by the close of the first week of March, 1880, the topographical work was completed as far up as the Falls at Richmond and Manchester.

A resurvey of the jetties and wing walls erected by the James River Improvement Company was made to include the structures added within the year. Dutch Gap Canal was also retraced to show the result of cutting on the east side since the survey of 1877.

To facilitate the hydrographic work, the shore lines of the river from Graveyard Reach to City Point were traversed with the plane table, for the purpose of locating points to be used by the sounding party. About two hundred signals were set up, and three hundred points were determined in position. In the course of March, April, and part of May the hydrography of the river was pushed from Warwick Bar down to City Point, where a junction was made with the sheet of soundings previously completed. Above Warwick Bar the soundings will be made by Assistant Engineer H. D. Whitcomb, of the James River Improvement Company. Data for that work were furnished by Assistant Donn with the understanding that the results should be sent to this office.

For the hydrography temporary tidal stations were occupied at Falling Creek and at Curl's

Neck wharf. The former was referred to the gauge at Rockett's, of the James River Improvement Company, and the Curl's Neck Station to that at Shirley wharf, where Mr. Donn recorded a series of tidal observations through twenty-five days.

The following details are statistics of the work of this season:

Stations occupied with theodolite	4
Angles measured	32
Shore line surveyed of river and branches, miles	25
Shore line of streams, miles	65
Roads, miles	94
Area of topography, square miles	20
Miles run in soundings	212
Angles measured	2,104
Number of soundings	17,314

After closing work in the vicinity of Richmond, Assistant Donn transferred his party for work on the south shore of Long Island, in Section II.

Primary triangulation in Virginia.—In previous seasons progress has been made in the reconnaissance for points of triangulation westward of the Blue Ridge, such as to warrant the occupation of stations for conducting the work westward towards the Ohio River. In accordance, therefore, with previous arrangements, Assistant A. T. Mosman organized a party early in July at Gordonsville, and went in camp at the foot of Fork Mountain. The instruments were taken to the summit, the height of which is thirty-eight hundred and fifty feet, and by the middle of July, 1879, all preparations were complete for the measurement of horizontal angles. The weather was often unfavorable, being alternately hazy and rainy, but on the 6th of August the record of needful observations was closed, and the instruments were transferred to Humpback Mountain, the height of which is thirty-six hundred and forty-five feet. Bad weather was frequent, but by occupying all favorable intervals the work at the summit was completed by the 28th of August.

Early in September the instruments were in position at Tobacco Row (twenty-nine hundred and thirty-six feet high), another of the stations previously occupied for the triangulation which has been extended southward and westward along the Blue Ridge. In the course of four days Assistant Mosman recorded observations on signals to the westward, as at the other two stations, for pushing field work in that direction. Thus the chain of triangles in advancing towards the Ohio will be joined on two lines of the excellent triangulation which has been conducted through the Shenandoah Valley and southward to the base line near Atlanta in Georgia.

In the middle of September Mr. Mosman transferred his party to Bald Mountain, a station about fifty-six miles to the westward of Tobacco Row, and in the course of a few days following a period of cloudy weather the requisite angular measures were recorded there. The camp equipage and instruments were then stored at Healing Springs, to be in readiness for future operations after perfecting the scheme of triangulation by further reconnaissance.

After forwarding to the office his original records and duplicates of the same, Assistant Mosman started westward on the 1st of October, and by the 8th of December visited many summits in passing through West Virginia. The heights were ascertained approximately by the barometer, and all were kept in geodetic connection with the two western lines of the chain of triangulation going southward. The report from the field was accompanied by a sketch showing a practicable scheme of work as far as the Ohio River. Many of the stations chosen are upwards of three thousand feet in height.

Primary triangulation, latitude, and azimuth.—It has long been desirable to extend the time during which in the course of twenty-four hours observations may be recorded for horizontal directions. Generally the period is limited to a short interval after sunrise and another before sunset when exhalations occasioned by the sun's action have been sufficiently quieted to allow distinct vision on lines of sight ranging from twenty to eighty miles.

Since the year 1871, Assistant C. O. Boutelle has experimented occasionally upon methods for rendering signals visible at night upon long lines. In my annual report for 1878 mention was made of his results obtained by means of magnesium ribbon while the primary triangulation was in progress in North Carolina.

At Sugar Loaf, a primary station in Montgomery County, Maryland, a series of observations were instituted by Mr. Boutelle, and experiments were continued between July and November, 1879. The results as set forth in his report (Appendix No. 8) seem to promise an extension of three or more hours of successful observation after sunset on each clear night.

The experimental observations were made with a twenty-inch theodolite, and with reference to the relative cost of angular measurements by day and at night.

While the party was at the station on Sugar Loaf, observations for latitude and local time were made by Assistant F. D. Granger and Mr. J. B. Boutelle. Azimuth was also determined by the same observers from observations on Polaris.

SECTION IV.

NORTH CAROLINA.—(SKETCHES NOS. 9, 10, AND 11.)

Magnetic observations.—Under Sections I and II mention has been made of the determination of magnetic elements by Subassistant J. B. Baylor at points in New England and Canada. For continuing that special service the requisite instruments and outfit were provided at the end of the year 1879, and early in January following Mr. Baylor occupied a station at Beaufort, N. C. After determining approximately the latitude, longitude, and azimuth, the instruments were placed in position in the rear of a lot bounded by Ann street and Front street, and observations were recorded for magnetic declination, dip, and intensity. On the completion of the series in the record, Mr. Baylor moved southward. Mention of his progress in the work will be made under subsequent heads in this report.

Hydrography, coast of North Carolina.—The inshore soundings along the coast of North Carolina have been completed within the season at two localities by Lieut. Eugene B. Thomas, U. S. N., Assistant in the Coast and Geodetic Survey, with a party working in the steamer Endeavor. One of the projections represents the hydrography between Ocracoke Inlet and a point on the coast a short distance above Cape Lookout. The second sheet contains the results of soundings made from New River Inlet southward and westward to Barren Inlet. Both of the sheets join with hydrographic work previously completed, and in conformity with usage depths are shown on them to an average distance of about twelve miles seaward. The inshore hydrography of the coast of North Carolina is now continuous from the northern to the southern boundary.

The steamer Endeavor left New York for this section on the 26th of December, 1879, and again reached that port on the 29th of the following May. Lieutenant Thomas thus refers to the character of the hydrography in his concluding report:

"No shoals were discovered, nor any noticeable irregularity in the soundings; but Ocracoke Bar has shifted to the southward several hundred yards since the date of the last survey. A new inlet, called Sadbury's Inlet, has broken out between Old Inlet and Rich Inlet, with very little water on the bar.

"New Topsail Inlet sometimes has as much as eight feet of water at high tide, but after a southerly gale it was found to be shoaled up to three feet."

"Stump Inlet is closed up, and the bar off it has disappeared.

"New River Inlet is not known to have more than seven feet of water. The general depth is about five feet."

During the temporary illness of Lieutenant Thomas, the operations of the party were conducted with judgment and energy by Lieut. Hugo Osterhaus, U. S. N. Master Francis E. Greene, and Ensign William H. Allen, U. S. N., also served efficiently in the hydrographic party. The statistics of the work are:

Miles run in sounding	642
Angles measured	1,771
Number of soundings	10,032

At the close of the fiscal year Lieutenant Thomas made preparation for taking up hydrographic work in Section II. This will be further noticed in my next annual report.

SECTION V.

SOUTH CAROLINA AND GEORGIA.—(SKETCHES NOS. 11 AND 12.)

Longitude of Atlanta, Ga.—The longitude of Nashville, Tenn., in Section XIII, having been previously established, it will be noticed under that head and under Section VIII that Assistants G. W. Dean and Edwin Smith were assigned in November, 1879, to exchange signals between that station and several points in the South for longitude determinations. Between the 26th of December and the 14th of January, 1880, observations were successfully exchanged on five nights between Assistant Dean at Atlanta, Ga., and Assistant Smith at Nashville. As usual, the observers then exchanged places, and during five nights longitude signals were recorded between the 20th and 27th of January.

For the final determination of longitude at a point in Charleston, S. C., Assistant Dean started for that city on the 1st of May, 1880, and with the permission of the city authorities marked with two granite blocks a station on the highest part of Citadel Square. On ten nights, between the 13th and 24th of May, signals were exchanged with Assistant Smith, who remained at Atlanta. The mayor of Charleston visited the station while observations were in progress, and made arrangements for the protection of the granite blocks that mark the station.

Observations for latitude were recorded at Atlanta, and the computations from them were made by C. H. Sinclair, the aid attached to the party of Assistant Smith.

The two longitude parties of Assistant Dean and Assistant Smith were provided with astronomical and telegraphic instruments similar in construction and so far as possible alike in all essential particulars. The transit telescopes were forty-five inches focal length, and were used with a magnifying power of about one hundred. A thin glass diaphragm having thirteen vertical lines cut in it was used with the telescope. Each star was generally observed in its passage across the eleven middle lines forming the three middle groups, the equatorial intervals of a group being about two seconds of time.

"So far as practicable the same twenty stars were observed each night by both observers. The stars were selected from the standard list, and arranged in four groups with special reference to the stations and times at which they were to be observed. Each group had one circumpolar and four zenith stars, and after recording observations on a group the telescope was carefully reversed in position for observing on a second group. Then followed the exchange of longitude signals, after which two more sets of stars were observed, completing operations for the night.

"Arrangements were made for carefully measuring the armature times of the polarized and Farmer relays, and the following plan was adopted: The polarized relays were first adjusted to the standard tension of the current as indicated upon the scale of a tangent galvanometer (forty-eight divisions), and the positions of those adjusted were marked upon each relay. For convenience, the standard reading on the galvanometer (forty-eight divisions) was made ten or more divisions less than the galvanometer would indicate when connected in the ordinary telegraph circuit.

"At each station the relay magnets were arranged to pass the entire current of the main circuit through the Farmer relay, but when the polarized relay was adjusted for exchanging longitude signals (by connecting the rheostat in its branch circuit) only a portion of the main current was allowed through the polarized relay. Of course when the rheostat is connected in its branch circuit *without* resistance the main current will be nearly equally divided, one-half or less passing through the galvanometer and polarized relay, causing the reading of the tangent scale of the galvanometer to be less than forty-eight divisions. Hence, by increasing the resistance through the rheostat, the current passing through the polarized relay is adjusted to the standard tension, when the galvanometer is made to indicate forty-eight on the tangent scale."

The Farmer relays were made with special reference to the reduction of armature time, and as far as practicable to insure an equality in the measurements of these times at two or more stations. The results of the season indicate that advance has been made in the right direction. Assistant Dean, under whose supervision the relays were constructed, says:

"The soft iron cores of this relay are flat bars one and seven-eighths inches in length, fifteen-sixteenths of an inch in width, and one-eighth of an inch in thickness. The cores were made flat to secure a prompt response of the armature when making or breaking the main circuit. A similar effect upon the armature of the main relay may be produced by making a slit lengthwise and to the center of the round iron cores.

"Each coil of the helix is one and three-quarter inches in length, and made of silk-covered copper wire No. 36, special care being taken to insure the most perfect insulation at each layer of the wire when placed in the coil. For convenience in adjusting one pole of the magnet at the maximum distance from the armature axis, the ends of the helix were placed one above the other upon the movable slide. The armature lever is about three inches in length, the weight of the armature being as little as the stability of the instrument would permit.

"To obtain a high tension upon the armature by means of slight adjustments of the armature spring, the spring is attached as near to the end of the armature lever as practicable. The helix is secured to a slide, by which it may be conveniently adjusted at any required distance from the armature, thereby increasing or diminishing tension upon the armature in accordance with requirement."

Mr. F. H. Parsons served as aid in the party of Assistant Dean and made part of the computations for longitude. In the course of the season, between the 25th of November, 1879, and the 24th of May, 1880, the passage of each of nine hundred and fifty stars across the meridian was observed upon eleven lines of the transit diaphragm.

As in past years, the Western Union Telegraph Company, by its president, Hon. Norvin Green, accorded all facilities requisite for the longitude operations, and all connected with the company along the lines upon which exchanges of signals were made co-operated to secure the results sought by the observers.

In telegraphic exchanges between the observers at Charleston, S. C., and Atlanta, Ga., an aggregate of one hundred and eighty-nine observations on twenty stars were recorded in the course of five nights. The latitude of Atlanta was determined by ninety-three observations on nineteen pairs of stars recorded in the course of nine nights.

Magnetic observations.—After completing his observations at Beaufort, N. C., of which mention was made in the preceding section, Subassistant J. B. Baylor proceeded to Charleston, S. C. At Breach Inlet, on Sullivan's Island, the magnetic instruments were mounted near the "Truesdale House," and as near to the point occupied in 1849 as the drifted sand would allow. There the usual series of observations were recorded for magnetic declination, dip, and horizontal intensity. The geographical position of the place in respect of latitude and longitude was determined approximately. This station was occupied on the 20th, 21st, and 22d of January, 1880. Without delay Mr. Baylor went southward to occupy a point in Georgia. The station selected was in Lawton, now known as Du Pont, a village in the southern part of Georgia, and about a hundred and thirty miles from Savannah. The place of observation is not far from the depot, but as in all other cases care was taken in regard to the possibility of local attraction. After recording observations on the 28th and 29th of January, the observer proceeded to Jacksonville. His operations there will be again referred to under the head of Section VI.

Atlantic Coast Pilot.—At the close of February last, Lieut. Frederick Collins, U. S. N., Assistant in the Coast and Geodetic Survey, completed and deposited in the office seven volumes in manuscript containing detailed descriptions of parts of the southern coast of the United States and adjacent islands, with sailing directions for the harbors and navigable waters. The localities described range from Cape Henry, Va., to Winyah Bay, S. C.; from Wassaw Sound to Altamaha Sound, Ga.; from Saint Simon's Sound, Ga., to Dry Tortugas, Fla.; the Bahama Bank, Salt Key Bank, and the north coast of Cuba; Providence Channel; and the interior waters of North Carolina and Virginia. In forwarding the volumes, Lieutenant Collins remarks: "While preparing this matter for publication I have studied to condense it as much as possible, but nothing is omitted that seems to be called for to carry out the general plan and scope of the work as shown in the portions already published."

SECTION VI.

EAST FLORIDA, SAINT MARY'S RIVER TO ANCLOTE KEYS ON WEST COAST.—(SKETCHES NOS. 13, 14, 15, AND 16.)

Magnetic observations.—In preceding sections of this report notice has been taken of the progress made in the course of the year by additional determinations of the magnetic declination, dip, and horizontal intensity. Subassistant J. B. Baylor closed observations on the 29th of January, 1880, at a station in Clinch County, Georgia, and without delay proceeded to Jacksonville, Fla. There he recorded observations for the magnetic elements at a station about an eighth of a mile from the water works, on a hill north of the city. This series was closed on the 3d of February. At Saint Augustine a station was occupied on the government reservation. The magnetometer tent was set up in the grass plot northwest of the old fort and north of the old gates. As at other places, the declination, dip, and magnetic intensity were determined in the usual way. The records needful at Saint Augustine were completed on the 11th of February. Proceeding to the southward, the instruments were set up at Enterprise. The station is in the rear of the village on the road to New Smyrna. Care was taken, as in all other cases, to guard against the effect of local influence on the magnet. After recording the usual series for declination, dip, and intensity, Mr. Baylor moved to Eau Gallie, in Brevard County, Florida. Observations were recorded there at a station two hundred and sixteen feet north of the old "Agricultural College," and the series was completed on the 25th of the month.

The next position selected was at Saint Lucie, on Indian River. On the beach the observing tent was set up two hundred and ninety-five yards south of Paine's wharf, and there the customary observations were recorded for declination, dip, and intensity.

At Jupiter Inlet, a station was occupied on the sand beach about three-quarters of a mile southeast of Jupiter light-house. The position of the instruments was ten feet from the mean low-water line, and a little eastward of the thicket on the north side of the inlet. There the requisite measures for magnetic declination, dip, and intensity were completed on the 8th of March. Mr. Baylor then started for New Orleans. His operations there will be stated under the head of Section VIII.

At Saint Augustine, all facilities needful in the operations of the observer were courteously supplied by Lieutenant-Colonel Dent, U. S. A.

Deep-sea explorations in the vicinity of Cuba.—The steamer Blake, with the hydrographic party of Commander J. R. Bartlett, U. S. N., Assistant in the Coast and Geodetic Survey, left New York on the 20th of December, 1879, to continue the investigations which were begun last year in the waters of the Caribbean Sea.

On the north side of Cuba, lines of soundings were run at different points across the Bahama Channel, and these were traversed by diagonal lines for verifying the depths. The least water (two hundred and eighty-four fathoms) was found abreast of Paradise Light, but the depth increases to five hundred fathoms abreast of Lobos Cay Light, and going southeasterly to twelve hundred and fifty-five fathoms off Maternillos Light.

A line run from the coast of Cuba across to Cay Saint Domingo, and from thence by Brown Shoal, Miraprovos Island, and Cay Verde, gave an average depth of fourteen hundred fathoms, and the same depth was found on a line from Castle Island to Inagua Island. Earnest efforts were made to procure additional soundings for developing the ridge between Cuba and Hayti, but owing to the strength of the trade winds only a few soundings were successfully recorded on the ridge. These, however, accord well with the depths found in the preceding season. From a depth of seven hundred fathoms, the dredge brought up a quantity of crust from the bottom composed of coral sandstone; the specimens of life were a few small flat sea urchins, spiral shells, small sponges, and one little fish. The only other haul made directly on the ridge (in seven hundred and seventy-two fathoms) brought up the same kind of coral rock and a large quantity of the shell of *Scalpellum regium*, a sort of barnacle, apparently very old and discolored. Commander Bartlett noticed that the sea bottom on the south side of the ridge yielded more Pteropod shells than the bottom on the opposite side. Serial temperatures were taken, and are in agreement with those recorded in the last cruise of the steamer Blake. In general, the data obtained tends to establish the theory put forward last year by Commander Bartlett, that much of the supply for the Gulf Stream passes near to the eastern end of Cuba.

Soundings run by the party, between Hayti and Jamaica, developed an average depth of eight hundred fathoms, except in a remarkably deep channel leading from the main Caribbean south of Saint Domingo, to the waters north of Jamaica. This channel runs close to Hayti, with a maximum depth of twelve hundred fathoms, but its mean depth is about a thousand fathoms. Its course is northerly along the western end of Hayti, where it does not exceed a width of five or six miles;

thence westerly below Navassa Island, with a tongue to the northward, between Navassa and Formigas Bank. Another tongue passes to the westward between Formigas Bank and Jamaica.

From Saint Iago de Cuba a line was run to the east end of Jamaica, where the depth of water was three thousand fathoms at a position twenty-five miles south of Cuba. By subsequent soundings this was found to be the eastern end of an immense valley in the sea bottom, beginning between Cuba and Jamaica, and extending below the Cayman Islands well into the Bay of Honduras. The Cayman Islands and Misteriosa Bank appear to be summits belonging to a submarine extension of the range running along the southeastern side of Cuba. At its eastern end the valley is quite narrow, but widens between the western end of Jamaica and Cape Cruz. On that line the depth was three thousand fathoms within fifteen miles of Cuba, and twenty-eight hundred fathoms within twenty-five miles of Jamaica. Near Grand Cayman the valley narrows again, and within twenty miles of that island a depth was found of thirty-four hundred and twenty-eight fathoms. Deep water was traced westward into the Bay of Honduras as far as a line joining Misteriosa Bank and the Swan Islands, with three thousand and ten fathoms within fifteen miles of the islands. On a line between Misteriosa Bank and Bonacca Island was found a general depth of twenty-seven hundred fathoms, and a depth of over two thousand fathoms extended to the westward.

Soundings were regular at twenty-five hundred fathoms between Misteriosa Bank and Chinchorro Bank, and the same general depth was found north of Misteriosa and Grand Cayman as far as the Isle of Pines and Cape San Antonio.

Between Jamaica and Mosquito Bank a few lines of soundings were run by Commander Bartlett, and serial temperatures were recorded. Below seven hundred fathoms the temperature at all depths was 39½°. At eight hundred fathoms on the ridge in the Windward Passage between Cuba and Hayti the temperature agreed with that of the same depth in the Caribbean Sea and Gulf of Mexico.

Soundings and serial temperatures being special objects of the cruise, dredgings were made only for purposes of comparison. It was found that the area passed over this season was not rich in specimens of animal life, as was the sea bottom under the lee of the Windward Islands, where the dredge was used last year.

Considered merely as a physical feature, the development of the submarine valley in the western part of the Caribbean Sea is of much interest. After completing the work projected at the outset of the season, Commander Bartlett returned to the north and reached New York in the steamer Blake on the 19th of May. He was assisted in the work near Cuba by Lieut. W. O. Sharrar, U. S. N.; by Masters H. M. Jacoby and G. W. Mentz, U. S. N.; and by Ensigns G. H. Peters and E. L. Reynolds, U. S. N.

The lines on which deep-sea soundings were recorded make an aggregate of more than four thousand nautical miles. Four hundred and seventeen depths were determined, and nearly four hundred observations were recorded for establishing the positions of the soundings. At five positions the depth found was greater than three thousand fathoms. Specimens of the sea bottom were procured at two hundred and fifty-one positions, and at all, the water densities were observed.

On the 1st of June, 1880, the steamer reached Providence, R. I., where the engine and boiler were thoroughly repaired, preparatory to a cruise along the axis of the Gulf Stream north of Charleston, S. C. That interesting work is fortunately in the hands of an officer of great sagacity, and much may be expected when Commander Bartlett returns from the cruise upon which he will enter in July. The details will be given in my next annual report.

Hydrography of Charlotte Harbor and approaches, Fla.—For completing the soundings requisite for the chart of Charlotte Harbor, Lieut. Commander C. M. Chester, U. S. N., Assistant in the Coast and Geodetic Survey, with his party in the steamer A. D. Bache, reached anchorage under the lee of Pine Island Shoal on the 30th of January. A sheet partly done last year was first taken up and completed by filling in soundings in the waters east of Gasparilla Island. For another, soundings were finished for developing Mattacha Pass. The hydrography of Pine Island Sound was then taken up, and, in connection with it, boat work along the Gulf shore of Lacosta Island and Captiva Island. Outside, to the northward and southward of Boca Grande, soundings were carried into the Gulf to distances of about a mile and a half off shore. The work inside of Charlotte Harbor was completed on the 14th of May. Lieutenant-Commander Chester then examined the Gulf shore in the steamer and erected signals for sounding about ten miles of the approaches, but a few days after the work was interrupted by a slight break in the machinery of the vessel, and, when that was repaired, by strong winds and heavy seas, which made it impracticable to continue the hydrography in the offing. The party was therefore recalled, and left for Baltimore on the 26th of May.

In the aggregate eighteen hundred and fifty nautical miles of soundings were run. The soundings have not yet been plotted, hence the mention of statistics must be reserved for the next report.

Lieutenant-Commander Chester was assisted in this section by Master T. G. C. Salter, U. S. N., and by Ensigns Henry Morrell, Henry F. Reich, and Charles H. Amsden, U. S. N.

Under the head of Section I, mention was made of the previous work of the party in the steamer Bache.

SECTION VIII.

ALABAMA, MISSISSIPPI, LOUISIANA, AND ARKANSAS.—(SKETCHES NOS. 17, 18, AND 19.)

Longitudes in Louisiana.—On his arrival at New Orleans, on the 30th of January, 1880, Assistant Edwin Smith noticed that the astronomical station formerly occupied in that city was no longer desirable, street cars now passing on soft ground within a few feet of the place at which his instruments must rest. Hence, with permission of the authorities, a station was selected in Lafayette Square, and, by reference to a point on Saint Patrick's church, the new station was connected with the former one on Basin street. Assistant Smith had been previously engaged at Nashville, as will be mentioned hereafter under the head of Section XIII. After the requisite exchanges there, Assistant G. W. Dean proceeded to Nashville, and on the nights of February 16, 19, 21, and 23 exchanged signals for longitude with Assistant Smith at New Orleans. The two observers then exchanged places, and similar observations were recorded for longitude on the 2d, 17th, 23d, 24th, and 27th of March, during which month the intermediate nights were unfavorable for astronomical work. Between New Orleans and Atlanta, Ga., signals for longitude were exchanged on the last two days of March and on the 5th and 6th of April, the observers changing places as usual. In the last week of April, Assistant Smith occupied an astronomical station at Baton Rouge, in the grounds of the United States barracks. The point there selected for observations was connected by Assistant F. D. Granger with the triangulation of the Mississippi River. Signals for longitude were exchanged on the nights of April 24, 26, 29, and 30, and at the same time observations for latitude were made by Mr. Sinclair.

Of the relays used in the exchange of signals for longitude, Assistant Smith thus remarks:

"The Farmer relays suggested by Assistant Dean are simply Morse relays with flat cores instead of round ones, and are for use with the highest adjustment possible, the object being to attain a discharge so rapid that discrepancies in observations on different nights shall be insignificant. * * * Both chronometer and arbitrary signals were always well received with the Farmer relays. With the polarized relays arbitrary signals were also well received, but in several cases the chronometer signals failed. In such cases the time required for the polarized relay to act was longer than the duration of the signal. * * * The Farmer relays have given superior results, and the manner of using them is so simple that I am in favor of abandoning the plan of permanent adjustment and substituting Farmer relays or some other rapidly discharging relays for the polarized ones. The rheostats and galvanometers will be used for testing the circuits, and, if desired, for equalizing currents through the relays at two stations."

Assistant Smith closes his report with the suggestion that very rapidly discharging relays can be made of cylindrical cores one and one-fourth inches in length, with a slot cut the entire length and filled with some insulating material, the resistance of the coils for such relays to be three hundred and fifty to four hundred ohms.

For the longitude at Baton Rouge, sixty-seven observations were recorded during four nights on twenty stars. The latitude was determined by forty-seven observations on seventeen pairs of stars observed during four nights. The geographical position of New Orleans had been previously determined.

Magnetic observations.—Subassistant J. B. Baylor, after occupying points in six of the Atlantic coast sections, reached New Orleans on the 21st of March, 1880. Instruments were immediately set up in the Fair Grounds in the center of what is known as the "wet pasture," and the ordinary series of observations were recorded for magnetic declination, dip, and horizontal intensity. This work was closed on the 25th of March.

Subassistant Baylor makes special mention of the courteous offer of facilities made at New Orleans by Mr. G. W. Nott for the furtherance of the magnetic observations.

Triangulation of the Mississippi River.—At the request of the Mississippi River Commission additional parties were detailed in the course of the fiscal year for determining points sufficient for the delineation of the river shore-lines. As stated in my last annual report, one of the parties, in charge of Assistant F. W. Perkins, with the schooner Research, continued at work through the last half of the previous fiscal year, and when the present year opened was engaged at stations above Donaldsonville. The work advanced slowly in that vicinity, owing to the necessity of clearing lines of sight. In the aggregate, one hundred miles were opened by tedious cutting through light growth entangled with vines and briers. Above the limit to which the triangulation was carried by Mr. Perkins, the lines were restricted in length, and consequently longer reaches of the river were passed over in the time employed by his party. The statistics of his work are:

Signals erected	25
Stations occupied	17
Points determined	70
Angles measured	266
Number of observations	6,828

On the 28th of November, 1879, the party in the schooner Research was transferred at Plaquemine to the charge of Assistant F. D. Granger. Work was taken up at the last two points selected by Mr. Perkins, and the triangulation was steadily pushed until the 30th of April, 1880. In advancing upwards, forty miles of the course of the river were defined by points, generally chosen in the immediate vicinity of the banks. When, of necessity, signals were set up on or outside of the levees special reference marks were placed on the land side to facilitate future identification.

In January, fog and mist prevailed to the delay of observations, but after the close of that month the weather was favorable. While conducting the work in the vicinity of Baton Rouge Assistant Granger connected his triangulation with the base line measured there in a previous season. Above Baton Rouge wooded swamps occur, and as it was found impracticable to continue along the banks the chain of triangles was carried across the western side of the neck to Bellevale. In the aggregate, twenty miles of lines of sight were opened by cutting so as to admit of observing with the theodolite. The statistics of the triangulation are:

Signals erected	39
Stations occupied	41
Angles measured	459
Number of observations	14,806

The remainder of the fiscal year was employed by Mr. Granger in office work connected with his triangulation.

The second party assigned to service on the Mississippi started work from a chained base at Bayou Sara, La., and included the river course for a distance of sixty-three miles above that place. Assistant W. H. Dennis commenced field operations on the 3d of December, 1879, and at the end of March of the following year effected a junction with the triangulation party which had worked down the river from Natchez. In general, the stations were confined to the river shores and so disposed as to form a chain of quadrilaterals throughout.

During February and March the work was impeded by high water in the river, but the weather at the same time was very good.

Assistant Dennis used the steamer Barataria for the transportation of his party. Mr. C. H. Van Orden rendered efficient service as aid. The statistics of the triangulation are:

Signals erected	73
Stations occupied	73
Points determined and located	93
Number of observations	7,008

In opening lines of sight, an aggregate length of twenty-nine miles was cut to admit of observing upon signals with the theodolite.

In the middle of April, Assistant Dennis commenced a topographical survey of the vicinity of Donaldsonville. The plane-table sheet includes a large amount of detail on both shores of the river. This work was somewhat retarded by the advanced state of the crops of rice and sugar, but the survey was completed on the 31st of May. The following are statistics:

Shore line surveyed, miles	14
Roads, miles	83
Area of topography, square miles	10

The party of Assistant C. H. Boyd was organized on board the steamer Baton Rouge on the 15th of November, 1879, and soon after commenced work in the vicinity of Natchez. Subassistant W. I. Vinal preceded the chief of the party and conducted work from the Vidalia base southward during the temporary illness of Mr. Boyd, who joined the vessel on the 23d of January. The work was pushed southward steadily, and on the 29th of March a junction was made with the triangulation of Assistant Dennis, mention of which has been already made. The triangulation by the party of Assistant Boyd develops about thirty-seven miles of the course of the Mississippi.

In the middle of April the party was transferred to Baton Rouge. Topographical work was commenced there without delay, and by the 24th of May two sheets were completed as far as the high stage of the river would then allow. These include the city of Baton Rouge and town of West Baton Rouge, and details along the banks are represented to distances of between three and four miles above and below the towns. Of necessity, the sheets remain at present without the low-water shore line, and are wanting in some details that were covered by back water when the survey was made. Master William Kilburn, U. S. N., was attached to the party and conducted the movements of the vessel. The statistics of work are:

Signals erected	47
Stations occupied	50
Angles measured, second and third order	735
Number of observations	11,087

In clearing lines to bring signals into view, about fifty miles of cutting were done by the party. The results of the triangulation furnished sixty-seven geographical positions. In the topographical survey the statistics are:

Shore lines surveyed, miles	18
Roads, miles	52
Area of topography, square miles	20

The detailed plane-table work represents seven miles of the banks of the river, and all features within a mile and a half of the water lines in the vicinity of Baton Rouge.

The revised computations for the latitude of Natchez show very good results from the observations recorded there by Assistant Edwin Smith.

By the party of Assistant Charles Hosmer the triangulation of the river was extended from Grand Gulf upwards to Vicksburg. He moved with the steamer Hitchcock on the 13th day of November, 1879, from Saint Louis, but the vessel met with an accident a short distance below that city and was compelled to return for repairs. In consequence, field work was not begun until the 1st of December. Triangulation was continued in the vicinity of Milliken's Bend until the 3d of January, when General Gillmore, president of the Mississippi River Commission, requested the transfer of the party for reconnaissance in the neighborhood of Grand Gulf. After tracing the shore lines and sounding at Grand Gulf, in which work Mr. Hosmer was engaged until the 19th of January, he commenced the river triangulation at stations a few miles above that place, and continued up the river until the 17th of April, when a junction was made with the previous work at Vicksburg. The extreme high water greatly retarded the triangulation.

After completing work to the limit just stated, the steamer Hitchcock was moved to Baton Rouge, and there a topographical survey was made by Subassistant Joseph Hergesheimer, to include the town and river shore and the village on the west bank of the river.

Master H. H. Barroll, U. S. N., was attached to the party and directed the movements of the steamer. The statistics of the triangulation are:

Signals erected	45
Stations occupied	46
Angles measured	213
Number of observations	4,041

Fifty-two points were determined in geographical position by the work of this party. The topographical statistics, including the work done at Grand Gulf and Baton Rogue, are:

Shore line surveyed, miles	19
Roads, miles	30
Area of topography, square miles	4

At Grand Gulf Assistant Hosmer ran twenty-two miles of soundings, measured one hundred and fifty-two angles, and recorded nine hundred and three casts of the lead. The field work of this party was continued until the 10th of May. Mr. Hosmer then took up his office work, and on its completion will resume the survey of the Mississippi.

Base lines and azimuth, Mississippi River.—For the adjustment of work done by the several parties whose operations have been already noticed in this section, Assistant H. G. Ogden was assigned to service in November, 1879, provided with means for measuring base lines at intervals in the river triangulation, and also for determining azimuth. His party was organized at Cottonwood Point in Missouri, on the 8th of December, 1879, at the request of the Mississippi River Commission, for the measurement of a line to be connected with the triangulation conducted by the United States Engineers. After the completion of work at the Cottonwood base, Mr. Ogden occupied in succession stations near Bayou Sara, Baton Rouge, Lum's Point, and Lake Providence, and closed work on the 16th of May, 1880.

All the sites for measurement were selected with a view to the least probability of encroachment from the river, and the lines were marked in a substantial manner with stone piers set in concrete.

The base lines at Cottonwood Point, Baton Rouge, and Lum's Point are somewhat more than a mile in length. The line measured at Point Coupée, opposite to Bayou Sara, is fourteen hundred and thirty-four meters, and that measured at Lake Providence is fifteen hundred and fifty-six meters in length. All were measured twice.

Azimuth observations at Cottonwood Point, Lum's Point, and Lake Providence were referred directly to stations at the respective bases, but at Bayou Sara and Baton Rouge it was found more convenient to use lines of the triangulation for the determination of azimuth.

For reducing the azimuth observations, approximate latitudes were determined by zenith distances. At Cottonwood Point and Bayou Sara time was obtained by observing on two stars near the prime vertical; at other stations by the passage of time stars over a small transit set in the plane of the meridian. In observing for azimuth, the instrument was used in seven positions, two or more sets being recorded in each, with six to eight pointings on the star in each set.

Assistant Ogden was aided in the field by Messrs. Carlisle Terry and Isaac Winston. In measuring the azimuth and observing for time and approximate latitude, nearly one thousand pointings on stars were recorded. For connecting the bases with the adjacent triangulations, seventeen horizontal angles were measured by seven hundred and ninety-two repetitions.

Good results are reported from the Computing Division from the observations recorded at these five stations.

Mississippi River levels.—To further the purposes of the Mississippi River Commission two parties were sent to this section to run lines with the spirit level.

Subassistant Andrew Braid was at New Orleans, La., early in December, 1879. After fitting out the schooner Quick, he had the vessel towed to Carrollton and commenced work there on the 27th of the same month. The bench-mark established in 1875 on the iron step of the Carrollton Railroad depot was adopted as the basis for leveling operations, but as the Hampson bench-mark has been used for United States engineer surveys since 1850, and is the base of the grades of the town of Carrollton, the adopted bench-mark was carefully referred, and proved to be $0^{m}.2053$ higher than the Hampson mark. Concerning that mark the following information was communicated by Mr. W. W. Williams, assistant United States engineer at Carrollton:

"When the gauge at Hampson was first established the zero was placed as nearly as could be judged at the lowest water mark, and it was found that the bench-mark read 7.92 feet on the gauge as set. The gauge was used for many years at that adjustment, and though it was afterwards found that the zero was not down to the lowest water level by seven-tenths of a foot, the gauge has been kept unaltered, that later observations might be more readily compared with those of earlier date.

"There seems to be no well-ascertained relation between the Hampson bench-mark and sea level. The supposition that the zero of the gauge was sea level has been disproved. Now it is believed that the level of the Gulf of Mexico is from nine to twelve inches below the zero of the gauge, but in that conclusion the level of Lake Pontchartrain was assumed to be the same as that of the Gulf."

The line of levels run by Mr. Braid follows the east bank of the Mississippi from Carrollton to Baton Rouge; then, crossing to the west bank, the line follows the course of the river to Red River Landing, where the flooded condition of the country compelled another crossing. Along the east bank the line was continued up to Fort Adams, passing over the hills in that vicinity.

Permanent bench-marks were established along the line at intervals of from three to six miles, and occasionally at shorter distances. Between the primary marks subsidiary marks were placed, but these being temporary probably cannot be found after any considerable lapse of time. Granite posts were used for the permanent marks after Subassistant Braid found that hydraulic cement was not suitable for the purpose desired.

The method of observing is that heretofore described. Two lines are run simultaneously with the rods placed at different distances from the instrument; and alternate sections of the line were run in opposite directions in order to neutralize accumulation from any tendency to constant error. The report of Mr. Braid shows that there was such tendency in the course of forty-five miles. Then the two lines coincide in results and alternately separate and approach until, at the twenty-seventh bench-mark, they differ by only four millimeters; and at the forty-fourth by only one millimeter and seven-tenths. As determined by computation, the probable error for the distance run (upwards of two hundred and three miles) is 18.2 millimeters.

During the latter part of the season the progress of work was much retarded by the flooded condition of the country. Prevailing calms also caused delay, as the vessel could not, when desirable, be moved against the strong current of the river. Mr. W. C. Hodgkins was attached to the party as aid, and served efficiently in the field and in office work.

Forty-nine primary bench-marks were established and one hundred and forty-four subsidiary marks. The work was continued until the end of May. Mr. Braid then reported at the office and engaged in computing the results of field observations. The probable error for the entire distance run is less than one inch.

Subassistant Braid had been previously employed in Section XIV, and mention of his services in the field will be stated under that head.

Between Milliken's Bend and Greenville, lines of level were run by Assistant O. H. Tittmann and Subassistant J. B. Weir. This work was begun in January and closed in May, 1880. The distance traversed with the instrument is one hundred and four miles, and in that range one hundred and eighty-eight bench-marks were set.

Inspection of the records in the Computing Division revealed a systematic variation in the apparent height of bench-marks in observations made between two o'clock and three o'clock in the afternoon; the report from that Division adds: "There is strong reason to support the belief that refraction is very great in observing along lines that cross water near its surface." The computations produced a probable uncertainty in the resulting difference of height between the first bench-mark and the last of 188 of $\pm 0^{m}.021$, or somewhat less than seven-eighths of an inch.

The schooner Brisk was employed for transportation by the party working between Milliken's Bend and Greenville.

Hydrography of the Lower Mississippi.—In April last, Assistant H. L. Marindin made a comparison of recent surveys of that reach of the Mississippi which is comprised between the Head of the Passes and a line across the river about four thousand feet above the north point of Cubitt's Gap. The comparison reveals that shoaling had occurred on both banks within the limits stated, between 1872 and 1876, and that there was a marked deepening along the center of the river and towards the right bank or west shore.

Below Cubitt's Gap the comprehensive report of Mr. Marindin contrasts the surveys made between 1866 and 1877. All changes are carefully noted, and illustrating tables are appended to the paper, a copy of which will be found in the Appendix No. 10. The information contained in the report was promptly furnished for the use of the Mississippi River Commission.

SECTION IX.

TEXAS AND INDIAN TERRITORY.—(SKETCH No. 20.)

Hydrography, coast of Texas.—In December, 1879, Lieut. Uriel Sebree, U. S. N., Assistant in the Coast and Geodetic Survey, took charge of the steamer Gedney, and after refitting the vessel left New York provided with projections for prosecuting soundings along the coast of the Gulf of Mexico in the vicinity of Corpus Christi. After setting up signals the hydrography was taken up at a point ten miles west of Cavallo Pass, but by reason of bad weather soundings advanced slowly. At such intervals signals were erected on the sand hills of Matagorda Island, Saint Joseph's Island, Mustang Island, and Padre Island; but by the 23d of June the Gulf shore was sounded to a point eight miles south of Corpus Christi Pass. In general, the signals were visible at distances of from seven to ten miles off shore. Beyond, and out to an average distance of fifteen miles from the beach, the lines were run by courses and distances. From the three-fathom curve inward short lines about three miles apart were run in boats to the edge of the breakers. A line parallel to the beach was run by the steamer in from two and a half to three fathoms of water, proving, as has been found heretofore, that the bottom slopes gradually to a depth of about fifteen fathoms at fifteen miles from the beach.

Two lines of soundings run across the bar at Corpus Christi Pass showed a depth of five feet at mean low water. The channel is about two hundred yards wide.

While soundings were in progress the tides were recorded at Decros Point, inside of Cavallo Pass. The rise and fall is less than one foot, and the water level, as at other places on the coast of Texas, is greatly affected by winds.

Lieutenant Sebree says in regard to the currents: "At times the current would be in one direction close inshore, and three hours afterward, in the opposite direction, at the end of a line of soundings. After a strong northeast or easterly blow the current sometimes sets for days at a time to the southwest at a rate of one to two knots per hour."

The statistics of the hydrography are:

Miles run in sounding	592
Angles measured	1,271
Number of soundings	5,613

Under the head of Section I, mention has been made of hydrographic work prosecuted by Lieutenant Sebree in the schooner Silliman. On the coast of Texas he was assisted in the steamer Gedney by Lieut. Perry Garst, U. S. N., and by Ensigns J. W. Stewart, J. C. Colwell, and M. L. Wood, U. S. N. Lieutenant Garst was detached from the party on the 8th of June and assigned to take charge of a hydrographic party in the schooner Earnest on the Pacific coast.

Triangulation and shore-line survey of Laguna Madre, Tex.—The field work in Laguna Madre was resumed at the opening of the fiscal year by Assistant R. E. Halter, who extended the triangulation southward to a junction with work done previously. This completes the triangulation to the Rio Grande boundary of the United States.

The shore lines of the lagoon had in a former year been traced to points about eighteen miles north of the mouth of the Rio Grande. There the topographical survey was taken up by Mr. Halter in August, and was pushed northward forty-five miles along the mainland and about thirty three miles on the Gulf side of the lagoon. When the work was closed for the season on the 23d of February the statistics were:

Signals erected	3
Stations occupied	5
Angles measured	384
Number of observations	4, 612
Shore lines traced, miles	399

Magnetic observations.—With the steamer Eagre, Lieut. S. M. Ackley, U. S. N., Assistant in the Coast and Geodetic Survey, sailed in December, 1879, to continue the series of magnetic observations which had been projected at the office, and partly completed in the preceding season, as mentioned in my last annual report. Early in January, Lieutenant Ackley reached the Tortugas, and there passed three days in recording magnetic observations. Passing on westward, he made similar records at Alacran Reef, and a partial series at Cay Arenas. On reaching Tampico the weather and condition of the bar were such that the vessel could not enter, and the same unfavorable circumstances made it impracticable to record observations, as intended, at Santander and Tuxpan. Proceeding to Vera Cruz, a full series of observations was made, and subsequently at Coatzacoalcos, Lagunas, Campeche, and Progresso, the last-named stations being on the north side of Yucatan.

At all the points occupied on the Mexican coast, Lieutenant Ackley was met courteously by the authorities, and any assistance needful in the observations was freely tendered.

This season's work, like that of last year, establishes the fact that the annual change of variation in the magnetic declination has increased in the lower part of the Gulf of Mexico, but the variation or deflection of the needle is diminishing. With one exception (Cay Arenas, where the anchorage is bad), observations were made for declination, dip, and intensity on three days.

For the epoch 1880 the isogonic lines have been drawn in the Computing Division of the office, and the variation of the compass, as derived from the latest observations, is now marked on charts as they are issued.

Lieutenant Ackley was assisted in this section by Lieut. H. T. Monahon, U. S. N.; by Master F. E. Sawyer, U. S. N.; and by Ensign W. H. Nostrand, U. S. N.

SECTION X.

CALIFORNIA.—(SKETCHES NOS. 22, 23, AND 24.)

Tidal observations.—With a self-registering tide gauge furnished from the office in Washington, a series of observations was commenced at Mazatlan, on the west coast of Mexico, in July, 1879. The records since that time have been regularly received from Mr. Fiacro Quijano, civil engineer, by whose aids the results have been tabulated monthly. The records give promise of special value.

Survey of San Nicolas Island, Cal.—For the survey of this island, the party of Assistant Stehman Forney was organized on the 1st of July, 1879, at Santa Barbara. Lieut. E. H. C. Leutzé received the party and instruments on board the steamer McArthur and without delay reached Corral Harbor, a small indentation on the north side of San Nicolas.

After landing, Mr. Forney commenced the topographical survey, and prosecuted the supplementary triangulation needful in that work. He also erected and determined in position all the signals required by the hydrographic party, and reset the ground marks at the triangulation points occupied some years ago. In the course of the season, as opportunity offered, angular measurements were recorded at two stations for determining the position of Begg Rock, which lies about nine miles westward of the island. The rock is frequently obscured by fog, and unfortunately was so at times when the signal on Santa Barbara Island came into view; the position of the rock, however, was well checked by additional measurements in the course of the plane-table survey.

The detailed topographical work on San Nicolas was completed on the 16th of September. A few days after the party was landed at Santa Barbara by the steamer McArthur. The island is thus referred to in the field report:

"San Nicolas is the most distant of the channel islands from the coast. It is nearly nine miles long, averages two and a half miles in width, and is eight hundred and eighty feet high, flat on top, with precipitous sides composed of coarse sandstone. About two-thirds of the surface is covered with sand, and the remainder with wild grasses like the vegetation of the mainland. Small patches of scrub oak are found in a few remote parts of the island.

"San Nicolas, like San Miguel, is covered with Indian graves and shell mounds. It is well supplied with springs of slightly brackish water. The only good boat landing is at Corral Harbor, a little basin with sixty feet of water at the northwest end of the island."

For use in the plane-table survey and the adjacent hydrography, Assistant Forney erected and determined in position seventy-seven signals, exclusive of thirteen used in his triangulation. All the points occupied by his own and preceding parties were securely marked. The ordinary statistics of the work of this season are:

Stations occupied	9
Signals observed on	14
Angular measurements	1,248
Miles of shore line surveyed	25
Area of topography, square miles	22¼

Mr. Forney reported in person at Washington on the 20th of October, and after turning in the plane-table sheet and records of his work engaged in duty in the office.

Hydrography of the Santa Barbara Islands and adjacent coast of California.—In previous seasons the coast hydrography was completed between Newport Bay and Point Arguello, and the approaches to the Santa Barbara Islands that border the channel were thoroughly sounded. Of the outlying islands, all the approaches to Santa Catalina and the south approach to San Clemente were sounded by Commander Coffin, at stated in my last annual report.

At the opening of the fiscal year the work requisite for completing the hydrography of the vicinity of the outlying islands was assigned to Lieut. E. H. C. Leutzé, U. S. N., Assistant in the Coast and Geodetic Survey. Leaving Santa Barbara with his party in the steamer McArthur on the 6th of July, 1879, weather so bad was unexpectedly encountered in the offing that the vessel was detained three days in the vicinity of San Nicolas, where it was intended to land the party of Assistant Forney for the topographical survey mentioned under a separate head.

As soon as practicable, Lieutenant Leutzé set up four signals on the north side of San Clemente, located two points carefully, and had tidal observations recorded at Catalina Harbor. Soundings along the north side of San Clemente were completed by the 23d of July. The resulting sheet shows depths ranging from six feet to six hundred and forty-five fathoms.

For the adjustment of soundings in the vicinity of San Nicolas Island, the tides were observed at Corral Harbor while hydrographic operations were in progress. The projection which takes in Begg's Rock was filled with soundings by the 18th of September, and the development shows depths ranging from two feet to three hundred and forty fathoms. Assistant Forney having completed the plane-table survey, his party was again received on board the McArthur and returned to the mainland.

For the hydrography around Santa Barbara Island seven signals were erected and as many points determined in geographical position. The tides were observed at a station in Prisoner's Harbor on Santa Cruz Island, and soundings in all the approaches to Santa Barbara Island were completed by the middle of October. On the resulting chart the depths range from thirteen feet to one hundred and seventy-eight fathoms.

Next in order of date, work was taken up along the coast south of San Luis Obispo. Ten signals were set up and determined in position; tides were recorded at Gaviota wharf, and by the

11th of December the chart was filled with soundings ranging between nine feet and twenty-three fathoms.

In order to join with the inshore soundings last mentioned, a fifth sheet was projected for extending the hydrography southward to Point Sal, where operations were closed for the season on the 11th of December. The aggregate statistics are:

Miles run in sounding	642
Angles measured	1,838
Number of soundings	7,676

Lieuts. E. K. Moore and L. C. Heilner, U. S. N., and Masters W. P. Elliot and R. H. Galt, U. S. N., were attached to the hydrographic party in the steamer McArthur.

Topography north of Point Arguello, Cal.—After completing the tertiary triangulation of the coast of California between Point Arguello and Point Sal, as stated in my report of last year, Assistant W. E. Greenwell closed that season by a detailed topographical survey of the middle stretch of coast included in the triangulation. The sheet returned to the office represents all the topographical features adjacent to Point Purissima. Of three other projections filled in the course of the present fiscal year one shows the shore line and surface details along the coast from Arroyo Hondo to Lompoc Landing, which is a short distance south of Point Purissima. The sheet of last year including that point delineates nine miles of the coast northward to Shuman's Cañon. There the plane-table survey was resumed, and during September, October, and November, 1879, was prosecuted northward around Point Sal to the entrance of Santa Maria River. Later in the year a third sheet was filled with details extending the topographical survey to Arroyo Grande, where a junction was made with the plane-table work formerly done on the shores of the San Luis Obispo Bay. The three sheets turned in by Assistant Greenwell represent the ground features to a distance of about two miles from the coast line. A synopsis of the general statistics is appended:

Shore line surveyed, miles	25¼
Roads, miles	55
Area of topography, square miles	55

Primary triangulation.—For completing observations at the eastern end of the great quadrilateral which so appropriately bears his name, Prof. George Davidson, Assistant in the Coast and Geodetic Survey, organized his party and took the field near the end of May, 1879, after arranging to occupy first Mount Lola (ninety-two hundred and eighty feet high) and next Round Top, the summit of which is ten thousand six hundred and forty-five feet above the sea level. The route to the last-named station was greatly impeded by snow until late in June.

"Mount Lola is about twelve miles north-northeast of Summit Station, on the Central Pacific Railroad, and is not specially distinguishable for elevation. It is on the main crest line of the Sierra Nevada, and may be reached from the eastward by several ways; but going by way of Lake Independence the party had only fourteen miles of teaming in a rise of twelve hundred feet. The summit was reached by packing and sledding five miles and a half over snow, with a rise of about twenty-eight hundred feet."

Much difficulty was encountered in consequence of drifts, but the party was thoroughly efficient and met all impediments successfully. While Assistant J. J. Gilbert and Subassistant E. F. Dickins advanced towards the station with the instruments and needful equipage, Assistant B. A. Colonna was detailed by Professor Davidson to post heliotropers at Mount Helena, Snow Mount, Mount Linn, and Marysville Butte. At the same time, Subassistant J. F. Pratt was sent to station heliotropers at Mount Diablo, Pine Hill, and Lessen's Butte. Near the last-named station the snow was very deep, but Mr. Pratt succeeded in reaching it and posting the hand engaged as heliotroper.

Much hardship was incurred in reaching Mount Lola, on account of snow and cold air. Officers, men, and animals sank in the snow to their knees, and all were severely tried in the ascent, which of necessity was done afoot in a rare atmosphere. Assistant Davidson went to the summit on the 9th of June, and then encountered a flurry of snow and found the temperature below the freezing point. As soon as possible, a space was cleared by the removal of detached rocks, and a pier was constructed by using cement. This was properly capped to receive the theodolite, and was marked for identifying the station point. In lieu of a wooden observatory, Assistant Davidson trusted to his canvas tent, and protected it by a heavy dry wall of stone which broke the force of many fierce winds in the course of the season. When the pier was ready, Subassistant Dickins was sent to post heliotropers at Carson Cone and Pah-Rah. Subassistant Pratt was detailed to proceed to Round Top and report upon the best means of reaching that summit and in regard to the subsistence of the party while there. Professor Davidson selected an azimuth mark somewhat more than five miles distant from Mount Lola, and in so doing guarded as far as possible against the effect of horizontal refraction.

After mounting the theodolite, observations for horizontal directions were commenced without delay, and while these were conducted by Assistant Davidson two piers were built by Assistants Colonna and Gilbert for the transit and zenith telescope. The foundations were of rock laid in cement; the superstructure of brick capped with a flat stone. The vertical circle was mounted on a very heavy block of pine, and another block was arranged to receive the magnetometer. For horizontal directions and azimuth, the twenty-inch theodolite No. 115 was mounted on the cast-iron repeating stand devised by Assistant Davidson in 1870. Observations were recorded in twenty-three positions of the limb of the instrument, and the readings were made by three micrometer microscopes with circle, direct and reversed, upon two hundred and seventy-six different graduations (of five minutes each) upon the limb.

Assistant Davidson, having stationed Assistant Colonna at Mount Shasta, succeeded in measuring two angles in the great triangle Lola-Shasta-Helena, having sides of one hundred and thirty-six, one hundred and sixty-nine, and one hundred and ninety-two miles. Under a subsequent heading, mention will be made of the operations upon Shasta. On the 29th of July, Mr. Davidson saw the heliotrope shown from that station, and observed upon it in five positions of the theodolite at Lola. Further tests were made there for the determination of azimuth by the use of a collimator, but the results served only to establish the conclusion reached previously, and reported by Professor Davidson, "that the collimator, to be effective, must be upon the same rock, or upon a pier connected in solidity with the pier of the theodolite." These conditions were impracticable at Mount Lola.

For azimuth, Assistant Davidson observed on the two stars, α Ursæ Minoris at eastern elongation, and upon B. A. C. 4165 at western elongation, in the twenty-three positions of the instrument. The observations were referred to the azimuth mark and also to the collimator. While this work was in progress Subassistant Dickins kept the record.

The latitude observations, and partly those for time, were made by Assistant Colonna, with zenith telescope No. 3. Twenty-five pairs of stars were observed through seven nights, and the usual record was made for determining the value of the micrometer screw, and for measuring the irregularity of each turn.

After the departure of Mr. Colonna for Mount Shasta, time observations with the transit were continued by Mr. Gilbert. In the measurement of vertical angles full series were recorded at Mount Lola upon all the signals in view, one of them being one hundred and sixty-nine miles distant.

Magnetic observations were made at the summit, but, as remarked in the field report, they are to be considered only a tentative for absolute measures. Later in the season, Professor Davidson set up the theodolite magnetometer at Lake Independence, which is twenty-one hundred feet below the summit of Mount Lola, and there Mr. Dickins observed for the magnetic declination during one day, while Assistant Davidson observed for time and azimuth. Dense smoke in the Sacramento Valley retarded operations at Mount Lola, but, pending the delay, a topographical reconnaissance of the mountain was made by Subassistant Dickins. For the resulting map, Assistant Davidson selected and measured a base, and made sketches of the characteristic features. Subsequently photographic views were secured of important points to the southward and eastward, in which directions smoke did not interfere as it did in other directions. Meteorological observations were recorded at Lola in July, and in August and September at Round Top. As before stated, the heliotrope on Mount Shasta was seen on the 29th of July, when all the baggage on Lola was already packed for the transfer to Round Top. There Mr. Pratt provided huts by the 9th of August, and had located a wagon road to the lower camp, as also a trail to the observing point near the summit of the mountain. Lumber, camp equipage, instruments, wood, water, and provisions were of necessity carried up to the station. There the pier for the large theodolite was built by Subassistant Pratt himself, of loose rocks at the summit, which he laid in cement. As before, the instrument was mounted on Mr. Davidson's cast-iron "position circle." The little wooden observatory, eight feet square, was protected from blowing away by a heavy dry wall of rocks, and holes with slides were cut in the lines leading to the different stations. Assistant Colonna built the piers for the zenith telescope and transit. Wherever needful, dry walls were put up for securing what had been taken to the summit, the elevation being ten thousand six hundred and forty-five feet, and the peak of the mountain swept by fierce winds.

As at Lola, horizontal angles were measured at Round Top under all circumstances of weather. Referring to the condition of the atmosphere late in September, Assistant Davidson says:

"I have stood hours at the instrument to get twenty minutes' work, and sometimes to get nothing. The cold was severe, and in the last snow, which was fifteen feet deep on the trail, we pulled ourselves up to the station by means of a life-line through snow breast high when the air temperature was near zero.

"In order to use at Round Top the same stars that had been observed on at Lola, the azimuth mark was set up by Subassistant Pratt at a point about six miles north-northwest of the station and seven hundred feet less in elevation."

Professor Davidson made the observations, and at the close assisted Messrs. Gilbert and Dickins in practice for observing azimuth.

For latitude, Assistant Colonna observed twenty-five pairs of stars on seven nights, and, as before, determined the value of the micrometer for an entire turn of the screw as well as for irregularity at each turn. He also made the transit observations, using the Davidson meridian instrument, the records being made by Mr. Dickins, who, after their completion, executed a topographical survey of the vicinity of the station on Round Top. Many difficulties were overcome in securing photographic views.

From Mount Lola, the lengths of the lines observed on are fifty-four, fifty-seven, fifty-eight, sixty-one, eighty-one, ninety-six, one hundred and thirty-one, one hundred and thirty-six, one hundred and thirty-eight, one hundred and forty-one, one hundred and sixty-nine, and one hundred and ninety-two miles, the last being to Mount Shasta. From Round Top the lines of triangulation range at thirty-eight, fifty-four, fifty-eight, sixty-seven, sixty-eight, sixty-eight, forty-five, one hundred and seven, one hundred and twenty, one hundred and twenty, one hundred and forty-six, and one hundred and sixty miles. At the two stations thirty-one hundred and forty-eight observations were recorded for determining the azimuth.

Latitude was determined at Mount Lola and Round Top by an aggregate of sixteen hundred and forty-four observations.

The meteorological records include upwards of two thousand entries.

At Lola, fourteen days and three nights were given to determine the coefficient of refraction, and sixteen days with two nights for the same purpose at Round Top. An aggregate of twenty-two hundred and ninety-three observations were thus recorded; and eighteen hundred and forty-six observations for the measurement of vertical angles. At Lola and at Independence Lake, Professor Davidson made about four hundred observations for determining the magnetic elements. The ordinary statistics for the measurement of horizontal angles at the two stations are:

Horizontal measures in twenty-three positions	3,310
Pointings of ocular micrometer	12,770
Primary signals observed on	23
Secondary signals observed on	40

At Jackson Butte, about forty-six miles southwest of Round Top, Assistant Davidson recorded about eleven hundred observations for determining the coefficient of refraction, and measured horizontal angles on two primary stations. Incidentally, Professor Davidson examined the region about Truckee, on the Central Pacific Railroad, with reference to the practicability of determining, by means of the spirit level, the difference in height between that point and the station on Mount Lola.

The report of Assistant Davidson gives the results of his observations on heliotrope spectra in remarks of special interest:

"At Lola, with the unassisted eye, the planet Venus was visible at any time in the day. Sirius could be seen at noon in the Davidson meridian instrument of two and five-eighths inches aperture, and appeared as bright as Polaris does at night. Polaris was visible in the same telescope, at any hour of the day, and the daytime observations for value of the micrometer, from 10 to 11 a. m., are as good as the night observations.

"Any first-magnitude star could be observed throughout the day; and second and third magnitudes before or after noontime."

Anticipating the necessity for adapting the size of heliotropes to the long lines of his triangulation, Mr. Davidson made a thorough study of the requisites, and embodied in his report the minimum reflecting surface for all practicable distances. For the longest lines as yet observed by him (longer than any line observed in Europe or elsewhere), he practically found that a heliotrope with a reflecting surface of seventy-seven and one-half square inches sufficed for a line of one hundred and ninety-two miles. At that distance, he saw a heliotrope of twelve inches square with a small telescope. His discussion in regard to heliotropes ends in the presentation of a simple formula, based upon a general law of optics, for determining the area of the square reflecting surface proper for any given distance.

Assistant Davidson compared the observed and computed latitudes at Mount Lola, and found an apparent attraction of the plumb line to the north amounting to 5″.8. This he attributes to irregularity in the configuration of the mountain, conjoined with differences in geological structure. In reference to Round Top, Mr. Davidson says:

"The station is on a sharp backbone lying east and west. To the south is the deep transverse cañon of the headwaters of the Mokelumne River, twenty-eight hundred and fifty feet below the station, and the mass of rock forming the further side of the cañon is granite. Round Top ridge is itself plutonic rock, with granite at the north base extending northward to the Carson road; thence sedimentary rocks upheaved by plutonic rocks, and reaching nearly the elevation of Round Top in the course of six miles. The attraction found at the station was 4″.4 to the north."

The party of Professor Davidson reached San Francisco at the close of October, and there engaged in the reduction of the field work and duplicating the records. In the coming season, the operations needful for connecting the Yolo base-line with the great triangulation will be perfected, and, if practicable, the line will be measured. For this purpose, improved apparatus has been devised, after careful study, by Assistant Charles A. Schott, of the Computing Division. The bars will be constructed in the course of the autumn of 1880 and completed in time for the measurement of the line in the spring of 1881. In regard to some of the details of arrangement in the apparatus, judicious suggestions were made by Assistant Davidson, and these will be adopted in its fabrication.

Mr. George Farquhar, long attached to the service, and in latter years on duty in the sub-office at San Francisco, died in that city on the 26th of April, 1880, in the sixty-fifth year of his age. He was entered at the office of the Survey in 1850 as hydrographic draughtsman, and the many manuscript charts completed by him evince skill and nicety in details. After serving in a hydrographic party on the coast of North Carolina, Mr. Farquhar was transferred to the Pacific coast in 1853, and was there in service with several parties. He was conscientious in the performance of duty afloat and in the sub-office, to which, within the last few years, his labors were restricted in consequence of failing health. During his last illness the unselfish care and constant sympathy of Assistant Colonna did all that was possible to mitigate the circumstances that attended the last hours of the deceased.

Reconnaissance.—In order to perfect the plan of triangulation to go north and south of the Davidson quadrilateral, Assistant L. A. Sengteller was assigned to the field early in the fiscal year for examining the region south of Mount Diablo and Round Top. In succession he visited the first-named station, and also Mount Hamilton, Mount Macho, and other peaks in that vicinity. Subsequently Mr. Sengteller passed a day on the summit of Round Top with a view of identifying points to the southward. He reached the summit of Mount Dana on the morning of the 3d of August, 1879, and passed the day in transmitting signals towards Round Top, but received none in return. His signals from Mount Hoffman were seen at Round Top, but the view to the southward and westward was obstructed by high neighboring mountains.

In the middle of August, Mr. Sengteller conferred personally with Assistant Davidson at Round Top, and started immediately to post heliotropers at Mount Macho and Mount Conness. Signals from the last named station were first seen at Round Top on the 4th of September. A week later Mr. Sengteller conferred with Assistant Eimbeck, who was then working at a primary station to the eastward, in regard to the connection of Cory's Peak with stations to the southward. It is confidently believed that the difficulties met in laying out a scheme of triangles with long lines in that direction will soon be overcome.

The work done by Assistant Sengteller after closing the reconnaissance will be stated under a separate head.

Special topography.—In pursuance of the arrangement mentioned in my report of last year for procuring types on or near the Pacific coast of the United States for the manual of topography, Assistant Edwin Hergesheimer commenced a plane-table survey of the moraines of Fallen Leaf Lake on the 20th of July, 1879. His topographical sheet, completed early in October, shows in elaborate detail about twenty square miles, and is accompanied by views. Fallen Leaf Lake is in California, and about two miles south of Lake Tahoe, which lies partly in that State and partly in Nevada. In allusion to the surface contours of the region, Mr. Hergesheimer remarks:

"Perhaps nowhere on the American continent are topographical features determined on so grand a scale by glacial drift as at the south end of Lake Tahoe, which is near the summit of the Sierra Nevada. Here at the confluence of four streams of the glacial period are found lateral and medial moraines four and five miles in length, a thousand feet high, and apparently undisturbed since the moving ice-streams deposited their cargoes of drift. The conditions seem to have been favorable for preserving them in their original forms. Precipitation of moisture is nearly all in winter as snow, which disappears gradually under the action of the sun as summer advances. Hence no torrents are formed greater than can be readily absorbed by the porous structure of the bowlder-built moraines."

On the completion of the survey before mentioned, Mr. Hergesheimer crossed the Sierra Nevada range by way of Silver Mountain Pass to Table Mountain, near Sonora, where is found one of the finest samples of deep placer formation known on the Pacific slope. Of that he says:

"By successive lava overflow and erosion the entire western slope of the Sierra Nevadas has undergone radical topographical changes. The beds of former streams are now filled with lava, which from its greater thickness in the deepest valleys longest resists erosion; and, finally, after the degradation of early summits these beds become the mountain tops. This shows plainly in a basaltic table about thirty miles long (from Columbia to Knight's Ferry) known as Table Mountain, under the lava of which is found, in the former river bed, auriferous gravel, often very rich."

At a point about three miles west of Sonora, Mr. Hergesheimer selected a section of Table Mountain including about two square miles as characteristic of the deep placer formation, and made a minute survey with a view to accompany the map. This work was completed on the 8th of November.

The next locality mapped was the headland of Montara Mountain, on the coast below San Francisco, which affords a subject of marine erosion. A view drawn to illustrate the topography of the headland proved that the survey by Assistant A. F. Rodgers truly delineated the characteristics of the place.

The tables along the coast near Santa Cruz, supposed to be former sea levels, were next examined, and views were drawn. While in that vicinity, Mr. Hergesheimer made a careful survey of the peculiar arroyo character of the erosion of the soft sedimentary strata of that region with accompanying views. Late in December he examined the supposed former sea levels or beaches at Point San Pedro, determined their height, and took views of the locality.

In January, 1880, Mr. Hergesheimer returned to Washington to resume office work upon maps and views for the topographical manual.

Tidal observations.—In February, 1877, Prof. George Davidson, Assistant in the Coast and Geodetic Survey, established at Saucelito the self-registering tide gauge, which has since that date been kept in operation by Mr. E. Gray. The indications are that the series will be one of the best as yet recorded on the Pacific coast.

Hydrography north of Bodega Head, Cal.—The inshore soundings from Bodega Head northward to Timber Creek, a distance of about twenty-two miles, were made between the 5th of September and the middle of November, 1879, by Commander G. W. Coffin, U. S. N., Assistant in the Coast and Geodetic Survey, with his party in the steamer Hassler. The work contained on three sheets showing soundings to an average distance of three miles from the coast line represents the following statistics:

Miles run in sounding	330
Angles measured	3,360
Number of soundings	7,709

During parts of the season Lieuts. W. H. Driggs, W. T. Swinburne, and C. W. Jarboe, U. S. N., and Ensigns C. F. Putnam, C. F. Pond, and W. D. Rose, U. S. N., were attached to the hydrographic party.

Triangulation and topography from Walalla River to Point Arena, Cal.—After closing the reconnaissance, of which mention has been already made, Assistant Sengteller promptly completed his arrangements for resuming the detailed survey of the coast of California between Walalla River and Point Arena. Early in October, 1879, a camp was established about midway in the range of the work, and from that station points were in succession determined to perfect the tertiary triangulation between Bodega Bay and the north limit of the work of the season. The junction was effected at Walalla River.

On the 6th of November, Assistant Sengteller resumed plane-table work upon the topographical sheet which he had commenced in the preceding season.

"In the topography developed are included three landings, namely, Bourn, Collins, and the landing at Haven's anchorage, which is locally known as 'Fish Rock.' All of these are exposed to the southeast and southwest swells of winter. The last named affords fair shelter against the northwest winds, but the others may be considered as entirely exposed. These 'landings,' as well as all others previously marked on the sheets of the survey from Bodega northward, are merely chutes suspended from the upper line of the bluff and projected into deep water. Under the apron of each vessels are moored, and directly receive or discharge freight.

"The shore line of the sheet worked on this season consists of precipitous bluffs ranging in elevation from forty to one hundred feet; much distorted and bordered by numerous outlying rocks to an average distance of a quarter of a mile from the shore."

One of these, indicated by breakers, is represented on the sheet as being about half a mile south by west of Bourn Landing.

The shore line is backed by a rapidly rising country, which is densely timbered and traversed by many roads for conveying lumber to different landings. Field work was closed in February, 1880, with the following results in statistics:

Signals erected	8
Stations occupied	14
Angles measured	186
Number of observations	4,188
Shore line surveyed, miles	10¼
Roads and trails, miles	24
Area of topography (square miles)	6½

Assistant Sengteller was aided in this work by Mr. Fremont Morse.

Hydrography between Bodega Head and Point Arena, Cal.—After the detachment of Commander Coffin, U. S. N., the charge of the party in the steamer Hassler was assigned to Lieut. H. E. Nichols, U. S. N., who made preparation to resume work early in June, 1880. On the 12th of that month, he left San Francisco with a projection, to include soundings within the limits mentioned, and, as weather permitted, the hydrography was prosecuted until the close of the fiscal year. Lieutenant Nichols will be assisted in the work of the coming season by Lieut. W. T. Swinburne, U. S. N.; Master C. F. Putnam, U. S. N.; and Ensigns F. W. Coffin, W. D. Rose, and C. F. Pond, U. S. N.

Primary triangulation north of San Francisco, Cal.—In previous seasons, points had been selected for conducting the primary triangulation of the coast of California from former limits as far northward as Point Gorda. At the opening of the present fiscal year the work had been advanced about one hundred and fifty miles, as reckoned by the coast line, above the entrance to San Francisco Bay. For its continuation, Assistant A. F. Rodgers, in the course of the season, occupied first the Great Caspar station near the coast, and subsequently Two Rock Peak. From these points nine signals were observed on, and from the last named vertical angles were measured for determining five elevations. Eight volumes, containing records of the horizontal and vertical angles observed at the two primary stations, have been received at the office. At the close of the fiscal year Assistant Rodgers was preparing to occupy Mount Sanhedrin for angular measurements to the northward. The statistics of the work done are:

Primary stations occupied	2
Angles measured	7
Number of observations	6,876

Subassistant D. B. Wainwright was attached to this field party, and also assisted in the computations.

Mount Shasta geodetic station.—Under a preceding head it was stated that a signal on Mount Shasta had been observed on from two stations of the great quadrilateral that crosses the State of California along the thirty-ninth parallel of latitude. From the two stations the distances to Shasta were approximately one hundred and sixty-nine and one hundred and ninety-two miles. The line joining the two stations was one hundred and thirty-six miles in length.

The desirable result just mentioned was effected by the steady endurance of Assistant B. A. Colonna, who passed nine days and nights on the summit of Shasta, the elevation of which is fourteen thousand four hundred feet above the sea level. During the ascent, and while on the summit, many collateral observations of interest were recorded and returned in the field report. At an elevation of about ten thousand feet, snow, white at the surface, was found to be red at a depth of two inches. The coloring matter extended to a depth of three inches, and a handful of the fungi, after evaporating the snow, had a decidedly fruity taste. From this elevation Mr. Colonna, accompanied by two men, started for the top of the mountain on the 25th of July, 1879. The instruments and requisite provisions were taken up in parcels by Indians hired for the occasion. Loose bowlders that would start down with a mere touch made the steep ascent somewhat dangerous, but accidents from such causes were carefully avoided. Under a steep wall of pumice, called "Red Bluff," as seen from the valley, the party, at the height of thirteen thousand feet, passed over a snow drift, part of which adjacent to the rock had melted, leaving a narrow chasm of which no bottom could be seen. There the rarefied air affected respiration, but by frequent halts this part of the journey was passed in safety, and at noon the party reached the hot springs, two hundred and fifteen feet below the summit of Shasta. All the carriers returned immediately to the valley. The two men retained by Assistant Colonna aided him in pitching a tent, but before night one of the men was taken ill and next morning went down the mountain and did not return. The record shows that after dark the thermometer stood at 30°.

As described by Mr. Colonna, the summit of Shasta consists of two peaks, about two hundred yards apart, one of them towards the northeast being about fifty feet higher than the other. The hot springs are in the valley between the two peaks, dotted over an area of nearly twenty yards square, and they constantly emit steam impregnated with sulphureted hydrogen and other gases. Assistant Colonna found the temperature of the water 184°, which, considering the elevation, is perhaps equal to the normal boiling point at sea level. The adjacent surface is a crust made up of loose earth and small stones cemented with sulphur, alum, and other substances. At one place the crust when broken through disclosed a cavern from which steam came out in great volumes; and from another break the steam was emitted as a small jet with a hissing sound like that caused by a locomotive. It was noticed that, although the temperature did not change, all the springs were more active on some days than on others.

Assistant Davidson had arranged for showing heliotropes, from the two stations Helena and Lola, of the great quadrilateral, but intervening smoke hid them from view at Shasta until the 29th of July, when, at 5^h 45^m a. m., Mr. Colonna "saw the Lola heliotrope for a second or two dark red, but it went before a pointing could be recorded. Helena was not seen until the 1st of August, and then four sets of six repetitions were measured. The same measures were repeated next day, but on the 3d Helena was not visible." The line from Helena to Shasta (one hundred and ninety-two miles) is the longest yet included in geodetic work. As before stated, Assistant Davidson observed on the Shasta heliotrope both from Mount Lola and Helena.

The experience of many tourists who have ascended Mount Shasta proves that few men could endure even the temporary sojourn of nine days and nights at such elevation. Assistant Colonna retained his appetite and was amply supplied with provisions, yet his weight was lessened fifteen pounds by the stay on the mountain. He experienced no difficulty in breathing, but noticed that by a little exertion the pulse rapidly increased, going as high as one hundred and twenty, though in repose at the summit it ranged from ninety to one hundred.

During his stay the highest temperature observed was 67°, when at the same time the thermometer in the valley marked 100° in the shade. At four o'clock in the afternoon ice would form in the sun, and at sundown the thermometer was generally at 25°. The coldest temperature recorded at the summit was 18°. With strong winds the temperature increased as though warm air had been thereby forced up the side of the mountain.

After visiting the Whitney glacier and making many collateral observations at other points on Shasta, Assistant Colonna left the station and reached San Francisco on the 9th of August.

Tidal observations.—The series of tidal observations commenced in June, 1877, near the entrance to the harbor of Honolulu, under the direction of Mr. W. D. Alexander, superintendent of the survey of the Sandwich Islands, has been continued. Records from the beginning and down to the 18th of February, 1880, have been received and filed at the office in Washington. As heretofore mentioned, the gauge in use at Honolulu was lent from this office on condition that the registers should be furnished for comparison between the tides there and the tides of the Pacific coast of the United States.

SECTION XI.

OREGON AND WASHINGTON TERRITORY.—(SKETCHES NOS. 24 and 25.)

Topography of Columbia River.—At the opening of the fiscal year, Assistant Cleveland Rockwell was again assigned to continue the survey of the banks of the Columbia. The sheet projected includes the course of the river between Kalama and Columbia City, and as returned to the office shows more than the usual proportion of intricate details within a sketch of rather more than eight miles. Both banks of the river were carefully mapped in contour, and all the islands are represented, as well as the streams that make into the Columbia.

Field work by this party was continued until the 8th of December, 1879, when the sloop Kincheloe, which had served for transportation and quarters, was moored for the winter at the mouth of Kalama River in a position secure from floating ice. The party was then discharged and Mr. Rockwell engaged in office work. A synopsis appended to the field report shows in statistics:

Shore line surveyed, miles	16
Sloughs and ponds, miles	44
Roads, miles	38
Area of topography, square miles	24

By the work here noticed the detailed survey of the Columbia has been extended to a point about seventy-five miles above the mouth of the river.

Triangulation and topography, Puget Sound, W. T.—At the opening of the fiscal year, Subassistant Eugene Ellicott entered upon the triangulation of Hammersley's Inlet, and completed that work early in August, 1879. In August, the shore lines were traced of the lower part of Hartstein's Island, the shores of Squaxin Island, part of the shores of Totten Inlet, and the east side of the north end of Case's Inlet. The shores of Hammersley's Inlet and Skookum Inlet were surveyed in September, and Mr. Ellicott furnished tracings of the sheets to Lieutenant Wyckoff, whose party was then engaged in sounding the upper waters of Puget Sound.

The topographical work was much retarded by high tides. It frequently happened that operations with the plane-table were practicable only four or five hours a day, and then at great disadvantage, as it was difficult to get far enough from the bluffs and hilltops for the measurement of angles of elevation. In October and November, plane-table work was completed at the head of Totten's Inlet, and along the west side of Pickering's Passage. The opposite side or western shore of Hartstein's Island had been previously surveyed. In the triangulation and topography forty points were determined in geographical position, and an aggregate of nine miles were run with the spirit-level. The general statistics are:

Signals erected	40
Stations occupied	37
Angles measured	216
Number of observations	3,756
Shore line surveyed, miles	106
Roads, miles	10
Area of topography, square miles	56

The industry of the party in charge of Subassistant Ellicott is evidenced by results reported from the Computing Division. Within the last three years the records of that party have furnished data from which two hundred and thirty-one entries have been added to the list of geographical positions.

Reconnaissance.—For connecting the triangulation of Puget Sound with that of Columbia River by the shortest route, Assistant J. S. Lawson was assigned to field duty at the opening of the fiscal year, and proceeded southward from Nisqually on Puget Sound. At intervals in the direction towards the Columbia, stations were selected, some thirty miles apart, but in parts of the region the scheme was of necessity restricted to lines of seven and ten miles in length. His report made in November describes the ground passed over, and each of the ridges or hills included in the proposed plan of triangulation. The altitudes were determined approximately, and record was made of all particulars that could be useful hereafter in the definite settlement of a plan for measuring the horizontal angles.

Hydrography of Puget Sound, W. T.—In order to gain as much as possible in the use of signals set up for the triangulation and topography, provision was made for prosecuting the soundings without delay. The schooner Earnest, already at Olympia, was placed in charge of Lieut. A. B. Wyckoff, U. S. N., Assistant in the Coast and Geodetic Survey, and four projections were forwarded to receive the plotted soundings. These now represent the hydrography of Carr's Inlet, Hale's Passage, Pitt's Passage, the lower part of Case's Inlet, Dana Passage, Eld Inlet, Totten Inlet, and Peale's Passage. A third sheet contains the soundings recorded in the upper part of Case's Inlet, and also those in Pickering's Passage. The fourth sheet exhibits the hydrography of Hammersley's Inlet, in reference to which Lieutenant Wyckoff says: "The tidal current is so strong, and no slack water at the changes, that soundings can be taken only about eight days in each month during favorable quarters of the moon when the tides are small. In other passages of Puget Sound we have met with the same difficulty, but in somewhat less degree."

In November, when work was closed for the season, Lieutenant Wyckoff reported the following statistics while forwarding the hydrographic sheets:

Miles run in sounding	756
Angles measured	9,380
Number of soundings	19,449

Ensigns S. J. Browne and Henry T. Mayo, U. S. N., were attached to the party of Lieutenant Wyckoff.

SECTION XII.

ALASKA TERRITORY.

Coast of Alaska.—After completing for the Coast Pilot of Alaska an elaborate report on meteorology, and also a compilation including the titles of all known charts, books, pamphlets, and other printed matter referring to that Territory, Assistant W. H. Dall made arrangements for resuming observations on the coast north of Sitka.

In the middle of June he established a station near the old Russian observatory on Japonski Island, and connected the point by angular measurements with the station formerly occupied by himself and by Professor Davidson on the parade ground in Sitka.

Commander Beardslee, of the U. S. S. Jamestown, had been active in hydrographic work, and under his direction a good chart was made in accordance with methods employed in the survey of the Atlantic coast. Two of the officers of the Jamestown (Lieutenant Symonds and Master Hanus) had rendered efficient service when attached to the Coast and Geodetic Survey, and were well acquainted with the processes for securing accurate results. For their chart Mr. Dall furnished positions for some of the outer reefs and a transcript of the tide table which had been computed for the Coast Pilot.

Mr. Marcus Baker, who accompanied Assistant Dall, made an expedition with the steam-launch of the Jamestown, and between Sitka and Chilkaht made observations at a number of stations for determining the magnetic declination. The opportunity was improved for marking the chart where it needed correction. When the fiscal year closed, the schooner Yukon was at Sitka in complete order for the use of Assistant Dall, and all arrangements had been completed for active service. The results will be noticed in my next annual report.

Tidal observations.—In March, 1880, a self-registering tide gauge, well supplied with requisites for running two years, was put in order and furnished to Assistant Dall, who was then about to start for the coast of Alaska. The apparatus at this time is doubtless in operation at Kadiak, but, owing to the delay in communication, no records have yet been received from the station.

SECTION XIII.

KENTUCKY AND TENNESSEE.—(SKETCHES NOS. 26 and 27.)

Base line near Louisville, Ky.—Before retiring from the charge of geodetic operations in Kentucky, Prof. Wm. Byrd Page selected a site for a base line, the north end of which is about four miles southwest of Louisville. From that end the line extends southward, and, as marked in the reconnaissance, was about six miles in length. From Cumberland Gap the triangulation had been previously extended across the State of Kentucky towards Louisville, and in Indiana a scheme has been since laid out to pass southward towards the same point. The base line and triangles in immediate connection with it were therefore adjusted so as to meet geodetic requirements in the two States.

At the opening of the present fiscal year Assistant G. A. Fairfield was directed to proceed to Louisville and measure the base line. After full examination it was found that better connections could be made by shortening the site, and as much of it passed over cultivated ground, Mr. Fairfield avoided the expense and labor of grading the site by using trestles for sustaining the measuring bars. As shortened, the line is rather more than five miles long, the final record of measurement giving for its length 8,188.055 meters.

In measuring, the tripods belonging to the apparatus were employed where the ground was nearly level, but on approaching a slope trestles were brought into requisition. These were placed four feet apart, and were continued down the slope until they were high enough from the ground to admit of the bars being run from them again to the ordinary tripods used with the measuring bars. The trestles were made by planks sixteen feet long resting on stubs driven firmly into the ground and adjusted in height so as to maintain continuity in the slope. Ditches and small creeks were crossed by driving in and bracing longer stubs to secure their stability, but in no case was it found necessary to use more than four of the plank trestles in succession. The measurement of the line was begun on the 15th of September, 1879, and was completed in ten consecutive working days. Remeasurement of the line early in October proved to be in close accord with the result first obtained.

After erecting signals in geodetic connection with the base, Assistant Fairfield occupied the stations at both ends of the base line. He was aided during the season by Messrs. Carlisle Terry, jr., and Isaac Winston.

At the opening of the season the geodetic work was placed in charge of Prof. J. B. Hoeing, but that observer was constrained by illness to leave the field early in July, 1879. His knowledge of the region in the vicinity of Louisville had been previously communicated to Assistant Fairfield.

At all favorable intervals between the 23d of October and the 28th of November, the measurement of horizontal and vertical angles was carried on, resulting in the completion of the first quadrilateral connecting with the base line, and partial observations in the second and third quadrilaterals.

On the 1st of September, 1879, Mr. Carl Schenk reported to Assistant Fairfield to take the place made vacant by the resignation of Professor Hoeing. Mr. Schenk took charge of details pertaining to the adjustment of the trestles used in measuring the base line, and subsequently assisted in observing for horizontal and vertical angles. To him Assistant Fairfield turned over the sketches requisite for a full understanding of the scheme of triangulation so far as laid out and completed between Cumberland Gap and Louisville across the State of Kentucky.

All the field notes, original and duplicate, have been placed in the office, with transcripts of the computations made in the field. The statistics of triangulation are:

Signals erected	7
Stations occupied	4
Points determined	8
Angles measured	39
Observations of horizontal angles	3,400
Observations of vertical angles	1,206

In the course of the season, Mr. Fairfield communicated with Professors Devol and Campbell, respectively, in charge of the geodetic work in Ohio and Indiana, and conferred with them in reference to the feasibility of connecting the triangulation of the two States with the base near Louisville.

After completing his office work, Assistant Fairfield made arrangements for resuming geodetic operations in Illinois. As the work in that quarter will occupy the summer of the coming fiscal year the notice of it will be reserved for my next annual report.

Longitudes in Kentucky and Tennessee.—Early in November, 1879, arrangements having been completed for field work, Assistant G. W. Dean proceeded with his party to Nashville, Tenn. Assistant Edwin Smith, on the 18th of that month, started for Washington, and as soon as practicable established an astronomical station at Louisville, Ky. At the two stations details were adjusted as soon as possible, and longitude signals were exchanged between the observers on the night of the 29th of November. Signals were repeated on the 1st and on the 6th of December, intervening nights not being favorable for the exchanges. In order to eliminate personal errors of observation as far as possible, Messrs. Dean and Smith then exchanged places, the first passing to Louisville and the latter to Nashville. Between the 11th and 15th of December longitude signals were passed between the observers for completing the observations requisite for determining the longitude of Louisville. Two days after closing at that station, Assistant Dean transferred his party to Atlanta, Ga., and there received signals from Assistant Smith, who remained at Nashville. Successful observations were recorded on five nights between the 26th of December and the 14th of January. The subsequent operations of the party have been mentioned under the heads of Section V and Section VIII.

Observations for latitude were made by Mr. C. H. Sinclair, aid in the party of Assistant Smith, at the astronomical station in the grounds of the Louisville University.

For longitude, sixty observations were recorded on 20 stars during the course of three nights, and at Nashville fifty-nine observations in three nights in exchanges with Louisville, and eighty-six observations in exchanging with the observer at Atlanta. Two sets of observations were recorded at Louisville for value of the micrometer, and for latitude sixty-two observations were recorded on seventeen pairs of stars in the course of six nights.

At Louisville, in exchanging signals with the observer at Nashville, sixty observations were made on twenty stars during three nights, and in the same period fifty-nine observations were recorded at Nashville. Computations for the longitude of the station in that city were made by Mr. F. H. Parsons.

Geodetic operations.—In continuation of the triangulation of Tennessee, Prof. A. H. Buchanan took the field at the opening of the fiscal year, and in July, 1879, occupied a station six miles south of the Lebanon base line. The position was chosen so as to admit of angular measurements on nine out-lying stations. Northward of the base another station was occupied in the same month and from it horizontal angles were measured on six other signals. In August an additional point was occupied to the westward of the base, and in connection with stations previously occupied and also with the capitol at Nashville. Twelve signals were observed on in the course of that month. A station on the State capitol was occupied in September, and angular measurements were recorded to connect that point with others in the vicinity of Lebanon base. About six miles eastward of the line a station was occupied in October and during part of November. In the month last mentioned Professor Buchanan moved to a point a few miles westward of Lebanon, and continued the measurement of horizontal angles until the 29th of December. He resumed field work on the 14th of June, 1880, at the northern end of the Lebanon base, and when the fiscal year closed he was engaged in perfecting the connection of the line with well chosen quadrilaterals. An abstract of the statistics is here given, as taken from the field report:

Signal erected	1
Stations occupied	7
Horizontal angles measured	53
Vertical angles measured	36
Number of observations	4,832

SECTION XIV.

OHIO, INDIANA, ILLINOIS, WISCONSIN, AND MICHIGAN.—(SKETCHES NOS. 26, 28, and 29.)

Geodetic levels.—The line of geodetic levels going westward in the vicinity of the thirty-ninth parallel was extended last season to a bench-mark at Athens, in Ohio, and there the work was resumed at the opening of the fiscal year by Subassistant Andrew Braid. Following the Marietta and Cincinnati Railroad to Cincinnati, and then the Ohio and Mississippi Railroad, the party reached Mitchell, in Indiana, by the 10th of November, and was there disbanded. After his return to the office Mr. Braid was assigned to duty, of which mention will be made under the head of Section VIII in this report.

In advancing the work to Athens, two lines were run simultaneously with the same instrument by observing on two sets of rods placed at different distances from the instrument. The two lines were brought together at each bench-mark so as to afford frequent comparison of results. In the operations of the present year the method was slightly changed. Instead of two lines observed at very nearly the same time and consequently under the same atmospheric conditions, alternate sections of the work were run by two lines in a forward or westerly direction, the intermediate sections being run also by two lines in the opposite direction. In this way two hundred and ninety miles of double line were run in the course of the present season, closing on a bench-mark at Mitchell, similar to bench-marks placed at Athens, Chillicothe, Loveland, Cincinnati, in Ohio, and at Lawrenceburg and Medora, in Indiana. At these places the marks were set with special care, and in all cases where practicable were placed on government or other public buildings. The secondary bench-marks are more numerous, but are also well marked, and in addition many temporary bench-marks were set. All are described in the records turned in by Subassistant Braid. The notes of the field work of this season are comprised in thirty-four volumes.

Geodetic operations in Ohio.—Reconnaissance for triangulation stations in Ohio was resumed by Prof. R. S. Devol on the 1st of July, 1879, and was prosecuted continuously until the 4th of October. The scheme of last year was first reviewed, resulting in improvement by the substitution of several points for others which had been provisionally selected. After careful examination it was found that in order to obtain lines averaging twelve miles in length tripods for elevating the theodolite would be requisite at eleven stations, and that in some instances lines of sight could not be had without cutting avenues through timber on hill tops or ridges near the stations most available for the extension of geodetic work. The scheme of work presented by Professor Devol provides for triangulation through Knox and Richland Counties, and is believed to be as good as the nature of the region covered by it will admit.

While the reconnaissance was in progress Assistant Richard D. Cutts continued in direct correspondence with Professor Devol, and, as heretofore, made suggestions in regard to the plan of triangulation.

Geodetic operations.—For perfecting the scheme of triangulation in Indiana from the Ohio River at New Albany northward to Indianapolis, Prof. J. L. Campbell took the field in July, 1879, and revised the system of quadrilaterals between the stations just named. North of Indianapolis the country was examined for a distance of thirty miles for extending the scheme of triangulation. In referring to the difficulty of finding points at distances sufficient for geodetic purposes, Professor Campbell says:

"The general level character of the country is broken only by water action; so that even the fine range of hills along the western border of the scheme presents such uniformity in height that little relief is obtained from the timber obstructions on lines which run with the range. The broad level section along the general line of the Jeffersonville, Madison and Indianapolis Railroad, with the lower range of hills east, make the opening of the cross lines comparatively easy."

The field report sent in at the end of October contains a list giving the approximate elevation of each of the stations proposed in the scheme of triangulation. Separately the quadrilaterals are described in respect of lines to form the sides and also the diagonals, with mention of the heights of tripods when needful to bring into view the adjacent stations.

Assistant Cutts advised from time to time in regard to the work while it was in progress. Professor Campbell conferred also with Assistant Fairfield, and in the development of the plan for future operations had the cordial co-operation of the State officers, including Governor Williams and Professor Collett, Chief of the Bureau of Statistics and Geology of the State of Indiana.

Geodetic operations in Wisconsin.—Prof. John E. Davies, having previously completed arrangements, took the field at the opening of the fiscal year for continuing the triangulation in Wisconsin. At Highland Station a signal was set up over a tripod and observing scaffold, and stations to the northward at Quarry Bluff and Point Judas were visited to make sure that there had been no displacement of the marks already set. To the eastward and southward, at Harker and Platte Mound, signals had been anchored to solid rock below the ground surface in the course of the reconnaissance. Westward the station Fennimore was selected. This point is about twenty-two miles from Prairie du Chien, and favorable for the extension of work in that direction as well as to the northward. Having adjusted the scheme with reference to checks within the region covered by the triangulation, and for continuing it beyond the present limits, Professor Davies occupied Highland Station and there completed the measurement of horizontal and vertical angles on the 12th of July, 1879. The instruments were then transferred to Fennimore, where the requisite measures were obtained by the 5th of August. Platte Mound was next occupied, and there the field operations were closed on the 13th of September. The statistics of the work are:

Stations occupied	3
Angles measured	104
Number of observations	4,296

In the course of the year six signals were erected by the party.

Magnetic observations.—At Madison, Wis., magnetic observations were continued throughout the year by Mr. David Mason. The self-recording instruments there have been in operation nearly three years and a half, and, if practicable, the series will be extended beyond six years, so as to include more than half of a sun-spot cycle. The annual observations for absolute values of the declination, dip, and horizontal intensity will be made by Mr. Mason in September of this year, at the station near the magnetic observatory, and also at the University, which is about a mile west of the magnetic observatory. All precautions have been taken to guard against local disturbances.

SECTION XV.

MISSOURI, KANSAS, NEBRASKA, MINNESOTA, AND DAKOTA.—(SKETCH No. 29.)

Triangulation in Missouri.—For continuing this work west of Jefferson City, Assistant J. A. Sullivan took the field on the 1st of July, 1879, and made arrangements for the erection of signals as far westward as Sedalia. By the middle of October tripods were built at ten stations; from the most western the town of Sedalia is visible. The points are well chosen, but, owing to the character of the region, structures of considerable elevation will be required at several of them in order to bring into view the adjacent signals.

At Pilot Knob, a station southward and eastward of Jefferson City, Subassistant H. W. Blair resumed the measurement of horizontal angles early in July, and in succession, going westward, occupied the stations McDaniel, Bradford, Cedar, Kennedy, Belshe, Moreau, Medlock, Christian, and finally the astronomical station at Jefferson City, west of which the triangulation was closed at a station near the town of California.

In the middle of November, observations for latitude were begun at Jefferson City. The record was closed on the 29th of that month, and observations for azimuth on the 1st of December. After their completion, Subassistant Blair, accompanied by the aid in his party, Mr. P. A. Welker, examined the site which had been proposed for a base line in Morgan County. The report made as to the practicability of smoothing the ground at little expense is satisfactory.

Mr. G. F. Bird accompanied Assistant Sullivan as aid at the outset of the season, but on the 1st of November, 1879, was transferred to the party of Subassistant Blair. While engaged at the several primary stations in measuring horizontal angles, the opportunity was taken to observe on prominent objects of permanent character. Amongst these were two church spires in Osage County; one in Cole County; the dome of the State capitol in Jefferson City; and two church spires in Moniteau County. The following summary shows the progress made in the course of the season in Missouri:

Stations occupied	10
Points determined	11
Signals observed on	19
Number of observations	6,448

The observations included the measurement of vertical angles.

SECTION XVI.

NEVADA, UTAH, COLORADO, ARIZONA, AND NEW MEXICO.—(SKETCH No. 30.)

Primary triangulation.—For continuing the primary triangulation in Colorado, Assistant O. H. Tittmann took the field at the opening of the fiscal year, and, as soon as practicable, established his party near the eastern end of the site selected for a base line. Until August 5, the time was occupied in tracing the proposed base line on the ground between the eastern and western ends, and in making preliminary measurements with a wire of known length. The contour of the ground was determined by means of the spirit-level, and monuments were set up at the termini finally decided upon. The line thus marked for measurement is somewhat more than seven miles in length. Work at the base site was completed on the 5th of September. In order to lessen the inconvenience arising from changes of temperature in the course of the day, Mr. Tittmann experimented by measuring at night, but, after trial with the hands on two consecutive nights, he found no advantage as compared with the measurements by daylight. The length of the base was determined by steel rods, and in their use due account was taken of temperature. Two measurements were made under different conditions, yet the difference in length as thus determined proved to be very little more than one inch.

After completing the base measurement, signals were erected at the outlying stations on the plains by Assistant Tittmann, aided by Mr. J. B. Weir. At the eastern end of the Colorado base observations were recorded for latitude and azimuth.

The astronomical station at Colorado Springs, and also the station at which the observations were made by the United States Engineers, were connected with the triangulation previously laid out by Mr. Tittmann.

Later in the season the western end of the base was occupied, and in November the station *Corral Bluff* in immediate connection from the southward with the base. Two signals were erected west of Colorado Springs for connecting the astronomical station with the work now in progress.

The station "Divide," north of the base and in immediate connection with it, was last occupied, and there the operations for the season were closed in December. The statistics of work are:

Primary stations erected	4
Secondary stations erected	4
Signals erected	10
Subsidiary objects determined	5

An aggregate of forty miles was run by this party with the spirit-level.

Under the head of Section VIII mention has been made of the subsequent work of Assistant Tittmann.

Triangulation in Nevada.—Eastward of the Davidson quadrilateral, the great triangulation has been extended by Assistant William Eimbeck. The station "Genoa Cove," occupied by his party, is almost exactly on the thirty-ninth parallel of latitude, and in immediate connection with stations "Lola" and "Round Top," operations at which were the subject of mention under the head of Section X.

Besides the primary work carried on at Genoa Cove, Mr. Eimbeck determined several secondary and tertiary points, and made additional measurements of angles for connecting the State capitol in Carson City with the triangulation. The subsidiary observations include all the principal mountain peaks in view, and these lie within a belt about one hundred and fifty miles wide along the thirty-ninth parallel.

In the course of the season Mount Davidson, near Virginia City, was determined in position, having been observed on in the previous season at Pah-Rah, a primary station to the northward of Genoa Cove.

Cory's Peak was next occupied by Assistant Eimbeck. At this station Mount Conness, a station to the southward and westward, was observed on, as it was also from the most eastern station of the Davidson quadrilateral. In lieu of a heliotrope at Mount Conness, the observations were made upon a large cairn covered with black muslin on the side next to the observer.

Vertical angles were measured on the outlying primary stations and also on a number of the more prominent mountains in view from Cory's Peak.

In June, 1880, Assistant Eimbeck moved his party to the primary station "Carson Sink," and was there engaged at the close of the fiscal year. The statistics of the work will be given in my next annual report.

COAST AND GEODETIC SURVEY OFFICE.

The charge of the Coast and Geodetic Survey Office continued with Assistant J. E. Hilgard throughout the year, a standard of efficiency being maintained not less high than that of former years. With the extension of the territory embraced in the operations of the survey have come large accessions to the data and material available for maps, charts, and other publications. An increase commensurate with this has taken place in the correspondence of the office to meet the calls for information and transcripts from topographic and hydrographic records.

In this correspondence, and in the details of executive duty, together with the work involved in the preparation for publication of the reports and appendices, Assistant Hilgard had the aid of Assistant Edward Goodfellow.

Special attention was given during the year to the arrangement, classification, and cataloguing of duplicate hydrographic records; to the publication of an edition of the catalogue of the charts embodying a number of improvements, and to a study of the forms best adapted to secure clear and concise expression in the titles of publications.

Much time was also devoted to the development of improvements in the instruments and methods of the survey to meet the requirements of exact processes in geodesy, combined with increased rapidity and economy in the execution of field work. A new primary base apparatus was designed by Assistant Schott, as referred to later in this Report, and was partly constructed during the year. An account of this apparatus will be given after its completion and trial in the field. Improvements in the circular graduating engine designed to secure the automatic correction of its residual errors are in progress.

With the aid of field officers temporarily assigned to office duty, a number of investigations relating to the instruments and apparatus for field work were prosecuted under the direction of the assistant in charge.

Assistant H. G. Ogden, for a short time on office duty in December, compared the six-meter bars, Nos. 2 and 3, intended for the measurement of secondary base lines.

Assistant Stehman Forney reported for office work in December, and aided Assistant Ogden in comparisons of the six-meter base bars. He took part in the inspection, preparatory to measurement, of the Fort Whipple trial base, made tests of the graduation of theodolite No. 118, and after completing the records of his work on the coast of California, made an examination of repeating circle No. 92, and of geodesic levels Nos. 2 and 36. Having familiarized himself with the methods and computations of observations for time, latitude, and azimuth, preparatory to a resumption of field duty on the Pacific coast, Mr. Forney was directed to take charge of the preliminary measurement of the kilometer base line near Fort Whipple, and, having completed this work satisfactorily and deposited the records in the office, he was relieved from office duty early in June.

Subassistant H. W. Blair, upon his assignment to the office in February, was directed to aid Assistant Forney in the examination of geodesic level No. 2. He then began a compilation of matter for the Weights and Measures Report, attending to this in the intervals of time not occupied by other duties. These were chiefly as follows: An examination of the limb of the twenty-inch theodolite No. 3; a determination of the values of the subdivisions of a new standard foot-scale of brass, and of the errors of a set of rods and gauges for the Bureau of Ordnance; tests for standard thermometers; a series of experiments for the Internal Revenue Bureau as to the proof strength of certain alcohols, and an examination of the limb of theodolites Nos. 3 and 5. He also compared Arago platinum meter with the Berlin brass meter No. 49, and began the preparation of a report upon the tests of graduation of three twenty-inch theodolites. Towards the close of May Mr. Blair was assigned to field duty.

Subassistant C. H. Van Orden reported for office duty in September, and after making himself familiar with the methods of testing instruments, was directed to make an examination of the limb of theodolite No. 17. He also took part in field work incident to the occupation of Sugar-loaf Station, and to the proposed measurement of the Fort Whipple kilometer base line. Early in November he was ordered to field service.

Mr. F. H. Parsons, during his temporary assignment to office duty in July and August, tested the graduation of theodolite No. 108 under my immediate direction; made comparisons of several thermometers with the Kew standard; compared the star places of the Coast and Geodetic Survey Latitude List with those of the Wheeler Star List and those of the Northern Boundary Survey List, and brought up to 1880 the mean places of two hundred and fifty stars observed in 1878 at the Harvard College Observatory, these being stars of the Coast and Geodetic Survey List for which better determinations of position were desirable.

Towards the end of August Mr. Parsons was assigned to field service, and upon his return from the field in June following was occupied in comparisons of the secondary base bars Nos. 3 and 4.

No important change was made in the organization of the office during the year, and the full statement given in my last year's report of the functions of the several divisions renders it unnecessary now to do more than to recite in detail the work performed by each. The system of daily reports to each chief of division of the occupation of each employé, and of monthly reports by each chief to the assistant in charge, and by him to the Superintendent, is found effective in securing due responsibility for the amount and quality of work done.

Hydrographic Division.—In addition to duties as hydrographic inspector, relating to the care and outfitting of the vessels and hydrographic parties of the survey as elsewhere referred to, Commander E. P. Lull, U. S. N., has supervised the labors of the hydrographic draughtsmen in the Coast and Geodetic Survey Office. He was aided by the following named officers, acting as assistant hydrographic inspectors: Lieut. H. E. Nichols, U. S. N., from July 1 to February 12, and Lieut. C. T. Hutchins, U. S. N., from April 24 to the close of the fiscal year. Master W. Kilburn, U. S. N., was also on duty a portion of the year.

The office work done in the hydrographic division may be stated briefly as follows:

Mr. E. Willenbucher, hydrographic draughtsman, protracted, plotted, or drew fourteen hydrographic sheets, compiled a chart of the Caribbean Sea from the best authorities, and plotted upon it the deep-sea soundings taken between the West India Islands and the Florida coast; transferred and reduced the deep-sea soundings of 1878 and 1879, West India Islands, upon hydrographic office charts; made profiles of deep-sea sounding lines, and made a number of projections for hydrographic parties, and verifications of hydrography upon drawings for charts.

Mr. W. C. Willenbucher, hydrographic draughtsman, plotted and drew fifteen hydrographic sheets, verified, inked, and finished three hydrographic sheets, aided in the transfer and drawing of profile lines for deep-sea soundings, and made miscellaneous tracings and projections for the use of the office and for hydrographic parties. He also plotted upon a number of charts the corrections or additions needed to make the aids to navigation conform to the latest available data.

Mr. F. C. Donn, hydrographic draughtsman, verified, inked, and finished fifteen hydrographic sheets, plotted two sheets, and made a number of tracings to meet calls upon the office for information.

Computing Division.—The charge of the computing division was, as heretofore for many years, with Assistant Charles A. Schott, and the work executed was made to keep pace with the progress of the field work of triangulation. Mr. Schott states that additional computers are needed for the astronomical reductions, the temporary assignments made to the division not being enough to advance the computations of telegraphic longitudes as rapidly as desirable.

In addition to directing the preparation, distribution, examination, and revision of the work of the computers, the furnishing of geodetic and other professional information to field parties and to office divisions, and the preparation of data to meet calls for information upon the office, Mr. Schott gave special attention to the following subjects: In the department of terrestrial magnetism, additional discussions were made of the secular change of declination, and a third edition of a pamphlet bearing that title was produced and published; observations were made at the magnetic observatory in this city; this observatory was also used by Captain Sampson, U. S. N., by Lieutenant Ackley, U. S. N., by Assistant Dall, and by the Howgate Polar Expedition for testing magnetic instruments; a general collection of magnetic results, comprising declination, dip, and intensity, was made, comprising the whole of the United States and parts of adjacent countries, arranged by States and Territories, and extending from the earliest to the present time; this collection contains more than forty-five hundred entries. The magnetic observatory at Madison, Wis., has remained in charge of Mr. Schott. In the geodetic work of the survey an important change was made by the substitution of the Clarke spheroid (of 1866) for the Bessel spheroid of reference, which latter had been used for the development of our triangulations since 1844, but from our work was found afterwards to be too small. This change was directed, as recommended in a report entitled "Comparisons of local deflections of the plumb line in latitude, longitude, and azimuth of the oblique arc along our Atlantic coast, as developed on Bessel's and Clarke's spheroids." An examination was instituted of the records and computations of the differences of longitude determined by the electric telegraph since 1846; the results of sixty-nine principal determinations and of some secondaries were critically examined, combined, and collated, and the whole put in systematic form for use; a new longitude register was prepared containing these results arranged chronologically for each State and Territory; no recomputation was attempted for want of computing force. In February, 1880, Mr. Schott was charged by the Superintendent with the duty of designing a new primary base apparatus, one that should be less cumbrous to use than the old apparatus and be not less perfect in accuracy. With the assistance of Mr. W. Suess, mechanician of the Coast and Geodetic Survey, to whom he furnished plans for the details of the apparatus, the new design was made, and, after minor modifications, was finally adopted in June and its construction ordered. It embodies the principle of compensation for changes of temperature, the bar being nevertheless rigid and without any levers or joints, makes use of the Borda differential scale, of the Mudge contact slide, and in general embodies all improvements made in the Coast Survey primary and secondary apparatus up to date.

Two brass decimeters and two brass centimeters were standarded.

The following is a summary of the work performed by each computer during the fiscal year:

Mr. James Main computed the astronomical latitudes of Mount Helena, Cal., 1876, and revised several latitude computations; computed the astronomical azimuths of Lieutenant Ackley's magnetic stations, Gulf of Mexico, 1879 and 1880; of Berger, Mo., 1878; of Hopefield, Ark., 1879; of Sugar Loaf, Md., 1879; of Tanyard, Ala., 1878; and of Cottonwood, 1880; and revised several azimuth computations; computed telegraphic difference of longitude, Washington and Cambridge, 1872, and Washington and St. Pierre, 1872, and revised several longitude computations. He also furnished mean places of stars for field parties. On account of infirm health, Mr. Main is not required to compute for more than five hours a day.

Dr. Gottlieb Rumpf computed the following secondary or tertiary triangulations: Supplementary work, Delaware Bay, 1877; Indian River, Fla., 1879; Sarasota Bay and south of it, Fla., 1878; between Horseshoe and Daughtry bases, Fla., 1877; Mississippi River from Natchez northward, 1878–'79; Mississippi River between Helena, Ark., and Bennett's Landing, Miss., 1878; Promontory Point to Point Sal, Cal., 1878–'79; Catalina Island, Cal., 1877; Puget Sound, Wash. T., 1871; Hood's Canal and other waters connected with the sound, basing the new positions upon Clarke's spheroid of reference.

Mr. Edward H. Courtenay had charge of the geographical registers, both of the computing and drawing division, and chiefly attended to the preparation of geodetic data required by field parties; collected and revised magnetic constants for the several magnetometers; arranged a new register of the duplicate astronomical, geodetic, and magnetic records of the survey under his charge; computed magnetic observations made by Mr. Baylor in 1879, and by Mr. Mason at Madison in 1879; assisted in the preparation of the annual statistics; completed the adjustment of the triangulation of the Upper Potomac, 1865, and adjusted the main series of triangles, Puget's Sound and Admiralty Inlet, basing the results on Clarke's spheroid, and furnishing the needed bases for the work executed in 1878 and 1879 and computed by Dr. Rumpf.

Mr. Myrick H. Doolittle computed the adjustment of the primary triangulation between Charleston, S. C., and Savannah, Ga., 1868–1870; completed the computations of primary and secondary heights of the Blue Ridge triangulation, Maryland to Georgia; prepared abstracts of directions and adjusted primary triangulation vicinity of Staunton, Va., 1878 and 1879; computed triangulation of Pennsylvania, 1875–'76–'78–'79, executed by Professor Haupt, and of New Jersey, 1876–'77–'78–'79, executed by Professor Bowser; computed the triangulation Mississippi River, Memphis to Bennett's Landing, 1879, and between Helena, Ark., and Bennett's Landing, 1878; computed and adjusted the principal triangulation of the region bordering on the States of New York, Massachusetts, New Hampshire, and Vermont, 1874 to 1879; and computed the length of the El Paso base, Colo., 1879.

Dr. Jermain G. Porter completed abstract of horizontal directions of stations near Santa Barbara Channel, Cal., 1878; at Starr King and Gunstock, N. H., 1878; at Pah-Rah, Nev., 1878; computed the length of four base lines Mississippi River triangulation, 1878–'79; adjusted the primary and computed the secondary triangulation of the survey of Wisconsin, 1875–'76–'78; computed geographical positions San Nicolas and San Clemente Islands, Cal.; computed the main series of triangles Mississippi River, Magnolia to Donaldsonville base, La., and the old primary triangulation Mississippi Sound, basing them on Clarke's spheroid; computed the triangulation Mississippi River above Donaldsonville, La., 1879, between Vicksburg and Omega, Miss., 1879, and between Natchez and Jackson Point, Miss., 1879–'80. He also computed the length of the Louisville base, Ky., 1879.

Mr. Marcus Baker completed the computation of telegraphic difference of longitude Washington and Atlanta, Ga., 1879, and collected some magnetic results Alaska Territory. He gave five hours work a day to the computing division.

Mr. Alexander S. Christie completed the computations of astronomical latitude of Nashville, Tenn., 1877; Cairo, Ill., 1877; Clark, Pa., 1877; Travis, N. Y., 1877; Burt, Pa., 1877; Paducah, Ky., 1877; Finn, N. Y., 1877; Memphis, Tenn., 1877; Hickman, Ky., 1877; and nine stations on the boundary of New York and Pennsylvania, 1879; of Helena, Ark., 1878; Natchez, Miss., 1878; Harrisburg, Pa., 1877; Lola, Cal., 1879; computed the astronomical azimuth Mount Prospect, N. Y., 1878, and made progress with the computation of the spirit leveling, Mississippi River, Greenville to Vicksburg, Miss., 1880.

Mr. Erasmus D. Preston completed the telegraphic difference of longitude Washington and Statesville, N. C., 1878–'79; assisted Mr. Baker in the computation for longitude of Atlanta, Ga., 1879, and attended to some miscellaneous work, such as testing theodolites, measure of decimeter and centimeter scales, and copying abstracts of longitude results.

Temporary assistance was given to the computing division by the following-named persons:

Mr. J. E. McGrath, who continued the reading off and tabulation of the magnetic and thermometric traces at the Madison magnetic observatory, keeping this work up to date. He also attended to clerical and computing work in connection with the geographical registers.

Mr. F. A. Sawyer, who was engaged in revising computation of spirit leveling in West Virginia and Ohio, 1878.

Mr. T. E. Norelius, who was reading off chronograph sheets in connection with transits at Statesville, 1878–'79, and making tracings of topographical sketches.

Mr. Carlisle Terry, jr., who was engaged on miscellaneous geodetic work.

Mr. Willis C. Ames, who was engaged in clerical work principally, preparing sketches and geographical positions for field parties, duplicating records and making some plain computations.

Mr. G. F. Bird, who was engaged in indexing duplicate records, miscellaneous copying, and inserting geographical positions in registers.

Tidal Division.—Mr. R. S. Avery remained in charge of the tidal division during the year. In his report on the field and office work relating to tides, Mr. Avery renews his recommendation for the establishment of a tidal station at the Bermuda Islands, and another at some point on the southern Atlantic coast, to obtain by a simultaneous series of observations data for a more complete investigation of the Atlantic coast tides, and suggests also that series of tidal observations with self-registering gauges at some ports of the Gulf of Mexico are very desirable. Having observed that the tidal curves and tide tables deduced from the usually short series of staff observations by hydrographic parties give data more or less imperfect for the reduction of soundings, especially where single day tides prevail, as in the Gulf of Mexico, or where there are large irregularities in the heights of high and low waters, as on the Pacific coast, Mr. Avery was induced to prepare a set of working drawings for a self-registering gauge, which should be easily put up on any firm support, and used without a house. One of these gauges is now in course of construction, and its working will be tested as soon as practicable.

The following table gives a list of stations at which self-registering gauges were in operation during the fiscal year, indicating those where long series of observations are in progress as "permanent."

Section.	Name of station.	Name of observer.	Kind of gauge.	Permanent or temporary.	Time of occupation. From—	Time of occupation. To—	Total days.
I	North Haven, Me.	J. G. Spaulding	Self-registering	Permanent	April 25, 1879	April 25, 1880	366
I	Providence, R. I.		...do	Temporary			
I	Block Island, R. I.	J. M. Conley	...do	...do	July 14, 1879	December 1, 1879	141
II	Sandy Hook, N. J.	J. W. Banford	...do	Permanent	June 1, 1879	June 1, 1880	366
X	Saucelito, Cal.	E. Gray	...do	...do	June 1, 1879	June 1, 1880	366
XII	Kadiak, Alaska		...do	Temporary			
	Mazatlan, Mex.	Fiacro Quijano	...do	Permanent	January 1, 1880	April 30, 1880	121
	Honolulu, S. I.	J. S. Emerson	...do	Temporary	June 17, 1878	February 18, 1880	612

In the office work of the division, Mr. Avery gave his personal attention to the preparation of information needed to meet inquiries from officers of the survey and others in relation to tidal results and bench-marks; he prepared tide tables for charts, and directed the computation of the tide tables containing the predictions of tides for the principal ports of the Atlantic and Pacific coasts of the United States for 1881. These tables were ready for publication before the close of the fiscal year.

Mr. L. P. Shidy was chiefly occupied in the reductions of tidal observations received from hydrographic parties; in the predictions for ports where large diurnal inequality prevailed, and in the miscellaneous work of the division.

Dr. T. Craig was assigned to duty in connection with tidal investigations and kindred researches in July, and, after some practice in tidal reductions, entered upon a discussion of the theory of projections, and the laws governing the tides on a viscous spheroid; studied the relations of lines on the general ellipsoid to those on certain spheroids which are analogous to the parallels and meridians on the sphere; investigated the various problems presented by a heavy bar supported at two or more points symmetrically or non-symmetrically situated with respect to the center; discussed the effect of ice-caps at the poles on the ocean level and on the form of the solid nucleus; investigated the formulæ representing the flow of water in a curved and in a straight channel, and began the application of some principles of vortex motion to tidal equations.

Special work on predictions was done by contract by Mr. John Downes. The predictions for Boston Harbor were computed by Mr. J. G. Spaulding. Miss M. Thomas assisted in the reductions and miscellaneous work. Miss C. Turnbull attended to some of the minor tabulations and reductions, and to miscellaneous copying and tracing.

C. D. White and J. W. Butler were temporarily attached to the division; the former to learn the management of a self-registering gauge, the latter for miscellaneous work.

Drawing Division.—The immediate supervision of the work of this division was continued with Mr. W. T. Bright. The draughtsmen employed during the year were as follows:

Mr. A. Lindenkohl, was engaged in making the finer class of hydrographic and topographic reductions, and in constructing the small scale charts. He kept the principal finished general and coast charts up to date, as also the annual progress sketches which accompany the yearly reports, and made projections on copper for the charts to be engraved thereon. In September, Mr. L. was engaged in field duty, and made a survey of the site of Washington's birth-place.

Mr. H. Lindenkohl was employed in many different ways requiring skill and judgment; in reducing various classes of charts, preparing drawings for reproduction by the photolithographic process, and in engraving on copper and stone.

Mr. L. Karcher made, with celerity, most of the numerous field projections, besides a great many diagrams, projects, and tracings; reduced for engraving topography and hydrography, and prepared drawings of the sketches illustrating progress of the geodetic work.

Mr. P. Erichsen executed the mechanical and perspective plan-drawings of instruments of precision; filled in topographical details upon photographed outlines of several coast charts, and reduced shore lines for field projections.

Mr. C. Junken was employed chiefly in reducing hydrography for coast and harbor charts, and made copper-plate and field projections. He was absent from the division from July 16 to November 13 making a topographical survey of Rockaway, L. I., and was from January 29 to May 11 engaged in surveying and plotting the hydrography of the upper part of the Patapsco River, Md., for the Board of Harbor Commissioners of Baltimore.

Mr. E. J. Sommer has continued upon miscellaneous work, making projections and tracings, and inking topographic sheets; much of his time has been given to the drawing of photolithographic harbor charts.

Mr. T. J. O'Sullivan was employed in enlarging the topography and hydrography of the Mississippi River from a scale of $\frac{1}{20000}$ to $\frac{1}{10000}$; in verifying enlarged charts; making diagrams illustrative of the annual reports and appendices; drawings for photolithographing; lettering and inking plane-table sheets, tracing, and other miscellaneous work.

Mr. H. Eichholtz added corrections and colored the buoys and light-houses upon the published charts. Mr. E. Molkow was employed, also, in correcting lights and buoys, besides performing other work in tracing, and doing duty in the archives.

The following gentlemen were employed in the division from July 10 to December 31, qualifying themselves, by practice-work, for the position of draughtsmen, viz: W. R. Randolph, W. E. Ames, A. E. Burton, E. H. Fowler, R. E. Peary, and A. B. Graham. Since the 1st of January, the four latter have been regularly employed, and engaged upon the lettering and inking of the topographical sheets which are turned in by the field officers in pencil. Mr. Burton was sent to Memphis, Tenn., April 9, in the capacity of draughtsman to the National Board of Health, and remained there until June, when he returned to his duties in the division.

Mr. J. C. Barr acted as clerk to the division since June 14, the date of his assignment.

A general summary of the work commenced, completed, or in progress in the drawing division during the year will be found in Appendix No. 4, while a list of information furnished to the office, by tracings and otherwise, in reply to special calls, is given in Appendix No. 3.

Engraving Division.—The operations in detail of this division, in charge of Assistant J. S. Bradford, may be summarized as follows:

Twenty chart plates were completed; six were begun, and work upon thirteen has been continued (the most of them almost to completion); corrections and additions were made upon one hundred and sixty-eight plates, including Atlantic Coast Pilot charts and views, besides two new Atlantic Coast Pilot charts, and sixteen view plates, containing forty-five views. The progress sketches (twenty in number) were examined and corrected to date, and a large quantity of miscellaneous work was done.

The force of the division has remained about the same as last year: Messrs. A. Sengteller and W. A. Thompson having been continued as topographical engravers; E. A. Maedel, A. Petersen, H. M. Knight, J. G. Thompson, and F. Courtenay, as letter engravers; E. H. Sipe and W. H. Davis, as miscellaneous engravers, and Theodore Wasserbach and A. C. Ruebsam, employed on miscellaneous corrections and additions.

Besides the above-mentioned persons, Messrs. J. Enthoffer, H. C. Evans, and R. F. Bartle have been employed on contract as topographical engravers.

Since the death of Mr. J. J. Young, Mr. J. R. Barker has been employed in etching Coast Pilot views.

The clerical duties of the division, including the verification of lettering and general engraving, have been very satisfactorily performed by Messrs. Leeds C. Keer and John H. Smoot.

In Appendix No. 5 is given a list of plates completed, continued, or commenced during the year

Electrotyping and Photographic Division.—Dr. Zumbrock, in charge of this division, made thirty-one altos from engraved plates, and twenty-nine bassos, the total weight of which was one thousand and fifty-five pounds, and the whole surface forty-six thousand one hundred and seventy-five inches. He also made one alto and twelve bassos from the small plate of the office seal, and steel faced twenty-eight plates. For the use of the draughtsmen and engravers, forty-eight negatives, three positives, and two hundred and twelve prints were taken. Upon him devolved also the care of the galvanic batteries, by means of which the office sympathetic clocks are regulated and the call bells kept in working order.

Dr. Zumbrock had the aid of Mr. Frank Over.

Miscellaneous Division.—The work of this division has been performed by Mr. M. W. Wines. It includes the care of the stationery, and its distribution for the requirements of the office and field parties, the supervision and care of the office buildings and furniture, the distribution of the annual reports and other publications, and the correspondence with sale agents relating to the supply and sale of charts, Coast Pilots, and Tide Tables.

During the fiscal year there were received from the Public Printer the following-named publications:

One thousand copies Tide Tables for the Pacific coast for 1880.

Fifteen hundred copies Tide Tables for the Atlantic coast for 1880.

Five hundred and fifty copies Atlantic Coast Pilot, Division A.—Eastport to Boston: second edition.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 1.—Passamaquoddy Bay to Schoodic.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 2.—Frenchman's Bay to Isle au Haut.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 3.—Penobscot Bay and tributaries.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 4.—White Head Island to Cape Small Point.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 5.—Cape Small Point to Cape Ann.

Two hundred copies Atlantic Local Coast Pilot, Subdivision 6.—Cape Ann to Cohasset.

Two hundred and fifty copies Pacific Coast Pilot, Appendix 1.—Meteorology and Bibliography of Alaska.

One thousand copies Secular changes of Magnetic Declination in the United States and at some Foreign Stations: third edition.

One hundred copies Appendix No. 9, Report for 1876.—Changes in the Harbor of Plymouth, Mass.

One hundred copies Appendix No. 11, Report for 1876.—Proposed location of a Pier-Line for the improvement of navigation near the United States Navy-Yard at New York.

Two hundred copies Appendix No. 14, Report for 1876.—Note on the Theory of the Economy of Research.

Two hundred and fifty copies Appendix No. 15, Report for 1876.—Measurements of Gravity at initial stations in America and Europe.

Five hundred copies Appendix No. 20, Report for 1876.—On the adaptation of Triangulations to various conditions, with Notes on Methods of observing Horizontal Angles.

Five hundred copies Appendix No. 21, Report for 1876.—On a chart of the Magnetic Declination in the United States.

Five hundred copies Appendix No. 22, Report for 1876.—Standards of Measure of the United States compared with those of Great Britain and France.

Five hundred copies Appendices 16, 17, 18, and 19 (bound together), Report for 1876.—Contributions to Hypsometry.

Five hundred copies Notice to Mariners, No. 18.—Depth of water over the bar at entrance of Wilmington Harbor, California.

Five hundred copies Notice to Mariners, No. 19.—Location of Keen Rock, in the middle passage to Sitka Harbor, Alaska.

Five hundred copies Notice to Mariners, No. 20.—Closing of New Inlet, mouth of Cape Fear River, North Carolina.

Five hundred copies Notice to Mariners, No. 21.—Increased depth of water at entrance of Cape Fear River, North Carolina.

Five hundred copies Notice to Mariners, No. 22.—Sunken wreck in the track of vessels running along the New Jersey coast.

Seven hundred and fifty copies Notice to Mariners, No. 23.—Development of Johnson's Rock, Casco Bay, Maine.

Five hundred copies Notice to Mariners, No. 24.—Dangerous wreck near Isle of Wight Shoal, coast of Maryland.

Five hundred copies Notice to Mariners, No. 25.—Development of Schuyler's Ledge off Sakonnet Point, Rhode Island.

Five hundred copies Notice to Mariners, No. 26.—Development of dangerous rocks near Fort Ross, California.

Due distribution having been made to the departments of the government, copies of the Atlantic Coast Pilot and of its subdivisions, with the Tide Tables for the Atlantic and Pacific coasts, were placed on sale at the agencies on both coasts. The appendices to the Reports, of which extra copies were supplied, as enumerated above, are for free distribution to all suitable applicants; the "Notices to Mariners" were given a wide circulation through the press, and were sent to all the agencies in the chief seaports, regard being had to the subject of the notice and the locality referred to.

Four hundred and ninety-two copies of the Annual Reports of the Superintendent were distributed; also ten hundred and ninety-two divisions of the Coast Pilot, including subdivisions. A second edition, revised and enlarged, of Division A, Eastport to Boston, was published.

There were received in the chart room during the year, for distribution under the immediate supervision of Mr. Thomas McDonnell, thirty-three thousand seven hundred and twenty sheets of charts, of which number eight thousand six hundred and thirty-four sheets were printed from stone. Of these charts there were required for the use of the several departments of the government nine thousand four hundred and nineteen copies, and to meet the demands of sale agents fifteen thousand four hundred and twenty copies. The total distribution of charts during the year was twenty-seven thousand eight hundred and sixty-six copies, an increase of more than four thousand copies over that of the previous year.

The office printing was done by Mr. Frank Moore, aided by D. N. Hoover and J. S. Beck, and during part of the year by J. S. Reilly. The backing of charts, the preparation of backed drawing paper for field use, and the work of the folding-room was attended to by H. Nissen, aided by R. T. Bassett.

In the archives, under the care of Mr. G. A. Stewart, there were received and registered during the year nine hundred and seventy-seven original and five hundred and fifteen duplicate volumes of records, four topographic and forty-one hydrographic sheets, with one hundred and thirty-one specimens of sea-bottom. The whole number of topographic sheets registered to June 30, 1880, is fourteen hundred and sixty-five, and of hydrographic sheets fourteen hundred and thirty-two.

Additions were made to the library, under the charge of Mr. Samuel Hein, as follows, during the fiscal year: Volumes, two hundred and sixteen; periodicals, five hundred and eighty-four, Extra copies of periodicals swelled this number to six hundred and ninety-nine. The frequent use made of publications on file is shown by the relatively large number of volumes and periodicals given out during the fiscal year, namely, twelve hundred and three.

The direction of work in the instrument shop and the charge of the instrument room remained with Mr. G. N. Saegmuller, chief mechanician. He was aided by John Clark, W. Jacobi, E. Eshleman, and P. Vierbuchen.

Mr. Saegmuller gave much of his time during the year to improvements in the graduating engine, and his success in executing these was very marked, a number of theodolites having been regraduated with results of an exceedingly satisfactory character. Among these were the circles of Troughton and Simms' theodolite No. 4, and those of the two twenty-inch theodolites by Wurdemann, Nos. 3 and 5.

Experiments with dividing on glass also engaged Mr. Saegmuller's attention, this material presenting certain advantages over metal for use in constructing the circles of theodolites.

All of the carpentry work of the office, including the wood-work of instruments and their packing for transportation, was done by Mr. A. Yeatman, with the assistance of J. W. Clarvoe, and during part of the year of C. Webster and George Dorn.

The clerical work in the office was performed by Messrs. W. B. French, W. A. Herbert, and by Mr. C. D. Gedney as stenographer.

Expenditures for the work of the Survey are authorized only on detailed estimates made in advance and approved by the Superintendent. The disbursing agent, Mr. J. W. Porter, as usual, has carefully examined the accounts of field parties, and conducted the necessary correspondence with the Department and employés of the Survey in fiscal matters.

In details pertaining to my correspondence with parties in the field and afloat, and the preparation of an abstract of operations during the year, Assistant W. W. Cooper has rendered acceptable service, as heretofore.

Respectfully submitted.

C. P. PATTERSON,
Superintendent.

Hon. JOHN SHERMAN,
Secretary of the Treasury.

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APPENDICES.

APPENDIX No. 1.

Distribution of surveying parties upon the Atlantic, Gulf of Mexico, and Pacific coasts and interior of the United States during the fiscal year 1879–'80.

Sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION I.				
Maine, New Hampshire, Vermont, Massachusetts, and Rhode Island, including coast and seaports, bays and rivers.	No. 1	Topography	H. G. Ogden, assistant; W. I. Vinal, subassistant.	Topographical survey, including the shores of the headwaters of Frenchman's Bay, Me.
	2	Hydrography	Lieut. J. F. Moser, U. S. N., assistant; Masters J. B. Murdock, A. C. Dillingham, and F. E. Greene, U. S. N.	Hydrography of Frenchman's Bay, Flanders Bay, and of the approaches to Blue Hill Bay, coast of Maine. Development of a rock in Casco Bay, and of a ledge off the coast of New Hampshire.
	3	Topography	A. W. Longfellow, assistant	Plane-table survey of the vicinity of Ellsworth, and adjacent coast of Maine.
	4	Hydrography	Lieut. Uriel Sebree, U. S. N., assistant; Lieut. Perry Garst, U. S. N.; Ensigns J. W. Stewart and J. C. Colwell, U. S. N.	Hydrography of the middle part of Blue Hill Bay, Me. Development of a rock off Sakonnet Point, R. I.
	5	Hydrography	Lieut. Commander C. M. Chester, U. S. N., assistant; Master T. G. C. Salter, U. S. N.; Ensigns H. Morrell, H. F. Reich, and C. H. Amsden, U. S. N.	Soundings in the southeast approach to Mount Desert Island, and hydrography of the upper part of Blue Hill Bay, Me.
	6	Tidal observations	J. G. Spaulding	Series of tidal observations continued with self-registering gauge, and meteorological observations recorded at North Haven, entrance of Penobscot Bay, Me.
	7	Geodetic operations.	Prof. E. T. Quimby	Triangulation continued in the northern part of New Hampshire.
	8	Geodetic	Prof. V. G. Barbour	Reconnaissance and selection of points in connection with occupied primary stations for the triangulation of Vermont.
	9	Triangulation	Richard D. Cutts, assistant; C. H. Sinclair, aid.	Primary triangulation continued at Killington Peak, and that station connected by angular measurements with numerous points in New Hampshire and Vermont.
	10	Magnetic observations.	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at Eastport and Bangor, Me.; at Portsmouth and Hanover, N. H.; at Cambridge and Nantucket, Mass.; at Rutland, Vt.; at Halifax, N. S.; and at Quebec and Montreal, Canada.
	11	Special operations	F. H. Gerdes	Securing ground marks at stations of the primary triangulation along the coast of Massachusetts and Rhode Island.
	12	Tidal observations		Observations continued at Providence, R. I., with the self-registering tide gauge lent to the city engineer.
SECTION II.				
Connecticut, New York, New Jersey, Pennsylvania, and Delaware, including coast, bays, and rivers.	No. 1	Hydrography	Lieut. S. M. Ackley, U. S. N., assistant; Lieut. H. T. Monahon, U. S. N.; Master F. E. Sawyer, U. S. N.; Ensign W. H. Nostrand, U. S. N.	Sea currents observed at stations between Nantucket and the entrance of Delaware Bay.
	2	Special operations.	F. H. Gerdes, assistant	Securing primary ground marks at triangulation points, and determining the positions of life-saving stations along the coast of Connecticut and New York.

APPENDIX No. 1—Continued.

Sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION II—Continued.	No. 3	Tidal observations	C. H. Van Orden; J. M. Conley	Observations with self-registering tide gauge recorded between June and December, 1879, at the Block Island breakwater, Long Island Sound.
	4	Topography and hydrography.	J. W. Donn, assistant; Charles Junken.	Plane-table survey of the vicinity of Hempstead Bay, L. I., and its development by soundings.
	5	Tidal observations	J. W. Banford	Self-registering tide gauge continued in operation at Sandy Hook, N. J.
	6	Topography	H. L. Whiting, assistant; W. C. Hodgkins, aid.	Detailed topographical survey of the eastern side of Hudson River extended to points above Cold Spring, N. Y.
	7	Magnetic observations.	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at Rouse's Point and at Albany, N. Y.; at Sandy Hook, N. J.; and at Hartford, Conn.
	8	Reconnaissance	S. C. McCorkle, assistant	Reconnaissance across the northern part of the State of New York for triangulation between Lake Champlain and Lake Ontario.
	9	Astronomical observations.	Edwin Smith, assistant; F. H. Parsons, aid.	Determinations of latitude at nine points near the boundary line between Pennsylvania and New York.
	10	Geodetic	Prof. E. A. Bowser	Triangulation continued in the northern part of New Jersey.
	11	Triangulation	R. M. Bache, assistant	Points determined in position along the banks for the survey of Delaware River from League Island downward to Tonkin's Island.
	12	Special observations.	C. S. Peirce, assistant; Henry Farquhar; Marcus Baker.	Pendulum observations completed at Ebensburg and York, Pa.
	13	Geodetic	Prof. Lewis M. Haupt	Triangulation in the southeastern part of Pennsylvania, connecting with primary stations near the head of Chesapeake Bay.
	14	Topography	C. M. Bache, assistant	Topographical survey of the vicinity of Cape May, N. J.
SECTION III. Maryland, Virginia, and West Virginia, including bays, seaports, and rivers.	No. 1	Special operations	F. H. Gerdes, assistant	New life-saving stations determined in position on the coast of Delaware, Maryland, and Virginia.
	2	Hydrography	John W. Parsons	Soundings in the approaches and across the bar of Chincoteague Inlet, coast of Maryland and Virginia.
	3	Hydrography	Charles Junken, assistant; P. A. Welker and G. F. Bird, aids.	Soundings in Patapsco River, Md., between Lazaretto Point and Hawkins' Point, for the Harbor Commission of Baltimore.
	4	Magnetic observations.	Charles A. Schott, assistant; J. B. Baylor, subassistant.	Magnetic declination, dip, and intensity determined at the standard station on Capitol Hill, Washington, D. C.
	5	Special hydrography.	Master Francis Winslow, U. S. N., assistant; Master H. H. Barroll, U. S. N.	Development in position and area of oyster beds in Hooper's Strait, Kedge's Strait, Nanticoke River, and Little Annemessex River, Md.
	6	Triangulation, topography, and hydrography.	J. W. Donn, assistant	Detailed survey of James River, Va., completed between City Point and Richmond.
	7	Triangulation and reconnaissance.	A. T. Mosman, assistant	Stations on the west side of the Blue Ridge, Va., occupied for extending triangulation westward towards the Ohio River.
	8	Special observations.	C. O. Boutelle, assistant; F. D. Granger, assistant; J. B. Boutelle.	Observations at Sugar Loaf Mountain, Md., for determining the relative cost and precision of day and night measurements in geodesy.
SECTION IV. North Carolina, including coast, sounds, seaports, and rivers.	No. 1	Magnetic observations.	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at a station in Beaufort, N. C.
	2	Hydrography	Lieut. Eugene B. Thomas, U. S. N., assistant; Lieut. Hugo Osterhaus, U. S. N.; Master F. E. Greene, U. S. N.; Ensign W. H. Allen, U. S. N.	Inshore soundings along the coast of North Carolina completed between Ocracoke Inlet and Cape Lookout, and between New River Inlet and Barren Inlet.

APPENDIX No. 1—Continued.

Sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION V.				
South Carolina and Georgia, including coast, sea-water channels, sounds, harbors, and rivers.	No. 1	Astronomical observations.	G. W. Dean, assistant; Edwin Smith, assistant; C. H. Sinclair and F. H. Parsons, aids.	Longitude determined by exchange of telegraphic signals at Charleston, S. C., and Atlanta, Ga. and determination of the latitude of Atlanta.
	2	Magnetic observations.	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at Breach Inlet, near Charleston, S. C., and at Lawton (Du Pont), Ga.
SECTION VI.				
East Florida, from Saint Mary's River to Anclote Keys on the west coast, including coast approaches, reefs, keys, seaports, and rivers.	No. 1	Magnetic observations.	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at Jacksonville, Saint Augustine, Enterprise, Eau Gallie, Saint Lucie, and Fort Jupiter, in Florida.
	2	Hydrography	Commander J. R. Bartlett, U. S. N., assistant; Lieut. W. O. Sharrer, U. S. N.; Masters H. M. Jacoby and G. W. Mentz, U. S. N.; Ensigns G. H. Peters and E. L. Reynolds, U. S. N.	Deep-sea soundings in the Bahama Channel on the northeast side of Cuba, and southward of that island in the Caribbean Sea, with dredgings and serial temperatures.
	3	Hydrography	Lieut. Commander C. M. Chester, U. S. N., assistant; Master T. G. C. Salter, U. S. N.; Ensigns H. Morrell, H. F. Reich, and C. H. Amsden, U. S. N.	Soundings completed inside of Charlotte Harbor, Fla., and hydrography of the approaches continued.
SECTION VIII.				
Alabama, Mississippi, Louisiana, and Arkansas, including Gulf coast, ports, and rivers.	No. 1	Astronomical observations.	G. W. Dean, assistant; Edwin Smith, assistant; C. H. Sinclair and F. H. Parsons, aids.	Longitude determined by exchange of telegraphic signals at New Orleans and Baton Rouge, La., and observations for the latitude of a point at Baton Rouge.
	2	Magnetic observations	J. B. Baylor, subassistant	Magnetic declination, dip, and intensity determined at New Orleans, La.
	3	Triangulation	F. W. Perkins, assistant (part of season); F. D. Granger, assistant.	Triangulation of the Mississippi River from Donaldsonville upward to Bellevale.
	4	Triangulation and topography.	C. H. Boyd, assistant; W. I. Vinal, subassistant.	Triangulation of the Mississippi River from points above Fort Adams continued upward to Natchez, and plane-table survey of the vicinity of Baton Rouge, La.
	5	Geodetic..........	Andrew Braid, subassistant; W. C. Hodgkins, aid.	Lines of level run along the banks of the Mississippi River from Carrollton upward to Fort Adams.
	6	Triangulation and topography.	W. H. Dennis, assistant; C. H. Van Orden, aid.	Triangulation of the Mississippi River from Bayou Sara upward to points above Fort Adams; and detailed topographical survey of the vicinity of Donaldsonville, La.
	7	Triangulation, topography, and hydrography.	Charles Hosmer, assistant; Joseph Hergesheimer, subassistant.	Triangulation of the Mississippi River from Grand Gulf to Vicksburg. Topography and hydrography of the vicinity of Grand Gulf; and plane-table survey of the vicinity of Baton Rouge, La.
	8	Geodetic..........	O. H. Tittman, assistant; J. B. Weir, subassistant.	Lines of level run on the banks of the Mississippi River between Milliken's Bend, La., and Greenville, Miss.
	9	Astronomical observations.	H. G. Ogden, assistant; C. Terry and Isaac Winston, aids.	Measurement of base lines and azimuth for the triangulation of the Mississippi River at Lake Providence, Lum's Point, Baton Rouge, Bayou Sara, and Cottonwood Point.
SECTION IX.				
Texas and Indian Territory, including Gulf coast, bays, and rivers.	No. 1	Hydrography	Lieut. Uriel Sebree, U. S. N., assistant; Lieut. Perry Garst, U. S. N.; Ensigns J. W. Stewart, J. C. Colwell, and M. L. Wood, U. S. N.	Hydrography of the Gulf coast in the vicinity of Corpus Christi and Copano Bays, Tex.
	2	Triangulation and topography.	R. E. Halter, assistant...........	Triangulation of Laguna Madre completed, and topography extended northward from stations above Point Isabel.

APPENDIX No. 1—Continued.

Sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION IX—Continued.				
	No. 3	Magnetic observations.	Lieut. S. M. Ackley, U. S. N., assistant; Lieut. H. T. Monahon, U. S. N.; Master F. E. Sawyer, U. S. N.; Ensign W. H. Nostrand, U. S. N.	Magnetic declination, dip, and intensity determined at Tortugas, Alacran Reef, Cay Arenas, Vera Cruz, Lagunas, Campeche, and Progresso, in the southwestern part of the Gulf of Mexico.
SECTION X.				
California, including the coast, bays, harbors, and rivers.	No. 1	Tidal observations	Fiacro Quijano, civil engineer	Observations with self-registering tide gauge at Mazatlan, western coast of Mexico.
	2	Topography	Stehman Forney, assistant	Detailed topographical survey of San Nicolas Island, off the coast of California.
	3	Hydrography	Lieut. E. H. C. Leutze, U. S. N., assistant; Lieuts. E. K. Moore and C. L. Heilner, U. S. N.; Masters W. P. Elliott and R. H. Galt, U. S. N.	Inshore soundings along the coast of California completed between San Luis Obispo and Point Sal; also hydrography of the approaches to San Clemente Island, San Nicolas, and Santa Barbara Island.
	4	Topography	W. E. Greenwell, assistant	Topography of the coast of California completed between Point Arguello and Point Sal.
	5	Primary triangulation.	George Davidson, assistant; B. A. Colonna, assistant; J. J. Gilbert, assistant; E. F. Dickins, subassistant; and J. F. Pratt, subassistant.	Geodetic operations, including latitude, azimuth, and magnetic observations at Mount Lola and Round Top for the great triangulation across the Sierra Nevada in California. Angular measurements made at two stations to determine the position of Mount Shasta.
	6	Reconnaissance	L. A. Sengteller, assistant	Examination of the Sierra Nevada region for lines of triangulation southward of Mount Diablo, Round Top, and Cory Peak.
	7	Topography	Edwin Hergesheimer, assistant	Minute surveys of special topographical features at Fallen Leaf Lake, at Table Mountain, and Montara Mountain, and of supposed sea-benches near Santa Cruz and Point San Pedro, Cal.
	8	Tidal observations	E. Gray	Observations continued with the self-registering tide gauge at Saucelito, inside of San Francisco Bay.
	9	Hydrography	Commander G. W. Coffin, U. S. N., assistant; Lieuts. W. H. Driggs, W. T. Swinburne, and C. W. Jarboe, U. S. N.; Ensigns C. F. Putnam, C. F. Pond, and W. D. Rose, U. S. N.	Inshore hydrography of the coast of California extended from Bodega Head northward to Timber Creek.
	10	Triangulation and topography.	L. A. Sengteller, assistant; Fremont Morse, aid.	Triangulation and topography of the coast of California continued between Walalla River and Point Arena.
	11	Hydrography	Lieut. H. E. Nichols, U. S. N., assistant; Lieut. W. T. Swinburne, U. S. N.; Master C. F. Putnam, U. S. N.; Ensigns F. W. Coffin, W. D. Rose, and C. F. Pond, U. S. N.	Hydrography in progress between Bodega Head and Point Arena, coast of California.
	12	Triangulation	Aug. F. Rodgers, assistant	Primary triangulation of the coast of California continued northward towards Point Gorda.
	13	Geodetic	B. A. Colonna, assistant	Mount Shasta, Cal., occupied and its position determined by angular measurements at Mount Helena and Mount Lola.
	14	Tidal observations		Tidal observations continued with self-registering tide gauge at the entrance of Honolulu Harbor, Sandwich Islands.
SECTION XI.				
Oregon and Washington Territory, including coast, interior bays, ports, and rivers.	No. 1	Topography	Cleveland Rockwell, assistant	Detailed plane-table survey of the banks of Columbia River, Oregon, extended from Kalama upward to Columbia City.

APPENDIX No. 1—Continued.

Sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION XI—Continued.				
	No. 2	Triangulation and topography.	Eugene Ellicott, subassistant	Triangulation and topography of Hammersley's Inlet, and shore-line survey of adjacent waters at the head of Puget Sound, Wash. Ter.
	3	Hydrography	Lieut. A. B. Wyckoff, U. S. N., assistant; Ensigns S. J. Browne and H. T. Mayo, U. S. N.	Hydrography completed in the headwaters of Puget Sound, Wash. Ter., including Carr's Inlet, Case's Inlet, Hammersley's Inlet, and the passages in that vicinity.
	4	Reconnaissance	J. S. Lawson, assistant	Reconnaissance for connecting the triangulation of Puget Sound with that of the Columbia River.
SECTION XII.				
Alaska Territory, including the coast and the Aleutian Islands.	No. 1	Astronomical, magnetic, and tidal observations.	W. H. Dall, assistant; Marcus Baker, aid.	Astronomical and magnetic observations at stations between Sitka and Chilkaht, coast of Alaska. Self-registering tide gauge established at Kadiak.
SECTION XIII.				
Kentucky and Tennessee	No. 1	Geodetic operations.	George A. Fairfield, assistant; Prof. J. B. Hoeing (part of season); Carl Schenk, acting assistant; Carlisle Terry, jr., and Isaac Winston, aids.	Measurement of base line near Louisville, and triangulation adjacent to the base, for the geodetic survey of Kentucky.
	2	Astronomical observations.	G. W. Dean, assistant; Edwin Smith, assistant; C. H. Sinclair, aid; F. H. Parsons, aid.	Longitude determined, by exchange of telegraphic signals, at Louisville, Ky., and Nashville, Tenn., and determination of the latitude of Louisville.
	3	Geodetic operations.	Prof. A. H. Buchanan	Triangulation extended westward to Nashville, Tenn., from the Lebanon base line, and stations occupied northward and eastward of Lebanon.
SECTION XIV.				
Ohio, Indiana, Illinois, Wisconsin, and Michigan.	No. 1	Geodetic	Andrew Braid, subassistant	Geodetic levels run from Athens, Ohio, westward to Mitchell, in Indiana.
	2	Geodetic	Prof. R. S. Devol	Reconnaissance for the scheme of triangulation in Ohio.
	3	Geodetic	Prof. J. L. Campbell	Selection of stations for triangulation in Indiana.
	4	Geodetic	Prof. John E. Davies	Triangulation continued in Wisconsin at stations southward and eastward of Prairie du Chien.
	5	Magnetic observations.	David Mason	Magnetic observations continued with self-recording instruments at Madison, Wis.
SECTION XV.				
Missouri, Kansas, Iowa, Nebraska, Minnesota, and Dakota.	No. 1	Triangulation	J. A. Sullivan, assistant; H. W. Blair, subassistant; P. A. Welker and G. F. Bird, aids.	Triangulation in Missouri extended westward of Jefferson City to stations in the vicinity of Sedalia.
SECTION XVI.				
Nevada, Utah, Colorado, Arizona, and New Mexico.	No. 1	Triangulation	O. H. Tittmann, assistant; J. B. Weir, subassistant.	Measurement of base line in Colorado, and triangulation adjacent to the ends of the base.
	2	Triangulation	William Eimbeck, assistant; R. A. Marr, aid.	Triangulation continued in Nevada eastward along the thirty-ninth parallel of latitude.

APPENDIX No. 2.

Statistics of field and office work of the United States Coast and Geodetic Survey to the close of the year 1879.

Description.	Total to December 31, 1878.	1879.	Total to December 31, 1879.
RECONNAISSANCE.			
Area in square statute miles	265, 974	3, 976	269, 950
Parties, number of, in year	....	2	....
BASE LINES.			
Primary, number of	13	0	13
Subsidiary, number of	111	5	116
Primary, length of, in statute miles	79	0	79
Subsidiary and line measures, length of, in statute miles	251	$14\frac{3}{4}$	$265\frac{3}{4}$
TRIANGULATION.			
Area in square statute miles	116, 353	22, 040	138, 393
Stations occupied for horizontal angles, number of	9, 238	317	9, 555
Geographical positions determined, number of	17, 226	593	17, 819
Stations occupied for vertical angles, number of	536	25	561
Elevations determined, number of	1, 419	64	1, 483
Lines of spirit-leveling, length of	1, 064	292	1, 356
Parties, triangulation and leveling, number of, in year	....	35	....
ASTRONOMICAL WORK.			
Azimuth stations, number of	148	6	154
Latitude stations, number of	246	15	261
Longitude stations (telegraphic), number of	97	4	101
Longitude stations (chronometric and lunar), number of	110	0	110
Astronomical parties, number of, in year	....	12	....
MAGNETIC WORK.			
Stations occupied, number of	432	8	440
Permanent magnetic stations, number of, in year	....	2	....
Magnetic parties, number of, in year	....	2	....
TOPOGRAPHY.			
Area surveyed in square miles	26, 496	603	27, 099
Length of general coast, in miles	6, 013	86	6, 099
Length of shore line, in miles (including rivers, creeks, and ponds)	74, 408	1, 752	76, 160
Length of roads, in miles	38, 849	779	39, 628
Topographical parties, number of, in year	....	15	....
HYDROGRAPHY.			
Parties, number of, in year	....	18	....
Number of miles run while sounding	323, 253	6, 381	329, 634
Area sounded, in square miles	77, 342	1, 857	79, 199
Miles run, additional, of outside or deep-sea soundings	60, 546	5, 520	66, 066
Number of soundings	14, 981, 340	200, 986	15, 182, 326
Deep-sea soundings, number of, in year	....	664	....
Deep-sea temperature observations, number of, in year	....	1, 138	....
Tidal stations, permanent	233	8	241
Tidal stations occupied temporarily	1, 713	38	1, 751
Tidal parties, number of, in year	....	7	....
Current stations occupied	494	24	518
Current parties, number of, in year	....	3	....
Specimens of bottom, number of	10, 858	244	11, 102
RECORDS.			
Triangulation, originals, number of volumes	2, 522	286	2, 808
Astronomical observations, originals, number of volumes	1, 355	42	1, 397
Magnetic observations, originals, number of volumes	398	66	464
Duplicates of the above, number of volumes	2, 647	320	2, 967
Computations, number of volumes	2, 763	190	2, 953

APPENDIX No. 2—Continued.

Description.	Total to December 31, 1878.	1879.	Total to December 31, 1879.
RECORDS—Continued.			
Hydrographical soundings and angles, originals, number of volumes	7,707	183	7,890
Hydrographical soundings and angles, duplicates, number of volumes	1,082	122	1,204
Tidal and current observations, originals, number of volumes	3,186	68	3,254
Tidal and current observations, duplicates, number of volumes	2,070	45	2,115
Sheets from self-registering tide-gauges, number of	2,639	58	2,697
Tidal reductions, number of volumes	1,721	37	1,758
Total number of volumes of records	25,451	1,359	26,810
MAPS AND CHARTS.			
Topographical maps, originals	1,573	5	1,578
Hydrographic charts, originals	1,518	48	1,566
Reductions from original sheets	846	22	868
Total number of manuscript maps and charts, to and including 1879	2,607	22	2,629
Number of sketches made in field and office	3,044	30	3,074
ENGRAVING AND PRINTING.			
Engraved plates of finished charts, number of	223	4	227
Engraved plates of preliminary charts, sketches, and diagrams for the Coast and Geodetic Survey Reports, number of	581	9	590
Electrotype plates made	1,362	92	1,454
Finished charts published (including reissues)	275	19	294
Preliminary charts and hydrographical sketches published, number of	500	4	504
Engraved plates of Coast Pilot charts	19	22	41
Engraved plates of Coast Pilot views	46	7	53
Printed sheets of maps and charts distributed	406,752	24,459	431,211
Printed sheets of maps and charts deposited with sale agents	146,098	12,946	159,044
LIBRARY.			
Number of volumes	6,654	257	6,911

APPENDIX No. 3.

Information furnished from the Coast and Geodetic Survey Office, by tracings from original sheets, &c., in reply to special calls, during the fiscal year ending with June, 1880.

Date.		Name.	Data furnished.
1879.			
July	29	Lieut. F. H. Newcomb, United States revenue sloop Saville.	Charts of Pamplico Sound, N. C., brought up by hand.
Aug.	14	Mr. J. R. McClintock, New Orleans, La	Unfinished proof of coast chart No. 90, scale 1-80,000, brought up by hand, Lakes Borgne and Pontchartrain.
	19	E. C. Court, engineer of a ship-canal between New Orleans and Jacksonville.	Tracings of topographical sheets between Apalachicola and Mobile.
	23	E. H. Ludlow & Co., New York City	Hydrography of the lower part of Newark Bay, N. J.
	25	Hon. David Yulee, Florida	Tracing of coast of Florida, from Apalachicola to Cedar Keys.
	29	George M. Root, New York City	Sketch showing changes in shore-line of Staten Island.
Sept.	11	Prof. G. H. Cook, State geologist of New Jersey	Two projections, upon a scale of two miles to the inch, covering the entire State of New Jersey, with all trigonometrical points, determined within the State, plotted thereon.
	11	Capt. A. N. Damrell, United States Corps of Engineers	Unfinished proofs of coast charts of Charlotte Harbor and Cedar Keys brought up by hand.
	12	Col. S. T. Abert, United States civil engineer	Tracing of topography of Hampton Creek, Va.
	23	Commander George Dewey, United States Navy, secretary Light-House Board.	Proof of general chart of the coast, No. VIII, Cumberland Island to Cape Cañaveral, Fla., scale 1-400,000, brought up by hand.
	25	Maclay & Davies, civil engineers, New York	Topographical survey of the beaches along the southern coast of Long Island, between Fire Island and Rockaway Inlet, from the survey of 1835.
	29	United States Light-House Board	Proof of general chart of the coast No. VIII, Cumberland Island to Cape Cañaveral, Fla., scale 1-400,000, brought up by hand.
	29	Prof. G. H. Cook, State geologist of New Jersey	Shore-line survey of Sandy Hook and Sandy Hook Head of 1836 and 1862, scales 1-10,000 and 1-5,000.
Oct.	3	Prof. W. C. Kerr, State geologist of North Carolina	Proof of triangulation in North Carolina, showing all subordinate points determined.
	7	Mr. William Forsyth, Washington City	Topographical survey of 1865, of the Eastern Branch of the Potomac River, vicinity of Benning's Bridge.
	13	Mr. B. M. Harrod	Hydrographic survey of the Mississippi River, from Carrollton to Twelve mile Point.
	15	A. G. Menocal, civil engineer, United States Navy	Latest hydrographic survey, with resurveyed wharf line, vicinity of Fulton Ferry, East River, N. Y.
	22	Philadelphia and Reading Railroad Company	Hydrographic resurvey of 1878, of the Delaware River, Philadelphia City front, from Petty's Island to Fort Mifflin, scale 1-4,800.
	30	Gen. J. N. Macomb, United States Corps of Engineers	Hydrographic resurvey of 1878, of the Delaware River, Philadelphia City front, from Bridesburg to Fort Mifflin, scale 1-4,800.
	30	......do	Copies of the dynamic charts of the Delaware River, Philadelphia City front, from Bridesburg to Fort Mifflin.
Nov.	7	S. I. Kimball, general superintendent United States Life Saving Service.	Coast charts Nos. 27, 28, 29, and 30 (Cape Henlopen to Cape Charles), with position of life-saving stations shown thereon.
	12	Mr. N. H. Bishop, Lake George, N. Y	Unfinished proof, brought up by hand, of general chart of the coast No. VIII, Cumberland Island to Cape Cañaveral, Fla., scale 1-400,000.
	12	Hon. William M. Evarts, Secretary of State	Copy of the topographical survey of the Birth Place of Washington.
	18	Judge G. W. Dobbin, Baltimore, Md	Unfinished pooof of coast chart No. 59, Saint Augustine to Halifax River, Fla., scale 1-80,000, brought up by hand.
	22	Prof. J. H. C. Coffin, United States Navy	Topographical survey of the shores of the Sheepscot River, Me., vicinity of Wiscasset.
	25	Robert S. Forbes, agent and attorney for the city of Monterey, Cal.	Topographical survey of the shore of Monterey Bay, Cal., from near the mouth of Pajaro River to one mile below Salinas Great Bend.
	25	Mississippi River Commission	Sketch of triangulation of the Mississippi River, vicinity of Helena, 1878.
	26	Mr. Thomas C. Clarke, New York	Hudson River, vicinity of Bull's Ferry.
	26	Mr. Francis Boyd, Boston, Mass	Topography of the shores of West Bay, Gouldsboro', Me.

APPENDIX No. 3—Continued.

Date.		Name.	Data furnished.
1879.			
Dec.	6	Mr. J. Herbert Shedd, Providence, R. I	Shore line of part of Narragansett Bay and Providence River, from Warren Neck to Sassafras Point, with position of light-houses, beacons, and triangulation points shown.
	30	Richmond Dispatch	Distance in nautical and statute miles from Cape Henry to Richmond, Va.
	30	William Hamilton Hall, State engineer of California	Hydrographic resurvey of Suisun Bay, Cal., 1878; comparative charts of the surveys of Suisun Bay, Cal., of 1867 and 1868.
1880.			
Jan.	2	Joseph H. Curtis, civil engineer, Boston, Mass	Topographical survey of Graves' Island and adjacent coast, township of Manchester, Mass.
	6	Mr. George H. Homans, Boston, Mass	Topographical survey of the east side of Mount Desert Island, Me., from The Bowl to Anemone Cave.
	15	Senator Samuel B. Maxey, of Texas	Unfinished proof of coast chart No. 104, Galveston Bay; of No. 108, part of Matagorda Bay, Lavaca, Espiritu, and San Antonio Bays; and 109, Aransas, Copano, and Corpus Christi Bays, Tex., scale 1-80,000.
	20	Hon. R. H. M. Davidson, Florida	Measured coast line of the State of Florida.
	21	Mr. Henry Addix, Brunswick County, N. C	Tracing of the topographical survey of the coast of North Carolina, between Davis Creek and Elizabeth River, entrance to Cape Fear River.
	23	Hon. Nelson W. Aldrich, of Rhode Island	Unfinished proofs of coast charts Nos. 42 and 43, middle and eastern parts of Pamplico Sound, N. C., scale 1-80,000.
	26	Mr. J. Herbert Shedd, Providence, R. I	Hydrographic survey of Bissell's Cove, Narragansett Bay.
	26	Lieut. Eugene Griffin, United States Corps of Engineers	Comparative maps of Sandy Hook between the years 1855 and 1862.
	29	Hon. C. P. Berry, House of Representatives	Comparative chart of Suisun Bay, Cal., showing changes between the surveys of 1866-'67 and 1878.
Feb.	2	Mr. E. F. Daly, No. 170 Broadway, New York	Topographical survey of Far Rockaway and vicinity, from the sheets of 1855 and 1860.
	3	Mr. E. L. Corthell, resident engineer South Pass jettee works, La.	Topographical survey of the Mississippi River, vicinity of The Jump.
	10	Gen. F. A. Walker, Superintendent United States Census	Unfinished proof of general coast chart No. VIII, scale 1-400,000, from Cumberland Island to Cape Cañaveral, Fla.
	10	Mr. J. Herbert Shedd, Providence, R. I	Hydrographic survey of Warren and Kickamuit Rivers, Narragansett Bay, R. I.
	12	Gen. Q. A. Gillmore, United States Corps of Engineers and president Mississippi River Commission.	Map of reconnaissance, by Assistant C. Hosmer, of Grand Gulf, Mississippi River, made in January and February, 1880.
	12	Mr. E. F. Daly, 170 Broadway, New York	Copy of topographical survey of Far Rockaway and vicinity, Long Island, made in 1835.
	14	Mr. Moody Boynton	Hydrographic resurvey of mouth of the Merrimac River, entrance to Newburyport Harbor, Mass., made in 1878.
	18	Mr. Thomas Bernard, city engineer, Norfolk, Va	Topographical survey of the city of Norfolk, Va., surveyed in 1874, scale 1-10,000.
	19	Prof. George H. Cook, State geologist of New Jersey	Topographical survey of Princeton and vicinity, N. J., of 1840.
	19	......do	Topographical survey of 1841, of portions of Middlesex and Monmouth Counties, N. J.
	21	Mr. J. B. Stone, civil engineer New York and Long Beach Railroad, L. I.	Topographical and hydrographic survey of East Rockaway Inlet, entrance to Hempstead Bay, L. I.; survey of 1879.
	26	Mr. R. E. Earll, United States Fish Commission	Unfinished proofs of coast charts Nos. 42 and 43, middle and eastern part of Pamplico Sound; No. 50, Cape Fear River and vicinity; and 58, Cumberland Island to near Saint Augustine, Fla., brought up by hand.
	26	Mr. Charles G. Atkins, United States Fish Commission	Shore-line tracings, from the plane-table sheets of the Kennebec River, Me., from Brick Island (Merrymeeting Bay) to Green Point; from Green Point to Gardiner; and of the Androscroggin, Muddy, and Cathance Rivers, from Brunswick to Bowdoinham.
Mar.	1	Col. George H. Mendell, United States Corps of Engineers	Topographical survey of Port Orford, Cal., made in 1851, and copy of reconnaissance, made in 1869.
	2	Capt. Lemuel Mitchell, Annapolis, Md	Chart of Chesapeake Bay, with boundary line shown as ascertained and determined by arbitrators between Maryland and Virginia, in 1877.
	2	Mr. David V. Whiting, 3505 Race street, Philadelphia	Chart of the southwestern part of the Gulf of Mexico.
	3	Mr. F. Richardson, Norfolk, Va	Photographic prints, scale 1-80,000, of topographical work between Norfolk and Cape Henry, Va.

APPENDIX No. 3—Continued.

Date.		Name.	Data furnished.
1880.			
Mar.	8	Maj. F. U. Farquhar, United States Corps of Engineers, engineer secretary Light-House Board.	Hydrographic resurvey, made in 1878, of entrance to the Merrimac River, Mass.
	8	Hon. C. M. Shelley, House of Representatives	Unfinished proof, brought up by hand, of coast chart No. 109, Aransas Bay and part of Corpus Christi Bay, Tex.
	12	Census Bureau	Chart of New York Bay and Harbor, with 40 and 80 feet curves of elevation shown in red ink.
	13	Strong & Spear, lawyers, New York City	Hydrographic survey of Port Jefferson, Long Island, added to a tracing of the topography sent to the firm in November, 1878.
	18	Lieut. George C. Reiter, United States Navy, light-house inspector, thirteenth district.	Hydrographic survey of Walker's Island Channel, Columbia River.
	22	Mr. J. B. Stone, civil engineer New York and Long Beach Railroad.	Topography of Hempstead Bay, including Far Rockaway, Lawrence, Woodburgh, and East Rockaway to Christian Hook, with the hydrography of the bay, from the surveys made in 1879.
	24	Herman Ruge & Sons, Apalachicola, Fla	Unfinished proof of coast chart No. 82, scale 1-80,000, including Saint George's Sound and part of Apalachee Bay, Fla., and one of coast chart No. 83, Apalachicola Bay and coast to Saint Joseph's Bay, Fla., brought up by hand.
	25	N. H. Hutton, engineer harbor board, Baltimore	Tracing from the 1845 hydrographic survey of the Patapsco River, between the Lazaretto and Hawkins Point.
	29	Mr. O. H. Tripp, Blue Hill, Me	Topographical survey of the western shore of Blue Hill Bay, showing the location of Salt Pond, Me.
	30	C. P. Huntington, president Southern Pacific Railroad	Unfinished proof of coast chart No. 108, San Antonio, Espiritu, and Lavaca Bays, and part of Matagorda Bay, Tex.
	30	Hon. Daniel O'Reilly, House of Representatives	Hydrographic survey of Gowanus Bay, Long Island, N. Y.
Apr.	2	Mrs. George T. Vingut, No. 58 West 34th street, New York.	Hydrographic survey of Setauket Harbor, Port Jefferson, Long Island, N. Y.
	2	Prof. V. C. Barbour, Vermont	Projections for a map of the State of Vermont upon a scale of 1-200,000, in two parts.
	8	Mr. George S. Green, jr., department of docks, New York City.	Hydrography of the upper part of Buzzards Bay, vicinity of Black River Harbor, Mass.
	9	Commodore J. M. B. Clitz, United States Navy, light-house inspector, third district.	Hydrographic survey of Mamaroneck Harbor, north side of Long Island Sound, N. Y.
	12	E. H. Ludlow, No. 1130 Broadway, New York	Hydrography and shore line of the west side of the Narrows, from Clifton to New Brighton Landing, N. Y.
	14	Hon. Hamilton Fish, New York	Topographical survey of the east side of the Hudson River, vicinity of Garrison's Landing.
	15	Rear-Admiral John Rodgers, superintendent Naval Observatory.	Maps of the District of Columbia, with every hundred-feet curves of elevation.
	21	G. W. McGinness, superintendent Grand Gulf and Port Gibson Railroad.	Survey of Grand Gulf, Mississippi River, made in 1880.
	22	Hon. H. H. Bingham, House of Representatives	Delaware River, vicinity of Bordentown, N. J., from the surveys of 1844.
	22	Navy Department	Hydrographic survey of the Thames River, Conn., from Winthrop Point to southern boundary of naval station, from the chart of 1839, scale 1-10,000.
	29	N. H. Hatton, engineer harbor board, Baltimore	Hydrographic resurvey of the Patapsco River, between Lazaretto Point and Hawkins Point, Md.
May	3	Hon. Van H. Manning, House of Representatives	Charts of Saint Simon's Sound, Brunswick Harbor, &c., Ga., brought up by hand.
	31	Hon. Charles O'Neill, Philadelphia	Charts of the Delaware Bay and River, colored by hand.
June	11	Col. John Newton, United States Corps of Engineers	Topographical survey of the north shore of East River, from Hunt's Point to Randall's Island, including the Two Brothers, N. Y.
	11	Mr. S. R. Throckmorton	Topographical survey of part of Table Mountain, Marin County, Cal.
	25	S. T. Abert, United States civil engineer	Shore line and hydrographic survey of York River, vicinity of West Point, Va.

APPENDIX No. 4.

DRAWING DIVISION.

Charts completed or in progress during the fiscal year ending June 30, 1880.

1. Topography. 2. Hydrography. 3. Drawing for photolithographic reproduction. 4. Inking and lettering plane-table sheets. 5. Engraving topography. 6. Topographical details upon pantographic outlines. 7. New longitudes. 8. Verifying.

Titles of charts.	Scale.	Draughtsmen.	Remarks.
Sailing charts, Atlantic Coast:			
No. I, Cape Sable to Sandy Hook	1-1, 200, 000	2. A. Lindenkohl	Additions.
No. III, Cape Hatteras to Mosquito Inlet	1-1, 200, 000	2. A. Lindenkohl	Do.
No. IV, Mosquito Inlet to Key West	1-1, 200, 000	2. A. Lindenkohl	Do.
No. V, Gulf of Mexico	1-1, 200, 000	1, 2. A. Lindenkohl. 2. H. Lindenkohl.	Do.
General coast charts, Atlantic and Gulf Coasts:			
No. I, Quoddy Head, Me., to Cape Cod, Mass	1-400, 000	2. C. Junken. 8. A. Lindenkohl	Do.
No. VI, Cape Hatteras to Cape Romain	1-400, 000	2. A. Lindenkohl. 7. C. Junken	Do.
No. XIII, New Orleans to Cape San Blas	1-400, 000	1. A. Lindenkohl	Do.
Sailing charts, Pacific Coast:			
No. 1, San Diego to Santa Monica, Cal	1-200, 000	1, 2. A. Lindenkohl. 1, 5. H. Lindenkohl.	Do.
No. 2, Santa Monica to Point Conception	1-200, 000	1, 2. A. Lindenkohl. 1, 5. H. Lindenkohl.	Completed.
COAST CHARTS.			
No. 3, Petit Manan Light to Naskeag Point, Me	1-80, 000	1, 2. A. Lindenkohl. 2. H. Lindenkohl.	In progress.
No. 4, Penobscot Bay and approaches, Me	1-80, 000	2. A. Lindenkohl. 1, 7. L. Karcher	Completed.
No. 14, Eastern entrance to Long Island Sound—Point Judith and Block Island to Plum Island.	1-80, 000	2. A. Lindenkohl	Additions.
No. 15, Long Island Sound, middle sheet	1-80, 000	2. L. Karcher	Do.
No. 20, New York Bay and Harbor	1-80, 000	6. P. Erichsen. 8. T. J. O'Sullivan	Do.
No. 21, Sandy Hook to Barnegat light-house	1-80, 000	8. H. Lindenkohl	Completed.
No. 31, Entrance to Chesapeake Bay, Hampton Roads, &c.	1-80, 000	1. R. E. Peary; A. E. Burton	Additions.
No. 39, Oregon Inlet to Cape Hatteras	1-80, 000	2. A. Lindenkohl; L. Karcher	Completed.
No. 42, Pamplico Sound, eastern part	1-80, 000	2. L. Karcher	Do.
No. 43, Pamplico Sound, middle part	1-80, 000	2. L. Karcher	Do.
No. 61, Cape Cañaveral and coast south, Fla	1-80, 000	1. H. Lindenkohl	In progress.
No. 70, Key West to Marquesas and Rebecca Shoals, Fla	1-80, 000	2. L. Karcher	Completed.
No. 71, Rebecca Shoals to the Dry Tortugas, Fla	1-80, 000	2. L. Karcher	Do.
No. 77, Tampa Bay, Fla	1-80, 000	8. P. Erichsen. 7. A. Lindenkohl	Do.
No. 80, Cedar Keys to Steinhatchee River, Fla	1-80, 000	1. P. Erichsen. 2. L. Karcher	Do.
No. 82, Saint Mark's to Saint George's Island, Fla	1-80, 000	1, 2. E. J. Sommer	Do.
No. 83, Cape San Blas to Saint Joseph's, Fla.	1-80, 000	2. C. Junken	In progress.
No. 84, Saint Andrew's Bay, Fla	1-80, 000	1. H. Lindenkohl. 2. A. Lindenkohl	Do.
No. 88, Mobile Bay, Ala	1-80, 000	2. A. Lindenkohl	Additions.
No. 106, from Oyster Bay to Matagorda Bay, Tex	1-80, 000	2. C. Junken	In progress.
No. 107, Matagorda Bay, Tex	1-80, 000	2. C. Junken	Do.
Harbor charts and topographical sheets:			
Belfast Bay and Penobscot River, Me	1-40, 000	1, 6. P. Erichsen	Completed.
Isle au Haut Bay and Eggemoggin Reach, Me	1-40, 000	2. C. Junken; A. Lindenkohl	In progress.
Approaches to Blue Hill Bay and Eggemoggin Reach, Me.	1-40, 000	2. E. J. Sommer	Do.
Blue Hill and Union River Bays, Me	1-40, 000	6. P. Erichsen	Do.
Camden and Rockport Harbors, Me	1-40, 000	2. L. Karcher	Additions.
Bath to Booth Bay, Me	1-40, 000	7. L. Karcher	Do.
Entrance to Connecticut River	1-20, 000	2. L. Karcher	Do.
New York Bay and Harbor	1-40, 000	1. A. Lindenkohl; H. Lindenkohl; P. Erichson.	Do.
Hudson River (in three sheets)	1-60, 000 1-40, 000	7. C. Junken	Do
Raritan River, N. J. (in two sheets)	1-15, 000	1. H. Lindenkohl	Photolithograph; additions.

APPENDIX No. 4—Continued.

Titles of charts.	Scale.	Draughtsmen.	Remarks.
Harbor charts and topographical sheets—Continued.			
Cape May City and vicinity, N. J	1-10,000	3. T. J. O'Sullivan	Photolithograph; completed.
Norfolk Harbor, Elizabeth River and branches (new edition).	1-20 000	1, 2. T. J. O'Sullivan	Photolithograph; additions.
James River, from Sloop Point to City Point	1-40,000	1. H. Lindenkohl	Completed.
Potomac River No. 4, Indian Head to Georgetown	1-40,000	1. A. Lindenkohl	Additions.
North Landing, Va. and N. C. (new edition)	1-40,000	2. H. Lindenkohl; L. Karcher	Completed.
Georgetown Harbor, S. C	1-6,000	3. E. J. Sommer	Photolithograph; completed.
Bull's Bay, S. C. (new edition)	1-40,000	1, 2. A. Lindenkohl	Completed.
Savannah River, Ga. (resurvey)	1-40,000	2. C. Junken	Additions.
Florida Passage:			
Banana Creek and Banana River to Home Point	1-25,000	3. H. Lindenkohl	Photolithograph; completed.
Banana River, Home Point to Black Point	1-25,000	3. H. Lindenkohl	Do.
Indian River, Andrew's to Fisherman's Point	1-25,000	3. H. Lindenkohl	Do.
Indian River, Fisherman's Point to Elbow Creek	1-25,000	3. H. Lindenkohl	Do.
Tampa Bay, Fla	1-40,000	7. A. Lindenkohl	Additions.
Saint Mark's River, Fla. (new edition)	1-20,000	1, 2. A. Lindenkohl	Completed.
Mississippi River, from Grandview Reach to near Donaldsonville.	1-10,000	1, 2. T. J. O'Sullivan. 1. L. Karcher	Special map; enlarged from 1-20,000 scale; in progress.
San Diego Bay, Cal	1-40,000	2. C. Junken	Additions.
San Diego Bay, Cal. (resurvey)	1-20,000	1, 2. E. J. Sommer. 2. C. Junken	Photolithograph; completed.
San Francisco Bay, No. 1	1-40,000	1. P. Erichsen	In progress.
San Pablo Bay, Cal	1-50,000	2. C. Junken	Additions.
Alseya Harbor and Bar, Oreg	1-6,000	1, 2. E. J. Sommer	Photolithograph; in progress.
Columbia River, No. 4, Oreg	1-40,000	2. L. Karcher	Completed.
Port Madison, W. T	1-20,000	7. H. Lindenkohl	Additions.
Symonds Bay, Alaska Ter	1-7,200	1, 2. E. J. Sommer. 8. T. J. O'Sullivan	Photolithograph; completed.
Alaska harbor charts:			
No. 1, Cape Madge to Nahrvitti Bay	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Completed.
No. 2, Queen Charlotte and Fitzhugh Sound	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 3, Point Walker to Swanson Bay	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 4, Wake Island to Chatham Sound	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 5, Dixon entrance and vicinity	1-510,720	1, 2. A. Lindenbohl; H. Lindenkohl; L. Karcher.	Do.
No. 6, Portland Canal and Observatory Inlet	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 7, Behm Canal to Clarence Strait	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 8, Wolf Rock to Cape Decision	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 9, Summer Strait and vicinity	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 10, Frederick Sound, Stephen's Passage, &c	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 11, Sand Bay to Cape Edward	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 12, Northern border of the Alexander Archipelago.	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 13, Lynn Canal and Chilkaht River	1-510,720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
No. 14, Lituya Bay to Yakutat Bay	1-510 720	1, 2. A. Lindenkohl; H. Lindenkohl; L. Karcher.	Do.
Head of Union River Bay, Me	1-10,000	4. P. Erichsen	

APPENDIX No. 4—Continued.

Titles of charts.	Scale.	Draughtsmen.	Remarks.
Blue Hill Bay, Me., east side Long Island	1-10,000	4. R. E. Peary	
Blue Hill Bay, Me., west side Long Island	1-10,000	4. A. B. Graham	
Blue Hill Bay, Me., Bartlett's Island	1-10,000	4. E. H. Fowler	
Porcupine group of Islands, Me	1-10,000	4. T. J. O'Sullivan	
Babylon and vicinity, Long Island, N. Y	1-10,000	4. E. H. Fowler	
Hempstead and vicinity, Long Island, N. Y.	1-10,000	4. E. J. Sommer	
Hempstead Bay, Long Island, N. Y	1-10,000	4. E. H. Fowler	
Croton to Peekskill, Hudson River, N. Y	1-10,000	4. H. Lindenkohl	
Philadelphia city front, Delaware River (resurvey)	1-4,800	4. H. Lindenkohl; E. J. Sommer	
Washington's Birth Place, Va	1-10,000	4. A. Lindenkohl; H. Lindenkohl	
Cape Hatteras, N. C	1-20,000	4. A. E. Burton	
Cape Fear River, N. C	1-10,000	4. P. Erichsen	
Barataria Bay, La	1-10,000	4. E. J. Sommer	
Mississippi River above city of New Orleans	1-20,000	4. E. J. Sommer	
Mississippi River, Point Houmas and vicinity	1-20,000	4. T. J. O'Sullivan	
Mississippi River, reconnaissance of Grand Gulf	1-10,000	4. T. J. O'Sullivan	
North of Point Arguello, Cal	1-10,000	4. E. J. Sommer	
Point Sal and vicinity, Cal	1-10,000	4. E. J. Sommer	
Columbia River above Kalama	1-10,000	4. A. E. Burton	
Puget Sound, W. T. (parts of)	1-20,000	4. T. J. O'Sullivan; R. E. Peary	
Patapsco River, Md., hydrographic resurvey between Forts McHenry and Carroll.	1-10,000	2. C. Junken (plotting, &c.)	
MISCELLANEOUS.			
Base map of the United States	1-7,000,000	A. Lindenkohl (compiling); H. Lindenkohl (engraving on stone).	
Annual progress sketch work		A. Lindenkohl; L. Karcher	
Drawings illustrating meteorological researches		T. J. O'Sullivan	
Pendulum diagrams (on stone)		H. Lindenkohl	
Diagrams for article on projections		T. J. O'Sullivan	
Diagrams of oyster explorations		H. Lindenkohl	
Diagrams for 1876 report (on stone)		H. Lindenkohl	
Plan of optical salinometer		P. Erichsen	
Plan of improved plane table		P. Erichsen	
Plan of Borda thermometer for subsidiary base rods		P. Erichsen	
Plan of Erichsen planimeter		P. Erichsen	
Plan of line and end comparing apparatus		P. Erichsen	
Plan of base apparatus		P. Erichsen	
Plan of screw pile		P. Erichsen	
Plan of tidal machine		A. E. Burton	
Wreck charts of the Pacific Coast		E. J. Sommer	

APPENDIX No. 5.

ENGRAVING DIVISION.

Plates completed, continued, and commenced during the fiscal year ending with June, 1880.

1. Outlines. 2. Topography. 3. Sand. 4. Lettering.

Catalogue No.	Title of plates.	Scale.	Engravers.
	COMPLETED.		
B	Sailing chart B, Cape Hatteras to Key West (upper)	1-1,200,000	1. A. Petersen. 2 and 3. W. A. Thompson. 4. A. Petersen and J. G. Thompson.
B	Sailing chart B, Cape Hatteras to Key West (lower)	1-1,200,000	1 and 2. H. M. Knight, A. Petersen. 3. J. G. Thompson, H. M. Knight. 4. J. G. Thompson.
C	Sailing chart Gulf of Mexico, west part, 2 plates	1-1,200,000	1. W. A. Thompson. 2. J. G. Thompson. 3. W. A. Thompson. 4. J. G. Thompson and A. Petersen.
13	General coast chart No. 8, Saint Mary's River to Cape Canaveral.	1-400,000	1 and 2. R. F. Bartle. 3. W. A. Thompson. 4. E. A. Maedel and J. G. Thompson.
104	Coast chart No. 4, Penobscot Bay	1-80,000	3. H. M. Knight. 4. E. A. Maedel and A. Petersen.
123	Coast chart No. 23, Absecon Inlet to Cape May	1-80,000	3. W. A. Thompson. 4. E. A. Maedel and J. G. Thompson.
139	Coast chart No. 39, Oregon Inlet to Cape Hatteras	1-80,000	2 and 3. W. A. Thompson. 3. F. W. Benner. 1, 2, and 4. H. M. Knight.
158	Coast chart No. 58, from Saint Mary's entrance southward to 30° north.	1-80,000	1 and 2. A. Sengteller. 3. W. A. Thompson. 4. F. Courtenay and E. A. Maedel.
159	Coast chart No. 59, Saint Augustine Inlet to Halifax River.	1-80,000	1 and 2. A. Sengteller. 3. F. W. Benner. 4. F. Courtenay, E. A. Maedel, and J. G. Thompson.
177	Coast chart No. 77, Tampa Bay	1-80,000	1, 2, and 3. R. F. Bartle. 4. J. G. Thompson.
183	Coast chart No. 83, Apalachicola Bay to Cape San Blas.	1-80,000	1 and 2. A. Sengteller. 3. F. W. Benner. 4. E. A. Maedel, J. G. Thompson.
191	Coast chart No. 91, Lakes Borgne and Pontchartrain	1-80,000	1 and 2. W. A. Thompson. 4. J. G. Thompson.
207	Coast chart No. 107, Matagorda Bay	1-80,000	3. W. A. Thompson, H. M. Knight. 4. A. Petersen and William Smith.
311	Harbor chart, Penobscot River and Belfast Bay	1-40,000	1, 2, and 3. R. F. Bartle. 4. J. G. Thompson.
347	Harbor chart, Vineyard Haven	1-15,000	1 and 4. James Loughran. 3. F. W. Benner.
360	Harbor chart, mouth of Connecticut River (edition of 1880).	1-20,000	3. F. W. Benner. 4. James Loughran.
555	Harbor chart, Lake Champlain, No. 3, Burlington to Cole's Bay.	1-40,000	1, 2, 3, and 4. H. M. Knight. 4. E. A. Maedel.
556	Harbor chart, Lake Champlain, No. 4, Cole's Bay to Whitehall.	1-40,000	1, 2, 3, and 4. W. A. Thompson. 4. E. A. Maedel.
406	Harbor chart, North Landing River	1-40,000	4. J. G. Thompson and William Smith.
421	Harbor chart, Core Sound and Straits	1-40,000	3 and 4. E. H. Sipe.
471	Harbor chart, Tortugas Harbor and approaches	1-40,000	1, 2, and 4. William Smith.
	CONTINUED.		
142	Coast chart No. 42, Pamplico Sound, eastern sheet, Roanoke Island to Hatteras Inlet.	1-80,000	1, 2, and 4. H. M. Knight. 3. W. A. Thompson. 4 J. G. Thompson.
143	Coast chart No. 43, Pamplico Sound, middle sheet, Ocracoke Inlet to mouth of Pamplico River.	1-80,000	3. W. A. Thompson. 4. J. G. Thompson.
153	Coast chart No. 53, Winyah Bay to Long Island	1-80,000	1 and 2. A. Sengteller.
171	Coast chart No. 71, Marquesas Keys to Tortugas	1-80,000	4. E. A. Maedel.
181	Coast chart No. 81, Apalachee Bay, Fla	1-80,000	1 and 2. H. C. Evans. 4. W. H. Davis.
182	Coast chart No. 82, Saint Mark's River to head of Apalachicola Bay.	1-80,000	4. F. Courtenay.
307	Harbor chart, Blue Hill and Union River Bays	1-40,000	1 and 2. W. A. Thompson.
308	Harbor chart, approaches to Blue Hill Bay and Eggemoggin Reach.	1-40,000	1. J. G. Thompson.
309	Harbor chart, Isle au Haut Bay and Eggemoggin Reach.	1-40,000	1 and 2. W. A. Thompson. 4. E. A. Maedel and A. Petersen.
401*a*	Harbor chart, James River, No. 1, Newport News to Deep Water Light.	1-50,000	1 and 2. J. Enthoffer. 4. F. Courtenay.

APPENDIX No. 5—Continued.

Catalogue No.	Title of plates.	Scale.	Engravers.
	CONTINUED—Continued.		
401b	Harbor chart, James River, No. 2, Point of Shoals Light to Sloop Point.	1-50, 000	1 and 2. J. Enthoffer.
672	General coast chart, Point Vincent to Point Conception.	1-200, 000	1 and 2. H. Lindenkohl. 4. A. Petersen and E. A. Maedel.
621a	Harbor chart, San Francisco Bay entrance............	1-40, 000	1 and 2. J. Enthoffer. 4. J. G. Thompson.
	COMMENCED.		
160	Coast chart No. 60, Halifax River to Mosquito Lagoon..	1-80, 000	1 and 2. H. C. Evans. 4. F. Courtenay, E. A. Maedel, J. G. Thompson.
185	Coast chart No. 85, Saint Andrew's Bay to Choctawhatchee Bay.	1-80, 000	1 and 2. H. C. Evans.
192	Coast chart No. 92, Chandeleur and Isle au Breton Sounds.	1-80, 000	1 and 2. R. F. Bartle. 4. J. G. Thompson.
401c	Harbor chart, James River, No. 3, Sloop Point to City Point.	1-50, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel.
671	General coast chart, San Diego to Point Vincent........	1-200, 000	1 and 2. H. Lindenkohl. 4. A. Petersen and J. G. Thompson.
641b	Harbor chart, Columbia River, No. 4	1-40, 000	1, 3, and 4. H. M. Knight.
	LIST OF COAST PILOT CHARTS AND VIEWS ENGRAVED DURING THE YEAR.		
1559	Atlantic Coast Pilot chart, volume 2, Nantucket and Vineyard Sounds, Cross Rip to Nobska Point.	1-80, 000	
1557	Alaska Coast Pilot, Seymour Narrows..................	....	
1509	Atlantic Coast Pilot view, Kent Point, north entrance to Eastern Bay, &c.	....	J. J. Young and W. H. Davis.
1518	Atlantic Coast Pilot view, city of Baltimore, Lazaretto Point, &c.	....	J. J. Young and W. H. Davis.
1520	Atlantic Coast Pilot view, Potomac River, Breton and Saint Clement's Bays.	....	J. R. Barker and W. H. Davis.
1521	Atlantic Coast Pilot view, Potomac River, Point Lookout, Smith's Point, &c.	....	J. R. Barker and W. H. Davis.
1522	Atlantic Coast Pilot view, entrance to Patuxent River from southward, &c.	....	J. J. Young and W. H. Davis.
1527	Atlantic Coast Pilot view, Port Royal entrance, Broad River, &c.	....	J. J. Young
1528	Atlantic Coast Pilot view, Priest's Point, Saint Inigoes Creek, Saint Mary's River, &c.	....	J. R. Barker and W. H. Davis.
1529	Atlantic Coast Pilot view, entrance to Severn River from the northward, &c.	....	J. R. Barker and W. H. Davis.
1538	Atlantic Coast Pilot view, Potomac River looking up, Maryland Point, &c.	....	J. R. Barker and W. H. Davis.
1539	Atlantic Coast Pilot view, Potomac River, off Quantico, &c.	....	J. R. Barker and W. H. Davis.
1540	Atlantic Coast Pilot view, Potomac River, Nomini Cliffs, off Blackistone Island, &c.	....	J. R. Barker and W. H. Davis.
1562	Atlantic Coast Pilot view, Washington City from off Giesboro Point, &c.	....	J. R. Barker and W. H. Davis.
1593	Atlantic Coast Pilot view, approaches to New Bedford, &c.	....	J. R. Barker and W. H. Davis.
1594	Atlantic Coast Pilot view, west entrance to Vineyard Sound, &c.	....	J. R. Barker and W. H. Davis.
1595	Atlantic Coast Pilot view, approaches to Fisher's Island Sound from eastward.	....	J. R. Barker.
1596	Atlantic Coast Pilot view, Plum Gut from eastward	....	J. R. Barker.
1604	Atlantic Coast Pilot view, approaches to Narragansett Bay from eastward and westward, &c.	....	J. R. Barker.

APPENDIX No. 5—Continued.

GENERAL CORRECTIONS AND ADDITIONS.

List of plates having received additions and corrections from July 1, 1879, to June 30, 1880.

Catalogue No.	Plate No.	Title of plates.	Scale.	Dates of corrections and additions.
3	977	Sailing chart No. 3, Cape Hatteras to Mosquito Inlet	1-1, 200, 000	October 22, 1879.
4	989	Sailing chart No. 4, Mosquito Inlet to Key West	1-1, 200, 000	June 1, 1880.
5	1453	Sailing chart No. 5, Key West to the Rio Grande, east part	1-1, 200, 000	April 3, 1880.
5	1451	Sailing chart No. 5, Key West to the Rio Grande, west part	1-1, 200, 000	April 27, 1880.
7	1242	General coast chart No. 2, Cape Ann to Gay Head	1-400, 000	December 17, 1879.
8	1392	General coast chart No. 3, Gay Head to Cape Henlopen	1-400, 000	December 18, 1879.
9	1183	General coast chart No. 4, Cape May to Cape Henry	1-400, 000	June 9, 1880.
10	1147	General coast chart No. 5, Cape Henry to Cape Lookout	1-400, 000	December 12, 1879.
11	1429	General coast chart No. 6, Cape Hatteras to Cape Romain	1-400, 000	May 12, 1880.
12	1350	General coast chart No. 7, Cape Romain to Saint Mary's entrance	1-400, 000	In hand for correction.
15	1081	General coast chart No. 10, Straits of Florida	1-400, 000	March 20, 1880.
30	97	Harbor chart, Galveston Bay, 1851	....	February 11, 1880.
105	1249	Coast chart No. 5, Penobscot Bay to Kennebec entrance	1-80, 000	May 24, 1880.
106	1063	Coast chart No. 6, Kennebec entrance to Saco River	1-80, 000	January 21, 1880.
107	1271	Coast chart No. 7, Seguin Island to Kennebunkport	1-80, 000	November 6, 1879.
108	1201	Coast chart No. 8, Wells to Cape Ann	1-80, 000	May 26, 1880.
110	1199	Coast chart No. 10, Cape Cod Bay	1-80, 000	December 23, 1879.
111	1402	Coast chart No. 11, Nantucket Shoals to Muskeget Channel	1-80, 000	October 11, 1879.
112	1054	Coast chart No. 12, Muskeget Channel to Buzzard's Bay	1-80, 000	March 17, 1880.
113	1371	Coast chart No. 13, Cuttyhunk to Block Island	1-80, 000	March 15, 1880.
114	1363	Coast chart No. 14, Point Judith and Block Island to Plum Island	1-80, 000	May 5, 1880.
115	1419	Coast chart No. 15, Plum Island to Welch's Point	1-80, 000	May 26, 1880.
116	1473	Coast chart No. 16, Long Island Sound, Welch's Point to New York	1-80, 000	May 28, 1880.
117	979	Coast chart No. 17, southern coast of Long Island, Block Island, Montauk Point, &c	1-80, 000	May 22, 1880.
118	865	Coast chart No. 18, southern coast of Long Island, Napeague Beach to Forge River	1-80, 000	May 1, 1880.
119	866	Coast chart No. 19, Great South Bay, Fire Island and Long Beaches	1-80, 000	September 12, 1879.
120	1404	Coast chart No. 20, New York Bay and Harbor	1-80, 000	May 3, 1880.
121	1535	Coast chart No. 21, Sandy Hook to Barnegat Inlet	1-80, 000	April 28, 1880.
122	1536	Coast chart No. 22, Barnegat Inlet to Absecon Inlet	1-80, 000	April 24, 1880.
124	1185	Coast chart No. 24, Delaware Bay and River, Delaware entrance	1-80, 000	April 16, 1880.
126	1239	Coast chart No. 26, Delaware Bay and River, Port Penn to Trenton	1-80, 000	April 26, 1880.
127	1200	Coast chart No. 27, Cape May to Isle of Wight	1-80, 000	December 3, 1879.
128	1230	Coast chart No. 28, Isle of Wight to Chincoteague	1-80, 000	May 27, 1880.
129	1286	Coast chart No. 29, Chincoteague Inlet to Hog Island Light	1-80, 000	February 17, 1880.
130	1287	Coast chart No. 30, Hog Island Light to Cape May	1-80, 000	December 9, 1879.
131	1219	Coast chart No. 31, Chesapeake Bay, sheet 1, entrance to Chesapeake, &c	1-80, 000	April 21, 1880.
132	1211	Coast chart No. 32, York River to Pocomoke Sound	1-80, 000	November 9, 1879.
133	1222	Coast chart No. 33, Chesapeake Bay, sheet 3, Pocomoke Sound to Potomac River	1-80, 000	June 1, 1880.
134	1227	Coast chart No. 34, Chesapeake Bay, Potomac River to Choptank River	1-80, 000	November 28, 1879.
135	1232	Coast chart No. 35, Chesapeake Bay, Choptank River to Magothy River	1-80, 000	October 17, 1879.
136	1235	Coast chart No. 36, Chesapeake Bay, Magothy River to head of bay	1-80, 000	October 2, 1879.
137	1444	Coast chart No. 37, Cape Henry to Currituck Light	1-80, 000	November 4, 1879.
138	1435	Coast chart No. 38, Currituck Light to Oregon Inlet	1-80, 000	November 12, 1879.
139	1449	Coast chart No. 39, Oregon Inlet to Cape Hatteras	1-80, 000	May 8, 1880.
140	890	Coast chart No. 40, Atlantic Ocean to Pasquotank River	1-80, 000	October 30, 1879.
141	1377	Coast chart No. 41, Albemarle Sound, western sheet, Pasquotank to Roanoke and Chowan Rivers.	1-80, 000	April 22, 1880.
142	1272	Coast chart No. 42, Pamplico Sound, Roanoke Island to Hatteras Inlet, east part	1-80, 000	February 4, 1880.
144	1263	Coast chart No. 44, Pamplico Sound, sheet 2, Neuse River	1-80, 000	October 30, 1879.
154	1176	Coast chart No. 54, Long Island to Hunting Island	1-80, 000	October 15, 1879.
155	1353	Coast chart No. 55, Hunting Island to Ossabaw Island	1-80, 000	February 11, 1880.
156	1341	Coast chart No. 56, Savannah to Sapelo Sound	1-80, 000	April 12, 1880.
157	1346	Coast chart No. 57, Sapelo Island to Amelia Island	1-80, 000	April 12, 1880.
166	884	Coast chart No. 66, Key Biscayne to Carysfort Reef	1-80, 000	October 17, 1879.
168	1100	Coast chart No. 68, Long Key to Newfound Harbor Key	1-80, 000	October 16, 1879.
169	1125	Coast chart No. 69, Newfound Harbor Key to Boca Grande Key	1-80, 000	October 25, 1879.
170	1375	Coast chart No. 70, Key West, Marquesas Keys, &c	1-80, 000	May 10, 1880.
183	1347	Coast chart No. 83, Apalachicola Bay to Cape San Blas	1-80, 000	June 4, 1880.

APPENDIX No. 5—Continued.

Catalogue No.	Plate No.	Title of plates.	Scale.	Dates of corrections and additions.
189	842	Coast chart No. 89, Mississippi River, approaches to New Orleans, &c	1-80,000	November 10, 1879.
191	906	Coast chart No. 91, Lakes Borgne and Pontchartrain	1-80,000	December 9, 1879.
191	1483	Coast chart No. 91, Lakes Borgne and Pontchartrain	1-80,000	December 9, 1879.
194	1280	Coast chart No. 94, Mississippi River, passes to Grand Prairie	1-80,000	March 4, 1880.
195	1314	Coast chart No. 95, Mississippi River, forts to New Orleans	1-80,000	September 24, 1879.
204	1316	Coast chart No. 104, Galveston Bay	1-80,000	August 19, 1879.
205	1216	Coast chart No. 105, Galveston Bay to Oyster Bay	1-80,000	March 24, 1880.
206	1210	Coast chart No. 106, Oyster Bay to Matagorda Bay	1-80,000	August 28, 1879.
302a	1008	Harbor chart, Eastport Harbor	1-40,000	February 7, 1880.
304a	1203	Harbor chart, Moose-a-bec Reach	1-40,000	December 16, 1879.
291	1191	Harbor chart, Mount Desert, Southwest Harbor, and Somes Sound	1-40,000	January 6, 1880.
310	1354	Harbor chart, Penobscot Bay	1-40,000	April 6, 1880.
311a	1128	Harbor chart, Fox Island Thoroughfare	1-20,000	February 2, 1880.
312	1150	Harbor chart, Saint George's River and Muscle Ridge Channel	1-40,000	August 20, 1879.
314	1112	Harbor chart, Kennebec and Sheepscot Rivers	1-40,000	March 16, 1880
315	1204	Harbor chart, Casco Bay	1-40,000	November 12, 1879.
315a	1065	Harbor chart, Inside Passage, Bath to Booth Bay	1-20,000	May 1, 1880.
321	1015	Harbor chart, Rockport and Camden Harbors	1-20,000	April 9, 1880.
327	1352	Harbor chart, Richmond Island Harbor	1-20,000	November 20, 1879.
328	527	Harbor chart, York River Harbor	1-20,000	November 25, 1879.
329	1379	Harbor chart, Portsmouth Harbor, N. H.	1-20,000	November 7, 1879.
330	1016	Harbor chart, Isles of Shoals	1-20,000	June 11, 1880.
332	782	Harbor chart, Ipswich and Annisquam Harbors	1-20,000	April 7, 1880.
335	1328	Harbor chart, Salem Harbor	1-25,000	December 18, 1879.
337	1184	Harbor chart, Boston Harbor	1-40,000	February 11, 1880.
338	1326	Harbor chart, Plymouth, Kingston, and Duxbury Harbors	1-40,000	October 20, 1879.
341	1025	Harbor chart, Provincetown Harbor	1-50,000	April 26, 1880.
353	1240	Harbor chart, Narragansett Bay, Lower	1-40,000	August 7, 1879.
362	1311	Harbor chart, New Haven Harbor	1-20,000	September 17, 1879.
364	173	Harbor chart, Sheffield's Island and Cawkins' Island Harbors	1-20,000	August 9, 1879.
366	832	Harbor chart, Hempstead Harbor	1-20,000	July 16, 1879
369	1266	Harbor chart, New York Bay and Harbor, Lower	1-40,000	April 22, 1880.
369a	1304	Harbor chart, New York entrance	1-40,000	April 19, 1880.
370	1034	Harbor chart, Hudson River, No. 1, New York to Haverstraw	1-60,000	September 27, 1879.
371	888	Harbor chart, Hudson River, No. 2, Haverstraw to Poughkeepsie	1-60,000	September 30, 1879.
372	990	Harbor chart, Hudson River, No. 3, Poughkeepsie to Troy	1-60,000	September 29, 1879.
376	453	Harbor chart, Delaware and Chesapeake Bays	1-400,000	June 1, 1880.
385	1452	Harbor chart, Annapolis Harbor	1-60,000	November 25, 1879.
386	784	Harbor chart, Patuxent River, Lower	1-60,000	January 13, 1880.
388	1135	Harbor chart, Potomac River, No. 1, entrance up to Piney Point	1-60,000	April 12, 1880.
389	1171	Harbor chart, Potomac River, No. 2, Piney Point to Lower Cedar Point	1-60,000	April 12, 1880.
390	1148	Harbor chart, Potomac River, No. 3, Lower Cedar Point to Indian Head	1-60,000	August 23, 1879.
391	1319	Harbor chart, Potomac River, No. 4, Indian Head to Georgetown	1-40,000	August 23, 1879.
399	775	Harbor chart, York River, Va., No. 2, King's Creek to West Point	1-60,000	December 12, 1879.
408	1415	Harbor chart, Albemarle Sound	1-200,000	June 5, 1880.
409	983	Harbor chart, mouth of Roanoke River	1-30,000	August 5, 1879.
416	1223	Harbor chart, Hatteras Shoals	1-80,000	May 31, 1880.
419	1023	Harbor chart, Cape Lookout Shoals	1-80,000	May 31, 1880.
424	1161	Harbor chart, Cape Fear River entrance	1-30,000	February 10, 1880.
430	811	Harbor chart, Bull's Bay	1-60,000	December 11, 1879.
431	1192	Harbor chart, Charleston Harbor	1-30,000	May 31, 1880.
434	868	Harbor chart, North Edisto River	1-50,000	August 4, 1879.
435	1173	Harbor chart, Bull and Combahee Rivers	1-40,000	May 3, 1880.
439	940	Harbor chart, Calibogue Sound and Skull Creek	1-40,000	January 26, 1880.
440	1070	Harbor chart, Savannah River and Warsaw Sound	1-40,000	February 24, 1880.
441	948	Harbor chart, Ossabaw Sound	1-30,000	July 12, 1879.
444	946	Harbor chart, Sapelo Sound	1-30,000	July 16, 1879.
447	1155	Harbor chart, Saint Simon's Sound, Brunswick Harbor, and Turtle River	1-40,000	February 14, 1880.
453	1288	Harbor chart, Saint Mary's River and Fernandina Harbor	1-20,000	April 10, 1880.
454	663	Harbor chart, Saint John's River, No. 1, from entrance to Brown's Creek	1-25,000	January 28, 1880.
455	991	Harbor chart, Saint John's River, No. 2, from Brown's Creek to Jacksonville	1-25,000	November 18, 1879.
469	1170	Harbor chart, Key West Harbor	1-50,000	November 18, 1879.

APPENDIX No. 5—Continued.

Catalogue No.	Plate No.	Title of plates.	Scale.	Dates of corrections and additions.
474	1121	Harbor chart, Charlotte Harbor	1-40,000	March 4, 1880.
477	1400	Harbor chart, entrance to Tampa Bay, Fla	1-40,000	December 11, 1879.
497	378	Harbor chart, Horn Island Pass	1-40,000	January 30, 1880.
520	1149	Harbor chart, Galveston entrance	1-40,000	March 23, 1880.
601	1036	Sailing chart, San Diego to San Francisco	1-1,200,000	May 1, 1880.
602	435	Sailing chart, San Francisco to Umpquah River	1-1,200,000	June 4, 1880.
603	650	Sailing chart, Umpquah River to northwest boundary	1-1,200,000	April 26, 1880.
700	1083	Sailing chart, Cape Flattery to Dixon entrance	1-1,200,000	In hand June 30, 1880.
701	1132	Sailing chart, Dixon entrance to Cape Saint Elias	1-1,200,000	January 8, 1880.
675	1064	General coast chart, Point Pinos to Bodega Head	1-200,000	March 6, 1880.
606	920	Harbor chart, San Diego Bay	1-40,000	May 3, 1880.
618	670	Harbor chart, Monterey Bay	1-60,000	May 25, 1880.
620	1142	Harbor chart, Half-Moon Bay	1-20,000	November 18, 1879.
623	1006	Harbor chart, San Pablo Bay	1-50,000	October 1, 1879.
637	1107	Harbor chart, Koos Bay	1-20,000	October 14, 1879.
640	1245	Harbor chart, Columbia River, No. 1	1-40,000	February 27, 1880.
641	1454	Harbor chart, Columbia River, No. 2	1-40,000	February 28, 1880.
643	931	Harbor chart, Gray's Harbor	1-40,000	February 25, 1880.
647	742	Harbor chart, Port Townsend	1-40,000	April 24, 1880.
663	1118	Harbor chart, Port Madison	1-20,000	August 22, 1879.
662	1144	Harbor chart, Puget Sound	1-200,000	May 20, 1880.
654	1104	Harbor chart, Washington Sound and approaches	1-200,000	May 18, 1880.
......	1505	Atlantic Coast Pilot chart, entrance to East Penobscot Bay	1-80,000	August 15, 1879.
......	1492	Atlantic Coast Pilot chart, Castine Harbor	1-80,000	August 11, 1879.
......	1506	Atlantic Coast Pilot chart, Penobscot Bay, northern part	1-80,000	August 15, 1879.
......	1504	Atlantic Coast Pilot chart, entrance to West Penobscot Bay	1-80,000	August 13, 1879.
......	1374	Atlantic Coast Pilot chart, Boston Bay and Harbor	1-80,000	January 26, 1880.
......	1378	Atlantic Coast Pilot chart, Provincetown Harbor	1-80,000	March 12, 1880.
......	1380	Atlantic Coast Pilot chart, Vineyard Sound, Wood's Hole to Cuttyhunk	1-80,000	March 11, 1880.
......	1442	Atlantic Coast Pilot chart, entrance to Nantucket Sound	1-80,000	March 12, 1880.
......	1382	Atlantic Coast Pilot chart, Buzzards Bay	1-80,000	March 12, 1880.
......	1384	Atlantic Coast Pilot chart, Cuttyhunk to Point Judith	1-80,000	March 16, 1880.
......	1558	Atlantic Coast Pilot chart, Block Island Sound, Point Judith to Narragansett Beach	1-80,000	April 24, 1880.
......	1439	Atlantic Coast Pilot chart, Long Island Sound, Plum Island to Falkner's Island	1-80,000	May 22, 1880.
......	1438	Atlantic Coast Pilot chart, Long Island Sound, Falkner's Island to Stratford Point	1-80,000	April 1, 1880.
......	1437	Atlantic Coast Pilot chart, Long Island Sound, Stratford Point to Norwalk River	1-80,000	March 11, 1880.
......	1406	Atlantic Coast Pilot chart, Long Island Sound, Norwalk River to Throg's Neck	1-80,000	March 10, 1880.
......	1386	Atlantic Coast Pilot chart, eastern entrance to Long Island Sound	1-80,000	May 13, 1880.
......	1431	Atlantic Coast Pilot chart, Fire Island Inlet	1-80,000	March 7, 1880.
......	1433	Atlantic Coast Pilot chart, southern coast of Long Island, Montauk Point to East Hampton	1-80,000	April 1, 1880.
......	1560	Atlantic Coast Pilot chart, entrance to New York Bay	1-80,000	May 22, 1880.
......	1446	Atlantic Coast Pilot chart, Gulf of Maine, current chart	1-80,000	January 19, 1880.
......	1457	Atlantic Coast Pilot views, entrance to Choptank River, &c	....	January 21, 1880.
......	1470	Atlantic Coast Pilot views, entrance to Elk River, &c	....	January 21, 1880.
......	1487	Atlantic Coast Pilot views, Capes May and Henlopen	....	January 6, 1880.
......	1488	Atlantic Coast Pilot views, Delaware River, Cohansey light-house, &c	....	January 30, 1880.
......	1494	Atlantic Coast Pilot views, Delaware River, looking up from below Reedy Island, &c	....	November 12, 1879.
......	1502	Atlantic Coast Pilot views, Weskeag River from near Garden Island Ledge, Muscle Ridge Channel.	....	July 19, 1879.
......	1508	Atlantic Coast Pilot views, entrance to Casco Bay from eastward &c	....	July 25, 1879.

APPENDIX No. 6.

REPORT ON THE RESULTS OF THE LONGITUDES OF THE COAST AND GEODETIC SURVEY DETERMINED UP TO THE PRESENT TIME BY MEANS OF THE ELECTRIC TELEGRAPH, TOGETHER WITH THEIR PRELIMINARY ADJUSTMENT BY THE METHOD OF LEAST SQUARES.

BY CHARLES A. SCHOTT, Assistant.

COMPUTING DIVISION, *June* 30, 1880.

DEAR SIR: In compliance with your directions of September, 1878, placing the computations of telegraphic longitudes in charge of the Computing Division of the office, I have the honor to present a report on the present state of the computations and the accuracy of the work, together with a tabular statement of the results.

As a first step, it became necessary to collect and scrutinize the existing computations and tabulate the results, making, where necessary or desirable, new combinations, and supplying as far as possible any needful information for greater completeness of statement which the case seemed to demand. Next, complete abstracts of the individual results of each determination were made. These are necessarily diversified in their statements, depending mainly on the telegraphic method employed and the greater or less refinements introduced by the observers. These abstracts were, for the sake of convenience, divided into two groups: the first comprising the more important, the second the subordinate, stations. Of the former there are 80, and of the latter 47, determinations of differences of longitude, obtained by means of the electric telegraph. The following will serve as a specimen of abstract of the first class, though many are of a more elaborate character:

Difference of telegraphic longitude between Atlanta, City Hall square, Ga., and Washington (grounds U. S. Naval Observatory), D. C., from exchanges of automatic and arbitrary chronometer-breaks in January, February, and March, 1879.

Stations*	Atlanta.	Washington.
Observers.....	G. W. Dean and E. Smith.	E. Smith and G. W. Dean.
Instruments ..	Troughton & Simms transit, C. S., No. 6.	Simm's transit, C. S., No. 8.
	Magnifying power, new diagonal eye-piece, 90.	Magnifying power, 90.
	New glass diaphragm of 13 lines, 11 generally used.	New glass diaphragm of 13 lines, 11 generally used.
	Value of one division of level B = 0''.839.	Value of one division of level B = 1''.17.
	Pivot inequality, since 1869, clamp W, p = + ˢ.028 ± ˢ.001.	Pivot inequality, clamp W†, p = − ˢ.027 ± ˢ.002.
	Sid. break-circuit chronometer, Frodsham 3477.	Sid. break-circuit chronometer, Frodsham 3462.
	Hipp cylinder chronograph.	Bond spring governor chronograph C. S. No. 2.

*Time-determinations were had both before and after the exchange of signals: At Washington, pier of transit 146.7 feet west of center of dome; reduction to dome + 0ˢ.124; at Atlanta, station the same as in 1874. Reduction to cupola of City Hall − ˢ.077.

†Both pivots are perforated (since 1867), and clamp W above corresponds to lamp E in former times.

Personal equation: special observations were made in November and December 1878; again in March 1879. In 1878 from five nights we have D — S = — ˢ.088; in 1879 we have D — S = — ˢ.109; the longitude work through exchange of observers gives D — S = — ˢ.040

Time signals consisted of breaks of seconds by eastern chronometer for 4 minutes, followed by arbitrary breaks during one minute; next of breaks of seconds by western chronometer during 4, and of arbitrary breaks during 1 minute.

ATLANTA AND WASHINGTON.

Results for difference of longitude.

Date.	Observer at— Atlanta.	Observer at— Washington.	Automatic signals. From west or Atlanta signals.	Automatic signals. From east or Washington signals.	Automatic signals. W–E	Arbitrary signals. From west or Atlanta signals.	Arbitrary signals. From east or Washington signals.	Arbitrary signals. W–E	Weights.	Mean automatic and arbitrary. Mean of west and east or Δλ
1879.			*m. s.*	*m. s.*	*s.*	*m. s.*	*m. s.*	*s.*		*m. s.*
Jan. 25	D.	S.	29 21.08	29 20.95	0.13	29 21.05	29 20.97	0.08	4	29 21.01
29	D.	S.	21.09	20.96	.13	21.09	20.99	.10	2	21.04
Feb. 1	D.	S.	21.15	21.00	.15	21.15	21.03	.12	4	21.08
7	D.	S.	20.98	20.81	.17	20.95	20.81	.14	2	20.89
8	D.	S.	21.13	20.98	.15	21.11	21.02	.09	4	21.06
15	S.	D.	29 21.37	29 21.25	.12	29 21.34	29 21.26	.08	1	29 21.30
28	S.	D.	21.23	21.09	.14	21.21	21.11	.10	4	21.16
Mar. 1	S.	D.	21.17	21.01	.16	21.14	21.04	.10	4	21.09
5	S.	D.	21.14	21.00	.14	21.13	21.03	.10	4	21.07
7	S.	D.	21.10	20.97	.13	21.07	20.98	.09	4	21.04
8	S.	D.	21.12	21.00	.12	21.10	21.02	.08	4	21.06
Means..........			29 21.142	29 21.002	.140	29 21.122	29 21.024	.098	......	....

Applying the correction for personal equation + ^{s}.04 and — ^{s}.04, respectively, we have

	m. s.	*m. s.*
Weighted mean, first position of observers......	29 21.066	29 21.060 ± 0^s.013
Weighted mean, second position of observers....	29 21.051	
Reduced to center of dome of Naval Observatory.	$\Delta\lambda$ =	29 21.184 ± 0^s.013

These abstracts may be made the basis for a future publication of our results, but they are too bulky to be appended to this report; therefore the results only of the determinations are herewith given. They are arranged in chronological order. It has been thought best, for a complete understanding and as a matter of interest from a historical point of view, to preface the table of resulting longitudes with a brief review of certain facts bearing on the gradual development in our survey of the use of the telegraph for purposes of longitudes, and to indicate under whose charge the work has been carried on since its first conception and the demonstration of its practical feasibility.

In the autumn of 1845, Superintendent Alexander D. Bache issued instructions to Assistant Sears C. Walker for the purpose of determining geographical longitudes by means of the electric telegraph. The first published notice by the Superintendent for the use of the electric telegraph for geodetic purposes is found in Coast Survey Report of 1846, p. 32; also in Appendix No. 11, p. 72. The first difference of longitude actually determined, and comparing in accuracy with astronomical methods then in use, was on October 10, 1846, between Washington and Philadelphia. The co-operation of the Superintendent of the United States Naval Observatory having been secured, the Coast Survey built a telegraphic line connecting the telegraph office in this city with the Naval Observatory; also caused a connection to be made at Philadelphia with the (old) High School Observatory. For the history of the subject, see Astronomische Nachrichten, No. 632, letter by A. D. Bache, of February 7, 1848, pp. 119–126, and No. 666, letter by A. D. Bache, of December 26, 1848, pp. 273–278.

The field and office work connected with the determination of longitudes by the electric telegraph was placed by Superintendent A. D. Bache under the especial charge of Prof. S. C. Walker, Assistant in the Coast Survey from 1845 to 1852, when illness compelled him to retire from active work* (see Coast Survey Report of 1853, p. 166, also earlier reports). In December, 1852, Dr. Benjamin A. Gould, jr., assistant, was appointed to take charge of the telegraphic longitudes, and continued till 1867, when he resigned (see Coast Survey Report of 1853, p. 86, and of 1867, Appendix No. 6, pp. 57–133). From 1867 to 1874, inclusive, Assistant George W. Dean was principally in

*He died in February, 1853.

charge of this work, under the immediate instructions of the Superintendent. After the year 1874 no special appointment was made; the field work was done and the records were deposited in the Coast Survey archives, and computations made by special direction of the Superintendent. In September, 1878, the computations for telegraphic longitudes were directed to be made in the Computing Division as part of the regular duty of this branch of the office. Owing, however, in part to lack of sufficient means, only temporary and inadequate aid in computing force could be given, and therefore the work made but slow progress.

With regard to the publication of our telegraphic longitude results, comparatively few have been presented in the annual reports of the Survey; the principal publications, however, will be found as follows:

Report of 1851, Appendix No. 26. Collection of Assistant Walker's results, in which are given the results of all his reports on longitude made to September 30, 1851,* but without specifying the particular differences of longitude observed by means of the telegraph.

Report of 1861, Appendix No. 18. Dr. Gould's report on longitude of Albany, N. Y.

Report of 1863, Appendix No. 18. First collection of Dr. Gould's results. He gives twelve differences of longitude, though without detail and without assigning probable errors.

Report of 1864, Appendix No. 12. Second collection of Dr. Gould's results. Four additional longitudes are given, completing the work done up to that period, with the exception of two determinations (which were left in manuscript). The results are not accompanied by their probable errors.

Report of 1867, Appendix No. 6. Dr. Gould on the longitude between America and Europe.

Report of 1870, Appendix No. 12. Longitude between Cambridge, Mass., and San Francisco, Cal.

Report of 1870, Appendix No. 13. Assistant Schott on the longitude between Cambridge, Mass., and Washington, D. C.

Report of 1874, Appendix No. 18. Assistant Hilgard on Transatlantic longitudes.

Report of 1875, Appendix No. 9. Assistant Schott on the longitude of Key West, Fla.

Of results published outside our reports, the following may be mentioned: Report on the difference of longitude between Washington, D. C., and Saint Louis, Mo., by Prof. W. Harkness, in Washington Observations, United States Naval Observatory, 1870 [work done with co-operation of the Survey]; Longitude determinations across the continent, by G. W. Dean, Proceedings of the American Association for the Advancement of Science, Indianapolis, meeting 1871; Transatlantic longitude, by Dr. Gould, Smithsonian Contributions to Knowledge, No. 223, 1869; Determination of Transatlantic longitudes by means of the telegraph cables, by Prof. J. Lovering, Memoirs of the American Academy, January, 1873. A complete exposition of our telegraphic method, as practiced at the time, is contained in Chauvenet's Manual of Spherical and Practical Astronomy, Vol. I, Philadelphia, 1863. In preparing the abstract of results, the above publications have been consulted.

Respecting the special methods employed in the telegraphic longitude work and the combination of results, I beg leave to submit the following remarks: In his report to the Superintendent, of November 10, 1847, Professor Walker points out that the *alternation* of observers at the stations would eliminate from the result the effect of their personal equation (provided the same remained constant during the operation). This important suggestion, however, was not put in practice until 1854. This apparent tardiness may be explained by the fact that in the earlier years of the application of the telegraph to longitudes the difficulties to be overcome in exchanging signals were very great, the length of time required for completing a difference of longitude was great and extremely uncertain, and the cost proportionally large; hence the direct determination of the personal equation between the observers was preferred to their exchange of stations. In the infancy of the telegraphic method the chief difficulty and consequent loss of time had its origin in the very imperfect insulation of the line-wires, combined with a lack of sensitiveness of the telegraphic receiving instruments.

We can also readily account for the circumstance that in the earlier operations for telegraphic longitudes there are so few independent checks. At that period, when the purely astronomical non-telegraphic longitudes, even of principal places, were very uncertain, it was obviously of more

* In this report the following typographical errors should be corrected: p. 480, bottom line, for $29^s.05$ read $29^s.50$, and p. 481, line 9 from top, for $11^s.206$ read $11^s.006$

immediate importance to determine as speedily as possible as many places as could be reached by means of the new and precise method, than to lose time by applying checks to positions already newly fixed. This cause, however, no longer exists, and checks are at present of prime importance, both on account of the security of the results and as a means of satisfactory valuation of the degree of accuracy reached.

In combining the several results for difference of longitude of any two places, computers have used various methods, according to circumstances; in my revision, when there were no special reasons to do otherwise, I have generally preferred the indiscriminate mean "by nights" to any other combination, for the following reasons: The value of a result depends fundamentally upon the accuracy of the transits or upon the local time, hence on a knowledge of the instrumental deviations; secondly, on the state of adjustment of the telegraphic instruments, as determined or influenced by the electric condition of the line; and, thirdly, on the personal equation or condition of the observers, all factors which are more or less constant during a night's work, but which vary from night to night. Modifications and weights were introduced to suit special circumstances. In many instances the resulting probable error rests necessarily (either from the want of sufficient data, or in unimportant cases even from want of any) on a very slender basis.

The theoretically perfect but practically heavy method, both as regards observing and computing, of exchange of individual star transits, which was used almost from the beginning, was supplemented in April, 1860, by the equally precise and short method of automatic exchanges of clock-beats (breaks): this elegant method† soon supplanted the older methods, and has only of late (in 1879) undergone a further simplification by lessening the number of threads or, rather, lines on the transit telescope, glass diaphragms of 11 lines being now considered as effective as the 25 (and more recently 15) threads of former years. This materially diminishes the labor of reading off the chronograph sheets and of the computation.

In presenting the table of results, indeed throughout this paper, the differences of longitude are given in the sense of *western* minus *eastern* station; hence the numbers expressing this difference require no special sign, they being all positive, and the mere naming of the stations carries this information with it, the one *first* named being always the *western* one. The exact point of reference, a very important matter, is carefully attended to, a special column having been introduced in the accompanying table of results. Generally the reference is to the transit instrument (tr.), but at fixed observatories, where, not unfrequently, different localities (sometimes in the building, sometimes in the grounds surrounding it) were used at different times, all positions and results were referred to the meridian passing through the center of the dome, the transit circle, or other special local meridian, as the case may be. A star prefixed to any tabular result indicates that a note referring to it is appended to the table. In general where in the first table no probable errors are given, the result depends on a first or field computation alone, and consequently is not final. The names of the observers are given; persons in special charge of the work or directors of observatories, if not actually taking part in the observations, have their names inclosed within [ ].

Table of results of differences of longitude determined by the Coast and Geodetic Survey by means of the electric telegraph.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	s.
*1	Washington, United States Naval Observatory, D. C.	Center of dome.	S. C. Walker, M. F. Maury, J. J. Almy.	1846	October	0 7 34.14	±0.5
	Philadelphia, Central (old) High School.	Mer. circle	E. O. Kendall				
2	Washington, United States Naval Observatory.	C. of d.	[Maury], R. Keith	1847	July, August	7 33.61	.10
	Philadelphia, Central (old) High School.	M. C.	Kendall, Reynolds, A. Mason				
3	Philadelphia, Central (old) High School.	M. C.	Kendall, Reynolds, Mason	1847	July, August	4 29.89	.09
	Jersey City, Loomis' Observatory, N. J.	Transit	E. Loomis				
4	Washington, United States Naval Observatory.	C. of d.	[Maury], Keith	1847	July, August	12 03.50	.23
	Jersey City, Loomis' Observatory	Tr	Loomis				

†Not applicable, however, to long submarine cables, the working of which at present requires arbitrary signals alternately positive and negative.

Table of results of differences of longitude, &c.—Continued.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	s.
5	New York, Rutherfurd's Observatory Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Walker, Loomis W. C. Bond, J. Bond	1848	July, August	11 26.044	± 0.042
6	Cincinnati, Mitchel's Observatory Philadelphia, Central (old) High School.	Tr M. C.	O. M. Mitchel, Twitchell, Tarnall. Kendall, Mason, Reynolds	1848	October	37 20.586	.060
7	Hudson, Western Reserve College, Ohio Philadelphia, Central (old) High School.	Tr M. C.	Loomis Kendall, Mason	1849	August	25 05.696	.045
*8	Washington, Seaton Station, D. C Philadelphia, Central (old) High School	Tr M. C.	L. F. Pourtales, J. C. Langton Kendall, Mason, Reynolds	1849	August	7 20.81	.20
*9	Charleston, Gibbes' Observatory, S. C Washington, Seaton Station, D. C.	Tr Tr	L. R. Gibbes Pourtales, Langton	1850	February	11 45.27	.10
*10	Savannah, station near Exchange, Ga Charleston, Gibbes' Observatory, S. C.	Tr Tr	C. O. Boutelle Gibbes, Langton	1851	February, March	4 37.15	.11
11	Cambridge, Harvard College Observatory, Mass. Bangor, Thomas Hill Observatory, Me.	C. of d. Tr	W. C. Bond Walker, Pourtales, Langton.	1851	November, December.	9 23.080	.043
12	Bangor, Thomas Hill Observatory, Me. Halifax, Naval Yard Observatory, N. S.	Tr Tr	Walker, Pourtales, Langton. Captain Shortland, R. N	1851	December	20 46.557	.067
13	Petersburg, Roslyn Station, Va Washington, Seaton Station, D. C	Tr Tr	A. D. Bache, G. W. Dean Pourtales	1852	July, August	1 35.591	.022
14	Raleigh, State House grounds, N. C. Washington, Seaton Station, D. C	Tr Tr	B. A. Gould, jr. Pourtales	1853	April	6 32.873	.044
15	Charleston, Gibbes' Observatory, S. C Raleigh, State House grounds, N. C.	Tr Tr	Gibbes Gould	1853	April, May	5 12.08	.153
	[Charleston, Gibbes' Observatory; referred to Orphan Asylum cupola]					5 12.25	
16	Columbia, Capitol Square, S. C Raleigh, State House grounds, N. C	Tr Tr	Gould, Dean Dean, Gould	1854	January, February, March.	9 35 862	.041
17	Wilmington, De Rosset Station, N. C. Petersburg, Roslyn Station, Va.	Tr Tr	Dean, Bache, Pourtales Gould, Pourtales, Dean	1854	May, June	2 11.340	.033
18	Macon, Academy Square, Ga Columbia, Capitol Square, S. C	Tr Tr	Dean, E. Goodfellow Goodfellow, Dean	1855	January, February, March.	10 22.250	.051
19	Columbia, Capitol Square, S. C Wilmington, De Rosset Station, N. C.	Tr Tr	Dean, Goodfellow Goodfellow, Dean	1856	January, February.	12 21.731	.028
20	Montgomery, State Capitol grounds, Ala. Macon, Academy Square, Ga	Tr Tr	Dean, Bache, Goodfellow Goodfellow, Dean	1856	March, April	10 41.570	.015
21	Lower Peach Tree, Ala Montgomery, State Capitol grounds, Ala.	Tr Tr	Goodfellow, Dean Dean, Goodfellow	1857	April	4 58.789	.016
22	Mobile, Public Square, Ala Lower Peach Tree, Ala	Tr Tr	Goodfellow, Dean Dean, Goodfellow	1857	May, June	1 59.768	.016
23	Bangor, Thomas Hill, Me Calais, Academy grounds, Me	Tr Tr	Bache, Goodfellow, Dean Dean, Goodfellow	1857	September, October.	6 00.316	.015
24	New Orleans, Basin, near Canal street, La. Mobile, Public Square, Ala	Tr Tr	Goodfellow, Dean Dean, A. T. Mosman, Goodfellow.	1858	January, February, March, April.	8 07.147	.022
	[New Orleans, Basin, near Canal street; referred to transit station of 1880, Lafayette Square]					8 06.281	
25	New York, Rutherfurd's Observatory Albany, Dudley Observatory	Tr D	Goodfellow, Dean Dean, Goodfellow	1858	May, June	57.400	.012
26	Eufaula, Forsyth, near Broad street, Ala. Apalachicola, station near shore, Fla	Tr Tr	Goodfellow, Dean Dean, Goodfellow	1860	February, March	36.671	.010
*27	Eufaula, Forsyth, near Broad street, Ala. Macon, Academy Square, Ga	Tr Tr	Dean, Goodfellow Goodfellow, Dean	1860	April, May	6 02.986	.031
28	Mobile, Public Square, Ala. Pensacola, Barkley Point, Fla	Tr Tr	Goodfellow, Dean Dean, Goodfellow	1861	January, February.	3 20.316	.022
29	Heart's Content, Trinity Bay, Newfoundland. Foilhommerum, Valentia Island, Ireland	Tr Tr	Dean, Goodfellow Gould, Mosman	1866	October, November.	2 51 56.356	.029
30	Foilhommerum, Valentia Island, Ireland. Greenwich, Royal Observatory, England.	Tr Tr. circle	Gould, Mosman [G. B. Airy, A. R.], Greenwich observers.	1866	November	41 33.336	.049

Table of results of differences of longitude, &c.—Continued.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	s.
31	Calais, Academy grounds, Me	Tr	G. Davidson, C. O. Boutelle, S. C. Chandler.	1866	December	55 37.973	±.066
	Heart's Content, Trinity Bay, Newfoundland.	Tr	[Dean], Goodfellow				
32	Washington, Seaton Station, D. C	Tr	Dean, Goodfellow	1867	June	23 28.474	.023
	Cambridge, Harvard College Observatory, Mass.	C. of d	J. Winlock, G. M. Searle				
33	Washington, United States Naval Observatory, D. C.	C. of d	[B. F. Sands], S. Newcomb, A. Hall, C. Thirion.	**1867	June	23 41.116	.031
	Cambridge, Harvard College Observatory, Mass.	C. of d	Winlock, Searle				
34	Washington, United States Naval Observatory, D. C.	C. of d	[Sands], Newcomb, Hall, Thirion.	1867	June	12.634	.015
	Washington, Seaton Station, D. C	Tr	Dean, Goodfellow				
35	Galveston, Public Square, Tex	Tr	Goodfellow	1868	February	18 51.85	.037
	New Orleans, Basin street, near Canal, La	Tr	Dean				
	[New Orleans, Basin street; referred to transit station of 1880, Lafayette Square]					18 52.717	
36	Omaha, Capitol Square, Nebr	Tr	Goodfellow	1869	February	1 39 15.065	.023
	Cambridge, Harvard College Observatory, Mass.	C. of d	Winlock, Mosman, F. Blake, jr.				
37	Salt Lake City, Temple Block, Utah	Tr	Dean	1869	February	1 03 49.111	.009
	Omaha, Capitol Square, Nebr	Tr	Goodfellow				
38	San Francisco, Washington Square, Cal.	Tr	G. Davidson	1869	February	1 45 52.307	.014
	Omaha, Capitol Square, Nebr	Tr	Goodfellow				
39	San Francisco, Washington Square, Cal.	Tr	Davidson	1869	February, March	42 03.196	.011
	Salt Lake City, Temple Block, Utah	Tr	Dean				
40	Salt Lake City, Temple Block, Utah	Tr	Dean	1869	February, March	2 43 04.177	.021
	Cambridge, Harvard College Observatory, Mass.	C. of d	Winlock, Mosman, Blake				
41	San Francisco, Washington Square, Cal.	Tr	Davidson	1869	February, March	3 25 07.372	.022
	Cambridge, Harvard College Observatory, Mass.	C. of d	Winlock, Mosman, Blake				
42	Cambridge, Harvard College Observatory, Mass.	C. of d	Winlock, E. P. Austin	1869-'70	December, January, February.	1 50.191	.022
	Duxbury, near cable house, Mass	Tr	Goodfellow				
43	Duxbury, near cable house, Mass	Tr	Goodfellow	1870	January, February.	4 24 43.276	.047
	Brest, Tower of St. Louis, France		Dean				
44	Saint Louis, Washington University, Mo.	Tr	W. Eimbeck	1870	April	52 36.901	.026
	Washington, United States Naval Observatory, D. C.	C. of d	[Sands], W. Harkness, E. Frisby.				
*45	San Francisco, Washington Square, Cal.	Tr	S. R. Throckmorton	1871	May	20 59.64	.032
	San Diego, Newtown, Cal	Tr	Davidson				
46	San Francisco, Washington Square, Cal	Tr	Davidson	1871	September, October.	18.42	.018
	Seattle, Duwamish Bay, Wash	Tr	Throckmorton				
47	Columbus, Capitol Square, Ohio	Tr	Dean	1871	September, October.	47 27.774	.034
	Cambridge, Harvard College Observatory, Mass.	C. of d	[Winlock], H. Gannett				
*48	Columbus, Capitol Square, Ohio	Tr	Dean	1871	October	5 13.06	.08
	Cleveland, Marine Hospital, Ohio	Tr	Goodfellow				
49	Cleveland, Marine Hospital, Ohio	Tr	Goodfellow	1871	October	42 14.882	.020
	Cambridge, Harvard College Observatory, Mass.	C. of d	[Winlock], Gannett				
50	San Francisco, Washington Square, Cal.	Tr	Davidson	1872	June	9 47.333	.025
	Verdi, East Base, Nev	Tr	Throckmorton				
51	St. Pierre Island, Gulf of St. Lawrence.	Tr	Goodfellow	1872	July	3 26 44.810	.027
	Brest, Tower of St. Louis, France	Δ	[J. E. Hilgard], Blake				
52	Washington, United States Naval Observatory, D. C.	C. of d	[Sands], Harkness, J. R. Eastman, Frisby.	1872	July, August	23 40.967	.019
	Cambridge, Harvard College Observatory, Mass.	C. of d	[Winlock], E. Smith				
	[Combination of the determinations of 1867 and 1872.]					23 41.041	.018

** See second determination in 1872.

Table of results of differences of longitude, &c.—Continued.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	*s.*
53	Washington, United States Naval Observatory, D. C. St. Pierre Island, Gulf of St. Lawrence	C. of d. Tr	[Sands], Harkness, Eastman, Frisby. Goodfellow	1872	July, August	1 23 29. 553	±. 027
54	Brest, Tower of St. Louis, France Greenwich, Royal Observatory, England.	Δ Tr. circle.	[Hilgard], Blake [Airy], G. S. Criswick, and others.	1872	July	17 57. 598	. 022
55	Brest, Tower of St. Louis, France Paris, Astronomical Observatory, France	Δ Mer. of France.	[Hilgard], Blake [Delauney, Loewy], L. F. Folain.	1872	July	27 18. 512	. 027
56	Cambridge, Harvard College Observatory, Mass. St. Pierre Island, Gulf of St. Lawrence	C. of d. Tr	Winlock, Smith Goodfellow	1872	July, August	59 48. 608	. 021
57	Greenwich, Royal Observatory, England. Paris, Astronomical Observatory, France	Tr. circle. M. of F.	[Airy, Hilgard], Blake [Loewy], Folain	1872	August, September.	9 21. 000	. 038
58	Carpenter's Point, Port Jervis, N. Y. Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Smith [Winlock], W. A. Rogers	1873	May, June	14 15. 67	. 10
59	Omaha, Capitol Square, Nebr Madison, University of Wisconsin, Wis.	Tr Tr	Goodfellow Blake	1873	July	26 09. 849	. 024
*60	Denver, near D. and R. G. Railroad depot, Colo. Omaha, Capitol Square, Nebr	Tr Tr	Smith Goodfellow	1873	July, August	36 12. 07	. 023
*61	Colorado Springs, Experimental Garden, Colo. Omaha, Capitol Square, Nebr	Tr Tr	Smith Goodfellow	1873	August	35 30. 35	. 028
62	Omaha, Capitol Square, Nebr Minneapolis, University of Minnesota, Minn.	Tr Tr	Goodfellow Blake	1873	August	10 49. 567	. 063
63	Kalama, Astronomical Station, Wash San Francisco, Washington Square, Cal.	Tr Tr	Eimbeck Davidson	1873	September	1 43. 88	. 026
64	Omaha, Capitol Square, Nebr La Crosse, Court House Square, Wis	Tr Tr	Goodfellow Blake	1873	September	18 46. 850	. 021
*65	Trinidad, near jail, Colo Omaha, Capitol Square, Nebr	Tr Tr	Smith Goodfellow	1873	September	34 14. 32	. 052
66	Key West, Clinton Place, Fla Washington, United States Naval Observatory, D. C.	Tr C. of d.	Smith [Sands], Harkness, Eastman, Frisby.	1873–'74	December, January.	19 01. 554	. 017
*67	Punta Rasa, Charlotte Harbor, Fla Savannah, near Exchange, Ga	Tr Tr	Smith Blake	1874	February	3 41. 45	
68	Savannah, near Exchange, Ga Washington, United States Naval Observatory, D. C.	Tr C. of d.	Blake [C. H. Davis], Harkness, Eastman.	1874	February, March	16 09. 30	07
*69	Cedar Keys, near railroad and express office, Fla. Savannah, near Exchange, Ga	Tr Tr	Smith Blake	1874	March	7 45. 97	
70	Atlanta, City Hall Square, Ga Savannah, near Exchange, Ga	Tr Tr	Smith Blake	1874	March	13 11. 96	. 046
*71	Nashville, Tenn Columbus, Ohio	Tr Tr	Dean Eimbeck	1877	July, August	15 09. 13	
*72	Columbus, Ohio Washington, United States Naval Observatory, D. C.	Tr C. of d.	Eimbeck [J. Rodgers], Eastman, Frisby, A. N. Skinner.	1877	August	23 46. 89	
*73	Nashville, Tenn Washington, United States Naval Observatory, D. C.	Tr C. of d.	Dean [Rodgers], Eastman, Frisby, Skinner.	1877	October	38 56. 17	
74	Statesville, N. C Washington, United States Naval Observatory, D. C.	Tr C. of d.	Smith, Dean Dean, Smith	1878–'79	December, January.	15 22. 599	. 014
75	Atlanta, City Hall Square, Ga Washington, United States Naval Observatory, D. C.	Tr C. of d.	Dean, Smith Smith, Dean	1879	January, February, March.	29 21. 184	. 013
*76	Nashville, State House Square, Tenn Louisville, University grounds, Ky	Tr Tr	Dean, Smith Smith, Dean	1879	November, December.	4 04. 49	. 015

Table of results of differences of longitude, &c.—Continued.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	s.
*77	Nashville, Tenn	Tr	Smith, Dean	1879-'80	December, January.	9 34.74	
	Atlanta, City Hall Square, Ga	Tr	Dean, Smith				
*78	New Orleans, Lafayette Square, La	Tr	Smith, Dean	1880	February, March	13 08.68	
	Nashville, Tenn	Tr	Dean, Smith				
*79	New Orleans, Lafayette Square, La	Tr	Dean, Smith	1880	March, April	22 43.37	
	Atlanta, City Hall Square, Ga	Tr	Smith, Dean				
*80	Atlanta, City Hall Square, Ga	Tr	Smith, Dean	1880	May	17 48.65	
	Charleston, Citadel Square, S. C	Or. as. c	Dean, Smith				

Table of results of differences of longitude determining subordinate stations.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	s.
1	Cambridge, Harvard College Observatory, Mass.	C. of d	W. C. Bond	1851	December	0 30 09.442	±0.13
	Halifax, Naval Yard Observatory, N. S.	Tr	Captain Shortland				
2	Calais, Academy grounds, Me	Tr	E. Goodfellow	1857	October	2 34.73	.5
	Fredericton, Toldervy's Observatory, N. B	Tr	Dr. J. Toldervy, Dr. W. B. Jack.				
3	NewOrleans, Basin, near Canal street, 1858	Tr	Goodfellow	1858	January, February.	3 17.74	.16
	Head of Passes, Mississippi Delta, La	Tr	[F. H. Gerdes], J. G. Oltmanns.				
4-13	Clarksburg, near Academy, W. Va	A. st	A. T. Mosman	1863-'64	December, January.	13 09.43	
	Grafton, near railroad depot, W. Va	A. st	A. T. Mosman	1864	January	11 54.68	
	Cameron, near church, W. Va	A. st	A. T. Mosman	1864	January	14 05.46	
	Wheeling, near Sprigg House, W. Va	A. st	A. T. Mosman	1864	January	14 42.40	
	Parkersburg, on bluff, W. Va	A. st	A. T. Mosman	1864	January	18 04.68	
	Point Pleasant, near bank, W. Va	A. st	A. T. Mosman	1864	February	20 22.98	
	South Point, top of bluff, Ohio	A. st	A. T. Mosman	1864	February	22 09.70	
	Gauley Bridge, near Hale's house, W. Va	A. st	A. T. Mosman	1864	February	16 39.79	
	Cumberland, Decatur street, Md	A. st	A. T. Mosman	1864	March	6 49.57	
	Martinsburg, near railroad station, W. Va	A. st	A. T. Mosman	1864	March	3 37.46	
	With Washington, United States Naval Observatory, D. C.	C. of d	G. W. Dean, [J. M. Gilliss], J. R. Eastman.	1863-'64	December, January, February, March.		
14	Allegheny, Observatory, Pa	C. of d	S. P. Langley	1869	March	35 31.88	.04
	Cambridge, Harvard College Observatory, Mass.	C. of d	J. Winlock, Mosman, F. Blake, jr.				
15	Staunton, near Dr. Sears' house, Va	Tr	Mosman	1869	April	8 04.93	
	Washington, United States Naval Observatory, D. C.	C. of d	[B. F. Sands], C. Thirion				
	Omaha, Capitol Square, Nebr With	Tr	Goodfellow	1869	April, May, June, July.		
16	Mattoon, near school-house, Ill	Tr	E. P. Austin	1869	April, May	30 13.54	.10
17	Springfield, near New State House, Ill	Tr	E. P. Austin	1869	May, June	25 08.70	.11
18	Burlington, South Hill, Public Square, Iowa.	Tr	E. P. Austin	1869	June	19 20.38	.10
19	Des Moines, Court-House grounds, Iowa	Tr	E. P. Austin	1869	July	9 16.96	.12
20	Bushnell, railroad station, Nebr	Tr	O. N. Chaffee	1869	July	31 45.75	
21	Julesburg, railroad station, Colo	Tr	O. N. Chaffee	1869	July	25 39.38	
	with Omaha, Capitol Square, Nebr	Tr	Goodfellow	1869	July		
22	Bristol, Tenn., or Goodson, Va., Eclipse Station.	Tr	R. D. Cutts, Mosman	1869	July, August	20 32.84	.06
	Washington, United States Naval Observatory, D. C.	C. of d	[Sands], and various				
23	Cedar Falls, railroad station, Iowa	Tr	[J. E. Hilgard], Blake	1869	October	19 20.8	.5
	Chicago, University Observatory, Ill	Tr	T. H. Safford, A. N. Skinner				
24	San Francisco, Washington Square, Cal.	Tr	G. Davidson	1870	April, May	16 39.62	.12
	Buena Vista, Los Angeles, Cal	Tr	S. R. Throckmorton, jr				

Table of results of differences of longitude determining subordinate stations—Continued.

No.	Western and eastern station.	Ref. mark.	Observers.	Year.	Month.	Diff. of long.	Prob. error.
						h. m. s.	*s.*
*25	Burlington, Vt. Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Dean, Mosman [Winlock], Austin	1870	September, October.	8 18.58	±0.07
26	Chetopah, railroad depot, Kans. Saint Louis, Washington University, Mo.	Tr Tr	R. Keith W. Eimbeck	1871	July	19 35.56	.10
27	Allegheny, Observatory, Pa Cambridge, Harvard College Observatory, Mass.	C. of d. C. of d.	Langley [Winlock], H. Gannett	1871	September, October.	35 32.01	.05
	[Mean of the determinations of 1869 and 1871.]					35 31.94	.05
*28	Oakland, near Eclipse Station, Ky Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Mosman [Winlock], Gannett	1871	November	1 00 30.30	
*29	Shelbyville, College grounds, Ky Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Dean, Mosman [Winlock], Gannett	1871	November, December.	56 21.98	
*30	Falmouth, Coleman's Farm, Ky Cambridge, Harvard College Observatory, Mass.	Tr C. of d.	Goodfellow [Winlock], Gannett	1871	December	52 38.4	
31	Austin, Public Reservation, Tex Allegheny, Observatory, Pa	Tr C. of d.	Eimbeck Langley	1872	April	1 10 53.86	.06
32	Salt Lake City, Temple Square Observatory, Utah. Sherman, near railroad station, Wyo	Tr Tr	Mosman Cutts	1872	June, July	26 00.93	.04
	Washington, United States Naval Observatory, D. C., with	C. of d.	[J. Rodgers], various	1877	July, August, September.		
*33	Travis, Delaware County, N. Y.	Tr	E. Smith	1877	July	6 46.25	
*34	Burt, Bradford County, Pa	Tr	E. Smith	1877	August	1 17.14	
*35	Fin, Broome County, N. Y.	Tr	E. Smith	1877	August, September.	5 09.78	
*36	Washington, United States Naval Observatory, D. C. Harrisburg, near Capitol, Pa	C. of d. Tr	[Rodgers], various Smith	1877	September	40.788	
*37	Paducah, Ky Nashville, Tenn	Tr Tr	Eimbeck Dean	1877	September	7 15.86	
*38	Cairo, Ill Nashville, Tenn	Tr Tr	Eimbeck Dean	1877	October	9 32.93	
*39	Hickman, Ky Nashville, Tenn	Tr Tr	Eimbeck Dean	1877	October	9 38.68	
*40	Memphis, Tenn Nashville, Tenn	Tr Tr	Eimbeck Dean	1877	November	13 05.05	
41	Summit Station, Central Pacific Railroad, Cal. Washington, United States Naval Observatory, D. C.	Tr C. of d.	B. A. Colonna [C. H. Davis], various	1878	May	2 53 07.57	±0.16
*42	Helena, Ark Nashville, Tenn	Tr Tr	Smith Dean	1878	May	15 13.52	
43	San Francisco, Washington Square, Cal. Summit Station, Central Pacific Railroad, Cal.	Tr Tr	J. F. Pratt Colonna	1878	May, June	8 19.01	.06
*44	Natchez, Miss Nashville, Tenn	Tr Tr	Smith Dean	1878	June	18 28.22	
*45	Greenville, Miss Nashville, Tenn	Tr Tr	Smith Dean	1878	July	17 07.41	
*46	Vicksburg, Miss Nashville, Tenn	Tr Tr	Smith Dean	1878	July	16 24.10	
*47	Baton Rouge, La Atlanta, City Hall Square, Ga	Tr Tr	Smith Dean	1880	April	27 11.96	

**References to preceding results.*

To No. 1.—This result is now only of historical interest, as the first obtained by the Coast Survey.

8.—A weak result, resting on one night's work.

9.—A preliminary adjustment showed the result to be in error about 0s.25; it has in consequence been abandoned. Observations were made only on one night, and no personal equation was determined.

It thus appears that of a total number of 127 telegraphic differences of longitudes, 14 of the more important determinations require an office computation to be made, and 16 of the subordinate determinations likewise require a second or check computation. Of the nearly 100 results, which at present may be accepted as final, there may be some which it would seem desirable to re-examine or re-deduce, yet the change would probably be so small that we would hardly be warranted in expending the labor.

TELEGRAPHIC LONGITUDES—COMBINATION AND ADJUSTMENT OF OBSERVED DIFFERENCES OF LONGITUDES.

For the direct and immediate use of the Survey we need to combine the preceding results, and to disperse by the method of least squares all discrepancies existing between the results by various combinations. Two different solutions are open for use,† leading of course to the same results. Whether one or the other is more advantageous will mainly depend on the relative proportion of the numbers of differences of longitude, and the number of combinations or conditions between them.

Let l = number of determinations of differences of longitude; s = number of longitude stations involved; c = number of conditional equations between them, then

$$c = l - s + 1.$$

The introduction of proper weights is of prime importance; otherwise there is danger of good work being injuriously affected by the influence of less accurate determinations. The probable errors ε were made out whenever possible and are given in the preceding tables. The weight w is found by $w = \varepsilon^{-2}$

This being the first time on the survey of the presentation of a longitude adjustment (beyond that of a single triangular circuit), I give the steps a little more fully than would otherwise be necessary, in order to show the arrangement. The first adjustment herewith presented contains all stations at present available for this purpose; but as new work and verification work is added, larger and each time more complex figures will have to be treated; yet the resulting longitudes of the older work will be affected but very little, if at all, by the addition of such later determinations.

For figure of adjustment see accompanying diagram, plate No. 33.

The first column of the table below gives the year when the telegraphic longitude was executed, the second column the names of the two stations connected; the letters D refer to dome, T. C. to Transit circle, △ to trigonometrical stations, &c. When there is no designating letter the transit instrument is understood. The third column contains the observed difference of longitude, the fourth its assigned probable error, the fifth the symbolic correction, the sixth its value as found by the adjustment, and the last column the adjusted difference of longitude.

		h. m. s.	*s.*		*s.*	*h. m. s.*
1851	Cambridge (D)—Bangor	0 9 23.080	±.043	(1)	—.013	0 9 23.067
1857	Bangor—Calais	6 00.316	.015	(2)	—.002	6 00.314
1866	Calais—Heart's Content	55 37.973	.066	(3)	—.030	55 37.943
1866	Heart's Content—Foilhommerum	2 51 56.356	.029	(4)	—.006	2 51 56.350
1866	Foilhommerum—Greenwich (T. C.)	41 33.336	.049	(5)	—.016	41 33.320

**References to preceding results*—Continued.

To No. 10.—By adjustment was found to be about 0s.25 in error; no personal equation was determined; the result has been abandoned.
13.—Result not heretofore given.
15.—Result not heretofore given.
27.—*Automatic* clock-beats first transmitted at this station.
45.—A second computation very desirable.
48.—Of very little independent value when compared with Nos. 47 and 49.
60, 61, 65, 67, 69, 71, 72, 73, 76, 77, 78, 79, 80.—Rough field results, office computations required.

SUBORDINATE DETERMINATIONS.

To No. 25.—A result from rough field work.
28, 29, 30.—An office computation for each seems desirable.
33, 34, 35.—An office computation for each of these boundary stations seems desirable.
36.—An office reduction needed.
37, 38, 39, 40, 42, 44, 45, 46, 47.—Office computations needed.

†In the preliminary adjustment of part of the southern combinations, and which resulted in the rejection of the differences of longitude, Charleston-Washington, and Savannah-Charleston, the two methods were used as a check. Of course the difference of labor between them is of little consequence for a small number of stations, but it becomes of great importance in extended and complex cases.

		h. m. s.	s.		s.	h. m. s.
1872	Brest (△)—Greenwich (T. C.)	17 57.598	.022	(6)	−.013	17 57.585
1872	Brest (△)—Paris (M. of F.)	27 18.512	.027	(7)	+.025	27 18.537
1872	Greenwich (T. C.)—Paris (M. of F)	9 21.000	.038	(8)	−.049	9 20.951
1872	St. Pierre—Brest (△)	3 26 44.810	.027	(9)	+.020	3 26 44.830
1872	Cambridge (D.)—St. Pierre	59 48.608	.021	(10)	−.029	59 48.579
1869 1870	Cambridge (D.)—Duxbury	1 50.191	.022	(11)	−.010	1 50.181
1870	Duxbury—Brest (△)	4 24 43.276	.047	(12)	−.047	4 24 43.229
1867 1872	Washington N.O. (D.)—Cambridge (D.)	23 41.041	.018	(13)	+.001	23 41.042
1872	Washington N. O. (D.)—St. Pierre	1 23 29.553	.027	(14)	+.068	1 23 29.621
1867	Seaton—Cambridge (D.)	23 28.474	.023	(15)	−.050	23 28.424
1867	Washington N. O. (D.)—Seaton	12.634	.015	(16)	−.016	12.618
1852	Petersburg—Seaton	1 35.591	.022	(17)	−.002	1 35.589
1853	Raleigh—Seaton	6 32.873	.044	(18)	−.040	6 32.833
1853	Charleston (△)—Raleigh	5 12.250	.153	(19)	+.072	5 12.322
1854	Columbia—Raleigh	9 35.862	.041	(20)	−.041	9 35.821
1854	Wilmington—Petersburg	2 11.340	.033	(21)	−.005	2 11.335
1856	Columbia—Wilmington	12 21.731	.028	(22)	−.003	12 21.728
1874	Atlanta—Savannah	13 11.960	.046	(23)	−.020	13 11.940
1879	Atlanta—Washington N. O. (D)	29 21.184	.013	(24)	+.006	29 21.190
1874	Savannah—Washington N. O. (D.)	16 09.296	.070	(25)	−.046	16 09.250
1855	Macon—Columbia	10 22.250	.051	(26)	−.075	10 22.175
1856	Montgomery—Macon	10 41.570	.015	(27)	−.006	10 41.564
1857	Lower Peach Tree—Montgomery	4 58.789	.016	(28)	−.008	4 58.781
1857	Mobile—Lower Peach Tree	1 59.768	.016	(29)	−.008	1 59.760
1858	New Orleans (1880)—Mobile	8 06.281	.022	(30)	−.014	8 06.267
1880	New Orleans (1880)—Nashville	13 08.680	.020	(31)	−.021	13 08.659
1880	New Orleans (1880)—Atlanta	22 43.370	.016	(32)	+.021	22 43.391
1879 1880	Nashville—Atlanta	9 34.740	.012	(33)	−.007	9 34.733
1880	Atlanta—Charleston (△)	17 48.655	.010	(34)	+.000	17 48.655

CONDITIONAL EQUATIONS.

$$
\left\{
\begin{array}{l}
\text{s.} \\
0 = -0.086 - (6) + (7) - (8) \\
0 = -0.045 - (1) - (2) - (3) - (4) - (5) + (6) + (9) + (10) \\
0 = +0.049 - (9) - (10) + (11) + (12) \\
0 = +0.096 + (10) + (13) - (14) \\
0 = +0.067 + (13) - (15) - (16) \\
0 = +0.205 - (16) + (18) + (20) - (24) + (26) + (27) + (28) + (29) + (30) - (32) \\
0 = -0.050 - (31) + (32) - (33) \\
0 = +0.072 + (23) - (24) + (25) \\
0 = -0.040 - (16) + (18) + (19) - (24) + (34) \\
0 = -0.073 + (17) - (18) - (20) + (21) + (22)
\end{array}
\right.
$$

We next express each correction in terms of the correlatives and determine the latter from the following normal equations:

		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
0 =	−.086	+.00265	−.00048								
0 =	−.045	−.00048	+.01132	−.00117	+.00044						
0 =	+.049		−.00117	+.00386	−.00044						
0 =	+.096		+.00044	−.00044	+.00149	+.00032					
0 =	−.067				+.00032	+.00108	+.00023			+.00023	
0 =	+.205					+.00023	+.00810	−.00026	+.00017	+.00234	−.00362
0 =	−.050						−.00026	+.00080			
0 =	+.072						+.00017		+.00719	+.00017	
0 =	−.040					+.00023	+.00234		+.00017	+.02585	−.00194
0 =	−.073						−.00362			−.00194	+.00597
Values of correlatives		+33.69	+6.83	−21.24	−93.15	+95.2	−28.93	+53.1	−9.4	+3.055	−4.33

Residuals all zero; the solution was rapidly effected by Gauss' indirect method.

If we square the 34 corrections to our observed differences to get rid of the + and — signs, and form $\sqrt{\frac{\Sigma(\text{corr's})^2}{34}}$ we have the average corrections $\pm$ ˢ.031, quite a small quantity, which compares favorably with the average residual from Dr. Albrecht's discussion of 39 telegraphic differences of longitude determined in Europe; in his case 6 reach to 0ˢ.1 or over, whereas our maximum correction is less than 0ˢ.08. The corrections needed represent pure observing errors, the deflection of the vertical not coming into consideration.*

Our average probable error of a determination is $\pm$ ˢ.033; hence the average mean error assigned $= \frac{\pm .033}{.674} = \pm$ ˢ.049; now if we compare this amount with the average correction or $\pm$ ˢ.031, we find that the probable errors originally assigned to the results fairly represent the uncertainty of the determinations, and that no constant error of appreciable magnitude exists. The resulting longitudes of the European system require for the determination Greenwich—Paris the correction + ˢ.025, whereas the above adjustment requires — ˢ.049; hence in a new adjustment we might with advantage apply the mean correction — ˢ.012.

The resulting longitudes are given in the following table:

Resulting adjusted longitudes (west of Greenwich).

	h. m. s.	° ′ ″
Greenwich (T. C.), England	0 00 00.000	0 00 00.00
Paris (M. of F.), France	— 9 20.951	— 2 20 14.27
Brest (T. of S. L.), France	+ 17 57.585	+ 4 29 23.77
Foilhommerum (T.), Ireland	41 33.320	10 23 19.80
Heart's Content (T.), Newfoundland	3 33 29.670	53 22 25.05
Calais (T.), Me	4 29 07.613	67 16 54.20
Bangor (T.), Me	4 35 07.927	68 46 58.90
Cambridge (D.), Mass	4 44 30.994	71 07 44.91
St. Pierre (T.), Gulf of St. Lawrence	3 44 42.415	56 10 36.22
Duxbury (T.), Mass	4 42 40.813	70 40 12.20
Washington, United States Naval Observatory (D.)	5 08 12.036	77 03 00.54
Washington, Seaton (T.)	5 07 59.418	76 59 51.27
Petersburg (T.), Va	5 09 35.007	77 23 45.10
Raleigh (T.), N. C	5 14 32.251	78 38 03.76
Wilmington (T.), N. C	5 11 46.343	77 56 35.14
Columbia (T.), S. C	5 24 08.072	81 02 01.08
Atlanta (T.), Ga	5 37 33.226	84 23 18.39
Charleston (O. A.), S. C	5 19 44.572	79 56 08.58
Savannah (T.), Ga	5 24 21.286	81 05 19.29
Macon (T.), Ga	5 34 30.247	83 37 33.70
Montgomery (T.), Ala	5 45 11.811	86 17 57.16
Lower Peach Tree (T.), Ala	5 50 10.592	87 32 38.88
Mobile (T.), Ala	5 52 10.352	88 02 35.28
Nashville (T.), Tenn	5 47 07.959	86 46 59.38
New Orleans (T., 1880), La	6 00 16.618	90 04 09.27

The above results form the basis of the telegraphic longitude register kept in the Computing Division.

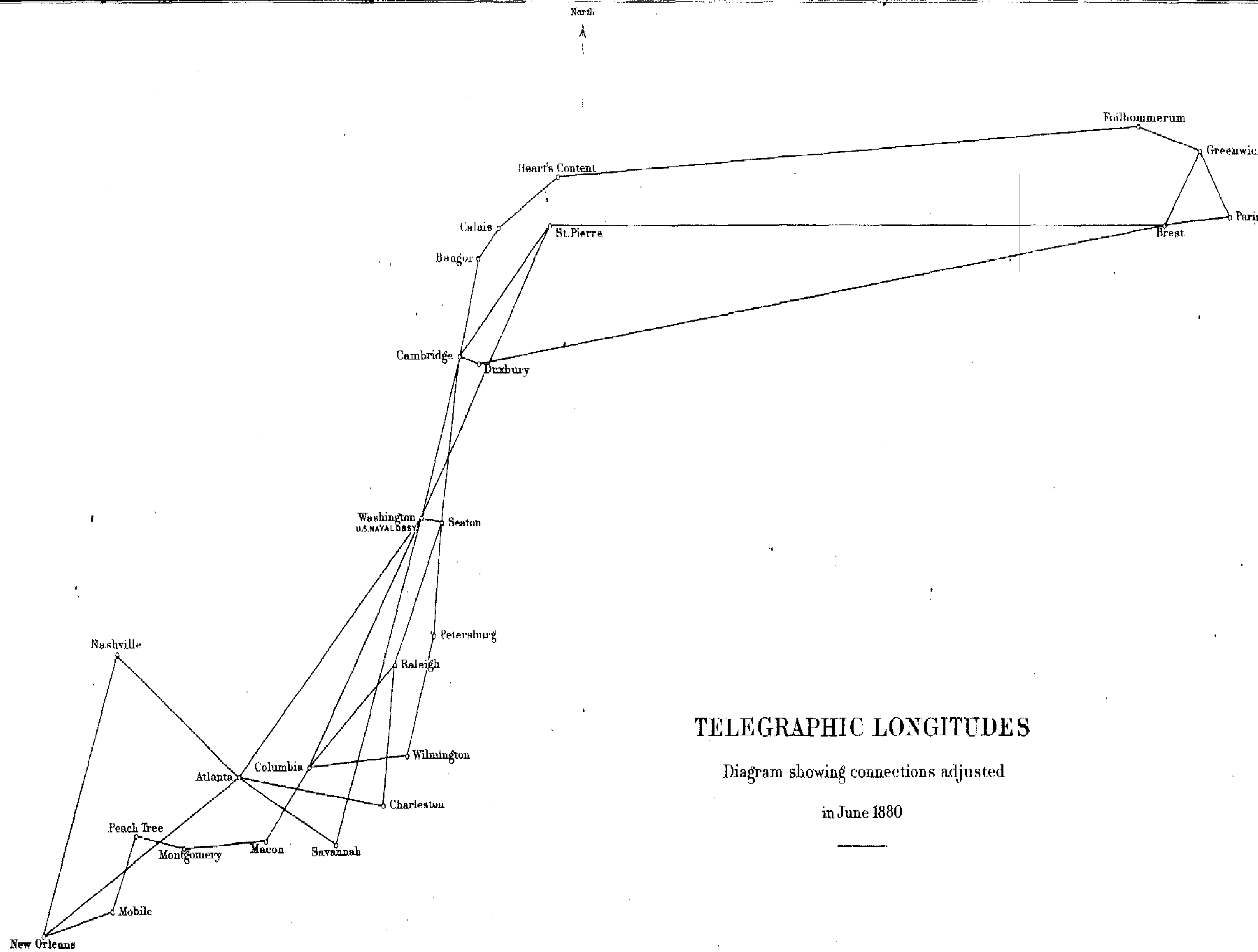
All computations connected with the results of this report were made by myself.

Yours, respectfully,

CHAS. A. SCHOTT,
Assistant.

C. P. PATTERSON,
Superintendent Coast and Geodetic Survey.

*At a few stations a *small* geodetic reduction enters, in which, however, no differential deflection of the plumb-line is apprehended.



TELEGRAPHIC LONGITUDES

Diagram showing connections adjusted

in June 1880

APPENDIX No. 7.

EXPLANATION OF APPARATUS FOR OBSERVATION OF TELEGRAPHIC LONGITUDES, WITH DIRECTIONS FOR ITS USE.

BY EDWIN SMITH, Assistant.

DESCRIPTION OF APPARATUS.

The chronographs, chronometers, batteries, &c., are to be connected with the binding posts a . . . o, as indicated in diagram of switchboard, plate No. 35. Diagrams 1, 2, 3, 4, 5, show the position of the plugs to make the connections shown in diagrams I, II, III, IV, V, plate No. 34.

I, 1.

Observing.—The chronometer breaks circuit A and the armature of chronometer-relay breaks circuit B—the observer at the transit also breaks circuit B with the observing key, and a record of both the chronometer and observation is made on the chronograph.

Correspondence.—The correspondence relay and key only are connected with the main circuit. The main circuit batteries are always at the main office of the telegraph companies.

II, 2.

Chronometer Signals.—The chronometer breaks circuit A and the armature of the chronometer relay breaks the main circuit, and the armature of the signal-relay breaks circuit B, making a record on the chronograph. The connections are the same at both stations. If the chronometers do not break at the same time they will record alternately on the chronographs at both stations. If the breaks coincide, a clear record may still be obtained if the observer who has the *one-second* chronometer will stop the break that coincides with the break of the *two-second* chronometer, by holding the armature of his chronometer-relay.

III, 3.

Arbitrary Signals.—The chronometer breaks circuit A and the armature of the chronometer-relay breaks circuit B as in I. The observer breaks the main circuit with the correspondence key or any other key he may connect with main circuit, and the armature of the signal-relay breaks circuit B, making a record on the chronograph. The connections are the same at both stations, so that the arbitrary signal is recorded on the chronographs at both stations.

In cases II and III, the rheostat is placed in a branch circuit D, R, V (plate No. 34). By regulating the resistance in this branch by removing or replacing the plugs of the rheostat, the current through the signal-relay may be regulated to any strength below the full strength in the circuit, as will be indicated by the galvanometer. If it is desired to have the full strength of current the plug of the rheostat marked *open* is to be removed, which will open the branch D, R, V.

IV, 4, and V, 5.

These cases are the same as II and III, except that the rheostat is directly in the main circuit. In exchanging signals in these cases all the plugs must be in the rheostat.

Resistance of main circuit.—To test the resistance of the main circuit take case V, plugging 11 and 12, so as not to interfere with the local circuits. Read the galvanometer-tangent scale and reduce this reading one-half by removing plugs from rheostat. The resistance unplugged will be the resistance of the circuit, including batteries and instruments.

To compare two local chronometers, take case I and remove plug between 13 and 14, which will put second chronometer in circuit A.

ADJUSTMENTS.

Talking Apparatus.—This is independent of all the other instruments on the board, and may be managed as the operator wishes.

Chronometer Relay.—This may be adjusted to give any length of break the observer may desire, but when adjusted it is desirable that the position of the coils and the tension of the spring should not be changed during a night's work. If in sending chronometer signals the break of the chronometer relay should not be long enough, it may be increased by lengthening the pass of the armature. This is done by moving the insulated point against which the armature strikes. This does not affect the instant of separation of the contact points, but causes them to be separated longer as the pass of the armature is increased.

Signal Relay.—This relay should have a very *high* adjustment; that is, the coils must be far from the armature and the tension of the spring as great as possible. The observer will first adjust as for correspondence and will then increase the tension of the spring until the armature trembles; he then will slowly reduce the tension until the signals come firmly. This adjustment is entirely tentative and should be repeated every night. The soft iron cores of this relay are hollow cylinders, 1¼ inches long, with a slit cut their entire length. The object is to obtain the greatest possible surface, so as to gain a very rapid discharge of the magnetism when the circuit is broken. The resistance of the coils is 350 ohms.[1]

Galvanometer.—The galvanometer must be placed so as not to be affected by the other instruments, or by the currents on the wires within the observatory. Set up level with the plane of the coil in the magnetic meridian: the pointer should read zero. The plug is to be placed in hole marked 2, which connects the 10 ohm coil; the hole marked 1 connects the copper band only. The tangent scale should be generally used.

Rheostat.—The coils of the rheostat are so arranged that any combination from 1 ohm to 11,110 ohms may be made. The coils are put into circuit by removing plugs and cut out by inserting plugs. The removal of plug from hole marked *open*, breaks the circuit through the coils.

INTERCHANGE OF LONGITUDE SIGNALS.

The two stations will be designated by W (western) and E (eastern).

1. Connections at both stations as in case III, with 11 and 12 plugged, and the rheostat open. Galvanometer (tangent scale) to be read at both stations. E will communicate his reading to W. If W finds his reading to be greater than E's, he will close his rheostat and remove the proper plugs to reduce his reading to E's, and then notify E that he is ready for signals. If W finds E's reading to be the greater he will communicate his reading to E, who will reduce his reading, as above, to W's, and notify W that he is ready for signals. If the readings do not differ more than 15 divisions the rheostat can be left open at both stations; this will usually be the case.[2]

[1] Experience of the season of 1881 has shown that these relays work most satisfactorily when the galvanometers read between 85 and 110 divisions on the tangent scales. This indicates a strength of current equivalent to that obtained from one cell (large size) of gravity battery of the form in general use by the Western Union Telegraph Company, in a circuit whose resistance is from 45 to 35 ohms. The longest circuit used during the season was between Washington and Cincinnati, 581 miles of Nos. 6 and 7 galvanized-iron wire, with 200 cells of gravity battery. The mean reading of galvanometers was 108 divisions tangent scale, and the resistance of circuit was 7055 ohms. In this circuit the mean transmission and armature time was $0^s.017 \pm 0^s.0006$, and the greatest deviation from this on any of the nine nights was $0^s.006$. Even considering this $0^s.006$ as an absolute error, it is insignificant in the result of a night's work.

[2] During the season of 1881, owing to the difficulty of obtaining the telegraph lines a sufficient length of time before the time for exchanging signals, it was in many cases impracticable to balance the currents through the relays at the two stations, as described above, and there were but few nights on which the readings of the galvanometers at the two stations differed so much as 15 divisions. It was therefore deemed preferable, instead of cases II and III, to use cases IV and V, as no change of the plugs 1 to 17 would be required to test the circuit. It is better to always start with cases IV and V, and if the galvanometer readings at the two stations should differ very widely, the change to cases II and III is very easy.

Diagram of telegraphic apparatus for longitude work
showing electrical connections.

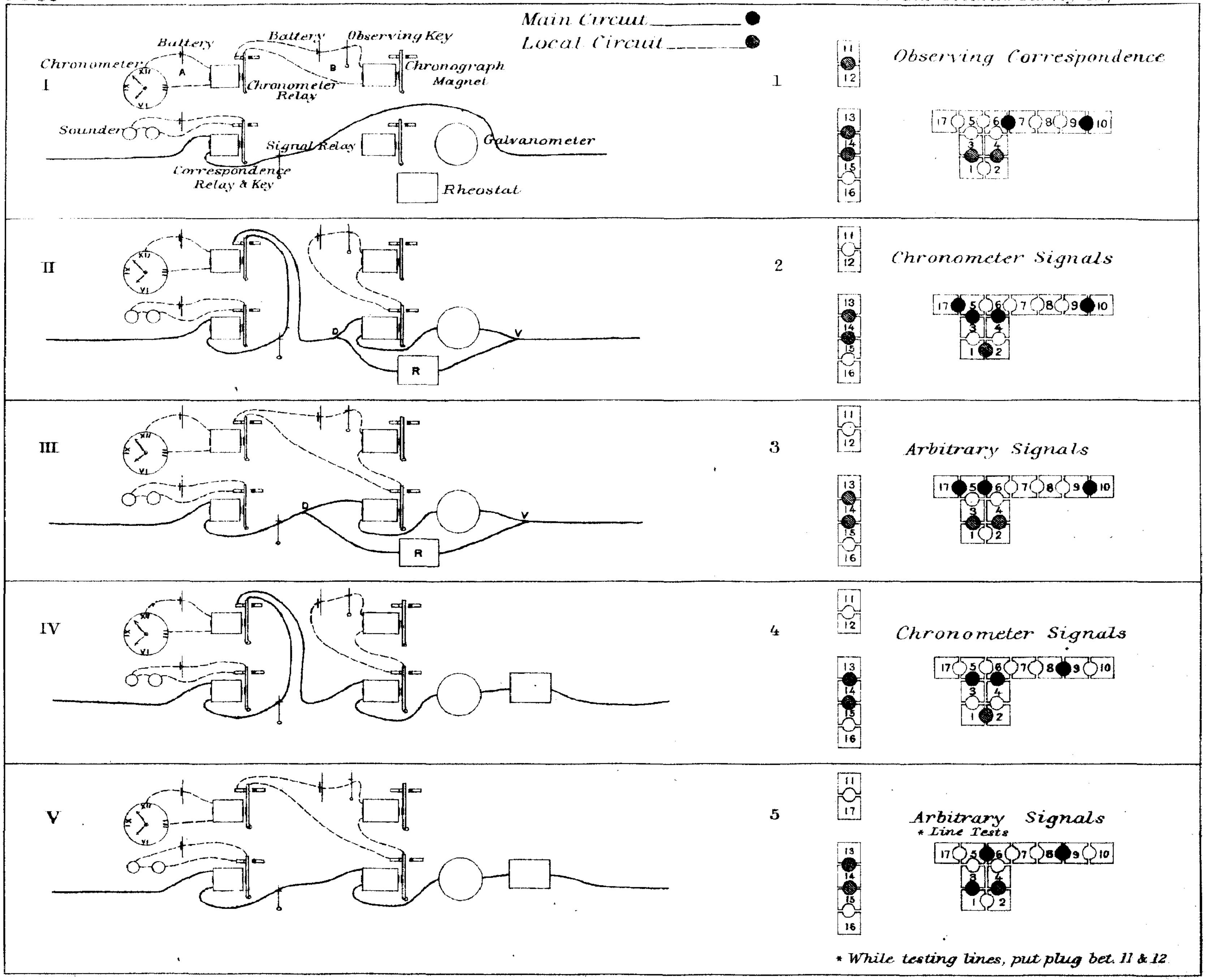
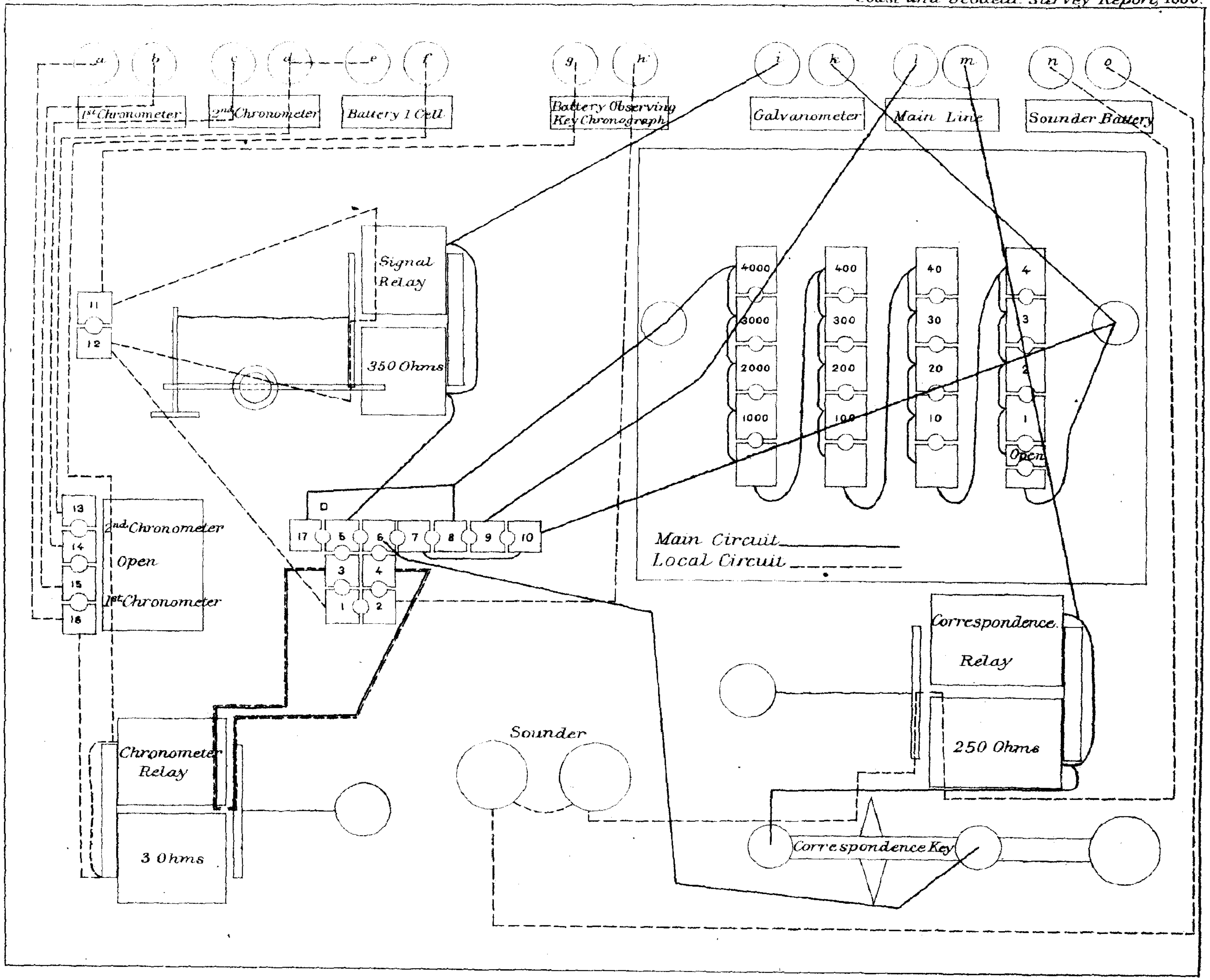


Diagram of telegraphic apparatus for longitude work showing switch-board

No. 35



2. Exchange chronometer signals in conformity with Case II for two minutes.
3. Exchange arbitrary signals in conformity with Case III—W sending first from 25 to 35 signals about two seconds apart. For this purpose Auburndale Timers, regulated to gain 1^s in 1^m, are provided.
4. W communicate to E the minutes by his chronometer, during which the chronometer signals were sent, and E give to W like information.

This whole operation (from 1 to 4) will not usually occupy more than eight or ten minutes.

If the lines can be held longer, the resistance of the main circuit will be determined as before explained, W making the first test.

A record will be kept of the length of circuit, kind and gauge of wire, and amount of battery used each night.

APPENDIX No. 8.

REPORT ON GEODESIC NIGHT SIGNALS.

NORFOLK, VA., *March*, 1880.

C. P. PATTERSON,

Superintendent United States Coast and Geodetic Survey, Washington, D. C.:

DEAR SIR: In June last you instructed me to occupy Sugar Loaf Mountain, Montgomery County, Maryland, for the purpose of making an exhaustive series of observations with the various methods of night signals, with a view to determine the most effective method to be used in triangulation.

I was directed to consider and observe—

1. "The simplest and cheapest method.

2. "The one best adapted to the intelligence of the class of men we generally employ as heliotropers.

3. "That easiest of transportation to heights.

4. "That giving the most penetrating light, with least diffraction and most precision of definition, and all other points covered by your consultations on the subject, such as the best hours for observing during the night, lateral and vertical refraction, and how far the rays are affected by the character of the country over which they pass," &c.

My attention was first called to the subject of night signals during the administration of your predecessor in 1871.

The first use of an intensified light for geodetic purposes occurred, so far as I can discover, in the progress of the ordnance survey over Ireland, when a "Drummond" or calcium light was used by Colonel Colby. But his predecessor, Colonel Mudge, had used 10-inch reflectors for distances of 24 statute miles (38.6 kms.) as early as 1797. Colonel Mudge says: "It was by the assistance of the white lights only that the most distant stations could be rendered visible, and there cannot be a doubt that in great operations of this sort they will be universally adopted hereafter."

Signals of artificial light were largely used in the trigonometrical survey of India, after 1830, and it is of interest to note the experience gained there in comparison with our own. Lieutenant-Colonel Everest,[1] who was supplied by Troughton and Simms with two dozen reverberatory lamps, Argand burners (see engravings, Plate 21, of volume of plates), makes the following statement (p. CXIX): "The only method of overcoming these sources of irregularity is to await a favorable state of the atmosphere, and be prepared to profit by every such opportunity which offers itself; such occasions occur for day observations almost every sunny day, for a shorter or longer period, between 4½ o'clock and sunset, and sometimes, but rarely, the lamp is beautifully adapted to intersection from sunset till past midnight or even later, so that the patience has to be tried, though not to that extent which was requisite when masts, flag-staves, and other opaque objects were the only marks to be intersected, for then days and days often passed away without a glimpse of the distant object. The state of the atmosphere immediately after sunrise, though often highly promising in appearance, is rarely to be depended on, for then it would seem that lateral refraction acts most insidiously."

In these lamps the light was reflected by a paraboloidal mirror of plated copper, 12 inches in diameter and 4.9 inches in depth.

When greater penetrating power of the light was required, Everest used blue lights, ***burned at intervals***, in frames of sheet-iron, accurately adjusted over the center of the station.

The French and other continental geometers have used reflectors for night observations up to a very recent period, when they have been discarded for the "optical collimators," introduced and now used by M. M. Perrier and Bassot, of which I shall have more to say further on.

[1] An account of the Meridional Arc of India: London, 1847.

From the commencement of the primary triangulation of the Coast Survey, up to he death of Mr. F. R. Hassler, the first Superintendent, in 1843, the Gauss heliotrope was used in primary triangulation upon all long lines.

Gradually, under the administration of his successor, Prof. A. D. Bache, the simpler forms of heliotrope, devised by officers and others of this Survey, were substituted and used extensively, as the scope of the primary triangulation was gradually enlarged.

In 1846, Professor Bache used, at Blue Hill, near Boston, an "optical collimator," consisting of a 10-inch object-lens, fitted in a sheet-iron tube, with a focus of about 3 feet. The lamp placed in its focus was made, if I remember rightly, of the Argand form, burning sperm-oil. It was placed at "Great Meadow" station, distant 23.6 miles (38 kms.) from Blue Hill, and was intended for use in connection with azimuthal observations.

But difficulties occurred in the way of rightly directing it and keeping it properly attended to, and the experiment was abandoned after a short trial.

In the season of 1871 I occupied Bull Run Mountain, in Fauquier County, Virginia, and was kept there more than twice the time usually required at a primary station, by the persistent "smoke" or haze which prevented vision upon long lines. This "smoke" remained during a range of the thermometer of 50°, and nearly two inches difference of barometric pressure, with the wind blowing from every quarter, and was specially dense and persistent with a cloudless sky. But I noticed that during westerly winds the haze or "smoke" settled at sunset, and before twilight ended our stations upon the mountain peaks of the Blue Ridge would appear in sharp and bold relief against the western horizon.

It naturally occurred to me that by the use of night signals the time lost from the day might be redeemed at night.

On bringing the matter to the notice of the Superintendent (Prof. Benjamin Peirce), I was authorized to inquire into and report upon some suitable form of night signals for use in the Coast Survey.

In 1872 and 1873 I laid out, graded, and measured three times the Atlanta base, and occupied seven stations of the base connections. These labors absorbed my whole time.

In the fall of 1874 I tried the use of two "German student lamps," fitted to burn kerosene oil in the focus of an 8-inch paraboloid reflector.

Owing, as I now think, to some failure in obtaining the right direction, the experiment did not then appear to succeed, and I came to the conclusion that an intensified light must be used. Of these there were three, all well known, viz, (1) the electric light, (2) the calcium or oxy-hydrogen light, (3) the magnesium light.

The necessary conditions of the problem I was trying to solve in finding a light for use in Coast Survey geodetic operations were:

1. That it should be cheap enough to be within our means.

2. That it should be capable of manipulation by uneducated persons of ordinary intelligence, like the mountaineers, of whom we usually made heliotropers.

3. That it should be light and small enough to be easily carried to the tops of high mountains, and should have simple adjustment.

The second and third of these conditions threw out both the electric and calcium lights, each of which requires a trained and educated person to manage it.

The electric light also necessitates a battery and motive power of some sort, as well as a free use of water, not always easy of access on mountains. The calcium light requires the transportation of apparatus for generation of the gases needed in its use, but may be managed and used with greater ease and at less expense than the other.

In February, 1875, I found for sale in New York an apparatus for burning two magnesium tapes in the focus of an eight-inch reflector, the tape being delivered by clockwork. It was of English make, bearing the name of J. Solomons, Red Lion Square, London, and its price was $35. Its weight was only 5 pounds, and it could be readily carried in one hand. I saw that it contained the elementary conditions of what was wanted, and purchased it to experiment with.

The drawback to its use was in the cost of the magnesium tape. This, at retail, was $3 per ounce of 40 yards.

Experiment satisfied me that one tube, burning one tape, gave all needed intensity, and, from correspondence with the American Magnesium Company, of Boston, I learned that it could be purchased by the pound for $36 or $2.25 per ounce of 40 yards.

Continued experiment proved that a consumption of from 12 to 18 inches per minute of the tape, or an average of 15 inches, would be required to maintain a brilliant and steady light. This at the above rate would make the light cost 2⅓ cents per minute, or $1.40 per hour, to burn it steadily.

Going back over my record of geodetic observations for two years, I found that the average time for good seeing, when the atmosphere was sufficiently steady to admit of observation, was, for morning and evening observations, rather less than two hours per day, where the lines of sight averaged 25 miles (40.2 kms.) in length.

Supposing the period after dark suitable for observation to be as long, each signal would cost about $3 per night, and if five were observed, the cost would be $15 per night, an expense well worth incurring to insure two hours of steady observing.

As regarded intensity, I had formerly a large experience of the intensity of the calcium light, during the time it was nightly burned on board the iron-clad frigate New Ironsides, off Charleston, during the war. So far as I could compare the two, the magnesium light appeared equally bright. Feeling sure that the thing sought for had been found I so reported, and four more of the same lights were ordered by your direction. Delays occurred and they were not received and altered to adapt them for our use until too late in 1876 to enable me to test them during that season.

On resuming work in June, 1877, at King's Mountain, in North Carolina, the first practical test was made of the power of the light, and of the working of the machinery for delivering the tape. The apparatus then appeared with the clockwork and reflector as purchased, and only changed by adding the reel and foot-screw, and a pointer under the middle of the reflector, to enable us to direct it properly.

The light was shown by my assistant, Mr. H. W. Blair, from the tower of Wofford College, in Spartanburg, S. C., distant 39.1 miles (63 kms.). The night was clear and the moon about one-quarter full.

The magnesium light shown by Mr. Blair was at once visible to the naked eye, showing nearly as large as the planet Jupiter. Our light at King's Mountain was also seen at once by Mr. Blair, who thereupon left for Paris Mountain, South Carolina, about 65 miles distant (104½ kms.), where he again showed his light to us at King's Mountain. It was again visible to the naked eye, while our light shown in return to Mr. Blair, and probably not so well directed, was plainly visible in the small telescope which he had with him.

These experiments upon three nights satisfied me as to the degree of intensity attainable, which I felt sure would render the light visible in the telescope over the longest side of any triangle which the character of the country would permit us to obtain.

It was not until October of the same year that I was able to carry out arrangements for observation upon these lights, and then only for three successive nights.

I was then at Poore's Mountain, in North Carolina. One light was placed at King's Mountain, distant 58.4 miles (94 kms.), and another at Young's Mountain, distant 35.4 miles (57 kms.). My "initial point" or "reference mark" for all observations, at Poore's Mountain, was the spire of a church in Wilkesboro, distant 5 miles (8 kms.), nearly. Here I placed for night observation a bull's-eye lantern, showing through an auger hole $0^{m}.02$ in diameter.

The light at King's Mountain was in charge of Mr. C. A. Ives, and that at Young's Mountain in charge of Mr. J. M. Hill. Each of these gentlemen had a resident of the locality with him, to work the light under his direction, and to have the capacity of that person tested for attending to it alone.

I also arranged to burn the lights by a time-table, one after the other, each light being supplied with a clock for the purpose, and the correct time being given to each by a signal from the observer before commencing the evening's observation.

The time signal was made by showing a light to each in turn, stopping at a certain prearranged instant, to which each clock was set. This time-table was very successful and saved a great deal of the costly magnesium tape. The observations began at $6^{h}\ 30^{m}$ p. m. and continued to $10^{h}\ 40^{m}$ p. m., or $4^h\ 10^m$; but each lamp was only burned for $1^h\ 20^m$ of this time, at a cost of $2.40 for each light, instead of $7.50 each, if they had been steadily burned.

The observations were made on the nights of October 9, 10, and 11, 1877. All three nights were clear, with a bright moon, more than half full.

Coast Survey theodolite No. 3 (20-inch) was used. There was a defect in the object-glass of the telescope of this instrument, causing a bright object like a heliotrope or a star to show with "tails," rendering accurate pointing difficult.

The microscopes of the theodolite were read with a lantern burning a candle, and having plane-glass sides.

The method of observation in series was similar to that in regular use by day. Three series were observed in each position, in the order, telescope direct, (1) Mark, (2) Young, (3) King; then, after reversing telescope, (4) King, (5) Young, (6) Mark, completing a series. Young, being in the middle of a series, showed 2½ minutes; King showed 5 minutes, in order to give time to reverse the telescope and point again. Each light showed 5 minutes in turn at the end of each position, to permit correction of doubtful observations.

I make the following extracts from notes made at the time:

"POORE'S MOUNTAIN, NORTH CAROLINA.

"*October* 9, *p. m.*—Night very clear, atmosphere transparent, temperature 55° Fahr. Young and King each commenced and showed during whole evening precisely on time. Both were visible to the naked eye and showed too large and bright for accurate pointing. Each subtended near 10″ with full illumination of × hairs. No motion perceptible, but variations in readings suggested lateral refraction while observing in first position (from $6^h\ 30^m$ to $7^h\ 20^m$).

"*October* 10, *p. m.*—Night clear and bright. Barometer 27.35, thermometer 62°. Atmosphere not quite so transparent as last night. Both lights at Young and King showed as per time-table up to end of programme at $10^h\ 40^m$ p. m. They were visible to the naked eye, as last night, but showed less irradiation in the telescope, were round instead of irregular, and were better objects to point upon. Objects *steady* during whole time. The whole work for four hours moved smoothly and to my entire satisfaction. Wind fresh from northwest after 9 p. m.

"*October* 11, *p. m.*—Night clear, with some haze in eastern and southern horizon. Moon larger and brighter. King not always visible to the naked eye, but showed well in the telescope. Machinery gave out at Young at $7^h\ 15^m$, and he stopped showing. King continued showing until $9^h\ 30^m$, when I stopped him by signal, being satisfied with result of experiment. The showing by time-table on the three nights has been satisfactory, but the lights are too large and the size of the reflector must be reduced on clear nights."

The result of this trial was highly satisfactory. Owing to the defect in the telescope used, to which I have referred, and to the unexpectedly great irradiation of the signals, increasing largely their apparent diameter, the test of relative precision as between day and night observations was not a good one.

The reflectors used were each $0^m.203$ diameter and subtended at Young's Mountain, distant 35.4 miles (57 kms.), 0″.73, and at King's Mountain, distant 58.4 miles (94 kms.), 0″.44, while their apparent diameter on the 9th was estimated at 10″ and was very large on each night. This was susceptible of an easy remedy in future by graduating the amount of reflecting surface exposed to view, according to the length of the line and the clearness of the atmosphere.

Messrs. Ives and Hill reported that the heliotropers at both stations had been easily taught to manage the apparatus. Each upon the second night had taken the instrument from its box, pointing it carefully upon the stand, winding up the clockwork regularly, and lighting and stopping it at the times indicated by the time-tables. This last matter was very important on account of its large reduction of expense.

But the great point ascertained, likely to be of so much future service, was that, on three successive nights, the sharp, clear, and *steady* outline of the horizon, only experienced by day-light at or near sunset, continued unbroken up to 11 p. m., or for five hours longer.

On each night the record of observation for each signal was "distinct," "steady," up to the end of my programme at 10.40 p. m., except that on one night my reference mark was obscured by mist rising from the Yadkin River about 9 p. m.

It was also evident by moonlight that mist from the streams which our lines crossed was rising each night about the time of our close of observation. I shall have occasion to refer again to this matter.

At your suggestion, I directed Mr. Ives at the close of each night's programme to remove the reflector and to show the magnesium light direct for a certain specified five minutes. He did so, and at the time fixed I carefully watched its appearance in the telescope. It was only visible in a dark field and would not bear illumination of the × hairs. This at first surprised me greatly, having seen it without a telescope shortly before, but a little consideration satisfied me that the light without the reflector, being little more than a pencil of rays having little or no phase, was dispersed upon a line of 94 kms. I remembered also a "case in point." In 1846 I placed upon the dome of Cambridge observatory a hollow glass hemisphere 6 inches in diameter, silvered on the inside. But only a brilliant pencil of rays proceeded from it, and I was unable to observe it with precision from the principal stations of the secondary triangulation of Boston Harbor and vicinity which I was then executing. The rays were dispersed in the atmosphere.

But at a later period a similar hemisphere, having the inside cast in facets, each about the size of a half dollar, and silvered, presented a brilliant light, as the rays from each facet in turn came to the proper angle. The phase or reflecting surface caused the difference in this case, as it did with the magnesium light, nearly invisible without, but intensely brilliant with, the reflector.

It was evident, as the result of the running of the clockwork of the lamps for three nights, that, as received from the maker, it was too weak for its object. All defects were carefully noted for future correction. But in all its main features the magnesium reflector light had fulfilled the conditions required for a geodesic night signal. It had—

1. Sufficient intensity for the longest lines.
2. It was of light weight and simple in adjustment.
3. It was capable of sufficiently accurate pointing.
4. It could be managed by men of ordinary intelligence without education.
5. By the use of time-tables the expense was brought within a limit very small in proportion to the time saved.

My party left the field shortly after the close of these experiments. The necessity which arose for my spending the season of 1878 in Alabama prevented their continuance until, by your direction, I encamped at Sugar Loaf Mountain, Maryland, in July, 1879, for the special purposes named in your instructions, and specified at the beginning of this report.

I have given here a history of all that had been done by me from the beginning of inquiry into the matter in the winter of 1871–'72 up to the first regular series of experiments, continued over several months. Many details are omitted. It was only in the intervals of continuous labor that I had been able to give attention to the matter, but it was never out of my thoughts, and I embraced every opportunity of adding to my experience.

I experimented upon the production of oxygen and hydrogen in rubber bags, with reference to the use of the calcium or oxy-hydrogen light, and at the close of the Centennial Exhibition in 1876 I spent part of a night with Professor Farmer, watching the operation of two electric automatic lights burning upon the top of "Machinery Hall."

Being everywhere met by the necessity for trained labor, it became necessary to concentrate my whole attention on magnesium, as the only kind of intensified light possible for our purpose.

I now take up the operations at Sugar Loaf Mountain in 1879.

Assistant F. D. Granger reported to me in person at Washington on the 14th July, and Mr. J. B. Boutelle, aid, with camp equipage, arrived at Barnesville, Md., near Sugar Loaf Mountain, on the 17th.

The rest of the month was spent by the party in repairing the mountain road up Sugar Loaf Mountain, in pitching camp, and preparing for observations.

The weather was intensely hot, and only one day was at all fit for observing between the time of our arrival at Sugar Loaf Mountain, July 15, and the end of the month. This was the beginning, a month earlier than usual, of a season of very thick and smoky atmosphere.

On the first week in August I sent out a party to erect signals at stations of the primary triangulation from which Sugar Loaf Mountain had been observed, while I put up a small building, nine feet square, for a geodetic observatory.

An insulated brick pier was laid in cement around the station point, and the 20-inch theodolite, C. S., No. 113, was mounted upon it.

Another insulated pier was set up inside the building for supporting an artificial horizon.

The magnesium light had been fitted at the office with new and strong clockwork, and the "Hipp spring" had been attached as a regulator in delivering the tape.

Five pounds of magnesium tape had been supplied by the American Magnesium Company of Boston. This was put up in tin reels of two ounces, about eighty yards of tape upon each reel.

The improvements suggested by our experiments of 1877 had been made, and I had five magnesium reflector lamps in order for work. They are in good order now for immediate use. One of them is represented in illustration No. 37, except that in the experiments at Sugar Loaf the reel for delivering the tape was attached to the handle. In future the reel will be detached, as now shown in the illustration, as also one of the clocks used, and a porte-feu for lighting the tape through the hole in front of the reflector.

Two of the "optical collimators" used by M. M. Perrier and Bassot in the prolongations of the "Nouvelle Meridienne de la France" had been received from France, and I was directed by you to test them at two stations. The aggregate weight of each, packed in two boxes, was 280 pounds. These were also fitted for use as heliotropes by day, the lantern being detached and mirrors substituted.

The following translation is given of a description of these "optical collimators," in a paper by M. Perrier, printed in the "Comptes Rendus," for June, 1877, Vol. 84, pages 1312 to 1315:

"For night signals we have given up the use of reflectors, which could not always be exactly pointed, are difficult to keep in adjustment, and must have considerable dimensions when the sides of the triangles are from 40 to 50 kms. long, and we have adopted the use of optical collimators, of which the first and most brilliant application goes back to the fine experiments of M. Fizeau on the velocity of light, and which have been adapted in later days to the needs of optical telegraphy by M. M. Murat and Cornue, and by M. M. Laussedat and Mangin.

"An apparatus for night signaling has been constructed from the designs of M. Mangin. In each the object-glass is $0^{m}.2$ in diameter and $0^{m}.6$ focal length; the lamp burns petroleum oil and has a flat wick two millimeters thick. The luminous rays emerging from the object-glass have a volume of nearly one degree and can be exactly directed by a telescope having its optical axis parallel to that of the collimator.

"By the illumination of the object-glass of this apparatus signals are obtained which in good weather are visible to the naked eye as far as a distance of 80 kms. The images seen in a telescope of a geodetic instrument appear most frequently of a red color, but are round, of limited contour, and a uniform tint, and they afford when they become steady an easy and sure bisection, like that upon stars of the first or second magnitude.

"After sunset the signals soon become visible and show the same phenomena of dilation and of jumping which affect signals from heliotropes before sunset. By degrees, however, the images become stationary, their diameter is reduced to a convenient size, and by an hour after sunset we enter upon a period of calm of a variable length, but often prolonged to midnight."

This last paragraph conforms to my description of our experience in North Carolina in 1877. It will be further corroborated as I go on.

It was not until the 18th August that we obtained a view of the distant horizon north of us.

Meanwhile many experiments at Sugar Loaf Mountain gave an estimated relative intensity of the French lights burning kerosene oil to the magnesium reflectors of two to five.

These were continued in various ways so long as we kept the lights together. Pasteboard caps, with apertures of $0^{m}.1$ and $0^{m}.15$, were fitted to cover the magnesium reflectors, diminishing the aperture. Of these the smaller aperture of $0^{m}.1$ was afterward found sufficient, and was used everywhere, except at Mount Marshall, in hazy weather.

Our view of the horizon upon the 18th of August only lasted for a few hours, the next morning being thick as ever, but we had data for a reconnaissance, which was made by Assistant Granger.

I desired to place a magnesium and a French light near each other, at distances of 60 to 70 kms. from Sugar Loaf, that I might observe them under the same physical and atmospheric conditions. I also wished to place the other French light at some point upon the Potomac near Washington.

Assistant Granger made several attempts to select a point, being baffled by the thick weather, but on the 28th August succeeded in finding a suitable place near the house of Mr. A. Strecker, on the Maryland side of the Potomac opposite Alexandria, from which it is distant about 3.1 miles (5 kms.). It could be easily reached also by driving about 7.5 miles (12 kms.) from Washington. The distance from Sugar Loaf was found to be 38.8 miles (62.4 kms.), and the line of sight would run near the surface, giving me the diversified profiles which I desired.

The station was adopted and a French light placed there on the 1st of September.

The month of August had given us only parts of two days with a clear horizon. But it had not been lost. Experiments at camp had developed difficulties in the running of the new clockwork of the magnesium lamps. Assistant Hilgard had kindly detailed from the office Mr. Werner Süess, to whom I was greatly indebted for skillful and ingenious alterations of various parts of the machinery, as also for aid in trials of the relative intensity of the lights, and in posting the lights at Strecker and Mount Marshall.

In September there were a few intermittent intervals of clear weather between the 3d September and the 25th, at which date a season of clear weather set in, lasting for five days and enabling us to make progress.

A French light was posted by Assistant Granger on Granite Hill, in Gettysburg, about 3.7 miles (6 kms.) east northeast of that place and 42.9 miles (69 kms.) from Sugar Loaf Mountain.

A magnesium light was also posted upon Wolf Hill, about 1.2 miles (2 kms.) southeast of Gettysburg, and 39.8 miles (64 kms.) from Sugar Loaf.

The lines of sight to Wolf and Granite hills passed over a rolling country, nowhere approaching very close to the surface. So far as I could see, both lines had the same physical conditions and were likely to be affected equally by any atmospheric disturbances.

Our preparations for observation were now complete. I had established a reference mark near the railroad station at Barnesville, distant 3.82 miles (6.14 kms.) from Sugar Loaf. It was the usual azimuth mark of my party, which had been used at the experimental observations at Poore's Mountain, in North Carolina, in 1877. It consists of a box perforated with holes for supplying air and closed by a slide. Its front is a board 31 inches ($0^m.8$) long and 16 inches ($0^m.4$) wide, painted white, with a vertical black stripe 0.98 inch ($0^m.025$) broad in its center for a day mark, and an auger hole 0.75 inch ($0^m.019$ in diameter) in the center of the stripe, through which a bull's-eye lantern in the box shows at night.

It was solidly secured, with a mark in the ground to refer to in case of possible disturbance.

The other two of my five points of comparison by day and night were Bull Run Mountain, in Fauquier County, Virginia, distant 31.1 miles (50 kms.), and Mount Marshall, in Rappahannock County, Virginia, distant 55.0 miles (88.5 kms.). These were stations of the primary triangulation, and Sugar Loaf had been observed from them. Heliotropes and magnesium lamps were placed at these stations, which are respectively 1,375 feet (419^m) and 3,376 feet ($1,029^m$) high.

Besides the five stations for day and night comparison, I also observed upon the stations Stabler, Soldiers' Home, Peach Grove, and Maryland Heights, in order to close the triangles upon these stations from whence Sugar Loaf Mountain had been observed. I also observed upon the Capitol at Washington and the Theological Seminary near Alexandria, as secondary points.

These constituted an entirely distinct and separate series of observations, called the "short series" by way of distinction. All were upon signal poles except at two secondary points.

The distribution and relative positions of all points observed upon will be seen in sketch No. 36.

Observations upon the "short series" began on the 18th August, and were continued at times when the more distant points could not be seen. They were completed on the 19th October.

I have mentioned that an interval of clear weather began on the 25th September. Bull Run and Mount Marshall were ready and at once began showing heliotropes by day and magnesium light at night, the latter by a prearranged time-table.

Bull Run being only 31.1 miles (50 kms.) distant, exposed only the central 3.9 inches ($0^{m}.1$) of the diameter of the reflector, but was always visible to the naked eye.

Mount Marshall also showed with the cap and was seen well on clear nights, but being 55 miles (88 kms.) distant, the full surface of the reflector was required on hazy nights.

Between September 25 and October 1, ten out of eleven positions were observed at night, two positions on each for five nights. I might easily have completed the other position, but preferred in experimental observations to observe but two positions, or six series, on any one night. During the same time eight positions were observed by day.

Neither Bull Run nor Mount Marshall were seen from October 1 to 20 and 25, when observations upon them were completed.

Strecker did not begin to show until September 30, and Granite Hill on the next night; but another season of smoke set in, lasting nearly three weeks, and never giving us perfectly clear weather until just as we had *wrung* the observations out of the persistent haze, about the middle of November.

By dint of close watching, all observations were closed by the 3d November, except a few by day upon Wolf and Granite. These detained us until the 19th November.

The following table exhibits the time of beginning and closing observations on each station, and the number of days and nights on which each was observed:

	No. of days observed.	Between—	No. of nights observed.	Between—
Bull Run	8	September 25 and October 25	7	September 25 and October 20.
Marshall	7	September 25 and October 30	6	September 25 and October 25.
Wolf	11	October 20 and November 19	8	October 20 and November 3.
Granite	10	October 24 and November 19	9	October 1 and November 1.
Strecker	8	September 30 and November 3	8	September 30 and October 29.

Wolf was ready, but through some mistake did not show at the right time on October 1. We saw neither Wolf nor Granite between October 1 and 20.

These two stations showed the immense advantage which the magnesium light had over the French apparatus in hazy weather. While the magnesium light at Wolf Hill was clearly visible, sometimes to the naked eye and always in the telescope, when we could not make out the outline at sunset of either Wolf or Granite, the French light at Granite Hill could barely be seen in the telescope with all light cut off, and it would not bear light enough upon the cross-hairs to enable us to observe it. It was showing with full size of the objective of the collimator, 7.9 inches ($0^{m}.2$), Wolf showing with only 3.9 inches ($0^{m}.1$) diameter of reflector, or, in inches, the French light was showing with 50 square inches of reflecting surface, and the magnesium light with but 12 square inches of effective reflecting power. The French lights on clear nights made very pretty marks to point upon. The light was generally tinged with red, and had not intensity enough to trouble us with irradiation, while the white light of the magnesium would sometimes appear too large for delicate pointing, even when showing with a cap.

On all the lines and with all the lights, but Strecker, during the whole season, the same steadiness and clearness of outline was found that we had observed in North Carolina.

The line to Strecker ran near the surface, and crossed the Potomac twice. Exhalations from the surface and from the river caused greater irregularity in the observations upon this signal, both by day and night, than upon any other.

But the irregular motion or dancing by night never equalled that of the same signal by day.

I feel now sure that we may depend upon the hours from sunset to midnight, on every clear night, as good for observing; and I now fear lateral refraction at night so little that I should advise observation to be made as rapidly as possible, closing up the observations in as short a time as the weather will allow, instead of distributing the observations over a certain length of time to get rid of possible lateral refraction at any one time, as has been the general practice.

Lateral refraction, as a chief source of error in geodetic observations, was not suspected, so far as I can discover, until early in the present century. Delambre writes (Base Metrique, vol. 1, p. 106), "S'il existe une refraction latérale, comme J'ai été parfois, tenté de le croire," &c.

I take lateral refraction to be due to unequal heating, causing unequal density, of the different media through which geodetic lines of sight pass. If I am right, it follows that it is likely to be greatest during the day and least at night.

With the introduction of position-instruments with fixed circles of graduation, the signal could be followed, and its variation from its natural position noted by its different readings upon the limb, while, also, the phenomenon seems to be one occurring more during the day than during the night.

The French geometers adhered to the repeating circles long after American observers had given them up. English observers never used repeating circles.

As late as 1853, Colonel Peytier, in an elaborate description of different geodetic instruments then in use, gives the preference over position-instruments to repeating circles, (Memorial Du Dépôt Général de la Guerre, vol. 9, pp. 398–401). I have used too many repeating circles successfully to say one word against them. With care and constant attention, no better instruments can be found of a size from 6 to 12 inches ($0^{m}.15$ to $0^{m}.30$) diameter, but the successful use of them depends entirely upon the power of the clamps and tangent-screws to maintain immovable the relation of the verniers to the graduations during a series of repetitions. I do not believe this fixity of tenure can be maintained with instruments of greater diameter than 12 inches, and even with these the most vigilant care is necessary.

Position-instruments, of a size from 16 to 20 inches ($0^{m}.40$ to $0^{m}.50$) diameter, must take their place in all great geodetic operations. Also, while the French circles by Gambey and others are admirably graduated and constructed, their telescopes are always too small, and have not sufficient space-penetrating power.

My methods of observing were those usual in my party for the past twelve years. They are all directed to the solution of the problem "What are the most probable directions of certain lines?" which is the question we have to solve with all "direction" or "position" instruments. All observations are referred to the "initial point" or "reference mark," which enters into every series observed.

I have found by the experience of many years that eleven positions, with three series in each position, gives a resulting relation of the station observed to the mark, with a precision having a mean probable error of less than $0''.2$ to the mean, and less than $1''$ for any single result.

The 20-inch ($0^{m}.5$) theodolite, No. 113, used by me has three microscopes and micrometers, reading to seconds. As each series consists of a pointing, telescope direct, and a pointing, telescope reversed, upon each signal in the series and upon the mark, twelve different graduations are read upon in each case. In the first position, the microscopes are set to read 0°, 120°, 240°, nearly, upon the reference mark, when three series are observed, and the reading upon each signal recorded.

Then the microscopes are set to read $\frac{360}{11}^{\circ}$, 32° 43′.6, nearly, from the first reading, and three series are again observed in Position II.

Position III and the others follow, the microscope being set at 2 ($\frac{360^{\circ}}{11}$), &c., upon the mark in each new position.

Eleven positions are taken because it is a prime number and is not a factor of two or of three (*two* positions of the telescope direct or reversed and three microscopes).

It follows that the final direction is the mean of thirty-three series, read upon one hundred and thirty-two different graduations, and that it has not been possible that the same graduated division shall have entered twice into the result.

This method was pursued with the day and night observations, which were kept as distinct as if made at separate stations. The only difference was that at night the cross-hairs of the telescope were illuminated by a small lamp attached to one of the pillars supporting the theodolite, with a counterpoise weight attached to the other pillar, and the microscopes were read by a lantern with three square sides of plane glass and a metal slide or door upon the fourth side.

The method of reading with this form of lantern was practiced by Professor Bache after 1844, and has been since by all observers taught in his school. It throws a square light upon the reflector attached to the microscope and gives a minimum of heat, and no opportunity for possible side lights and shadows at irregularly cut divisions, while it has the merit of the greatest simplicity.

The telescope of theodolite No. 113 has good defining and space penetrating power. Of its three eye-pieces I have used the lowest power of 58 as best suited for observations upon points in the horizon. With this description of the means employed I now give the resulting directions obtained from the observations:

Stations.	Observed directions, day.	r	R	Night.	r	R
	° ′ ″	″	″	″	″	″
Mark	0 00 00.0					
Bull Run	45 27 15.642	0.52	0.094	15.927	0.47	0.082
Mount Marshall	65 36 50.710	0.83	0.151	50.712	0.69	0.118
Wolf	207 46 15.497	0.77	0.133	15.233	0.69	0.120
Granite	209 55 11.224	0.54	0.095	11.115	0.51	0.088
Strecker	338 23 34.873	0.75	0.130	34.830	0.88	0.153
		0.68	0.121		0.61	0.112

All are indiscriminate means of 33 series in 11 positions. They are direct results from the observations corrected for run of the microscopes, but not combined by least squares; r and R represent the probable errors of a single result and of the means.

If the means and probable errors of positions are taken, the resulting directions will be the same, but the probable errors will be as follows:

Stations.	Day.	r′	R′	Night.	r′	R′
	″	″	″	″	″	″
Bull Run	15.642	0.41	0.123	15.927	0.36	0.108
Mount Marshall	50.710	0.57	0.181	50.712	0.38	0.115
Wolf	15.497	0.71	0.213	15.233	0.58	0.174
Granite	11.224	0.42	0.126	11.115	0.38	0.115
Strecker	34.873	0.65	0.197	34.830	0.80	0.241
		0.55	0.168		0.50	0.151

in which r′ and R′ represent the probable errors of the mean of a position and of eleven positions The indiscriminate mean best represents the observations, but I give both for the purpose of comparison.

The discrepancies in the resulting directions of Bull Run and Wolf stations by the day and night observations seem to be accidental at Wolf, but at Bull Run eight out of eleven positions give a larger angle with the mark by night than by day. I am wholly unable to give any reason for this difference. So far as the observations are concerned, they are all of equal value and all appear good. The night results fill all triangles better than the others, but there is no other reason for giving them preference.

It will be seen that the probable errors incline slightly to the side of the night observations, but the difference is so small that I am inclined to give them equal weight and to consider the relative precision as equal.

I desire in this connection to repeat and emphasize the statement, that each series observed by day has been simply a duplicate of another series observed at night.

The instrument, the observers, the methods of reading and pointing, and all conditions dependent upon the modes of observing have been absolutely identical.

The only differences have been in the character of the signals observed and in the times of observation.

At Granite and Strecker the heliotrope by day was also the light at night. At the other stations the utmost care was taken that the light at night should be in the identical line of the heliotrope and an eccentricity exceeding 0.39 inch ($0^{m}.01$) was impossible.

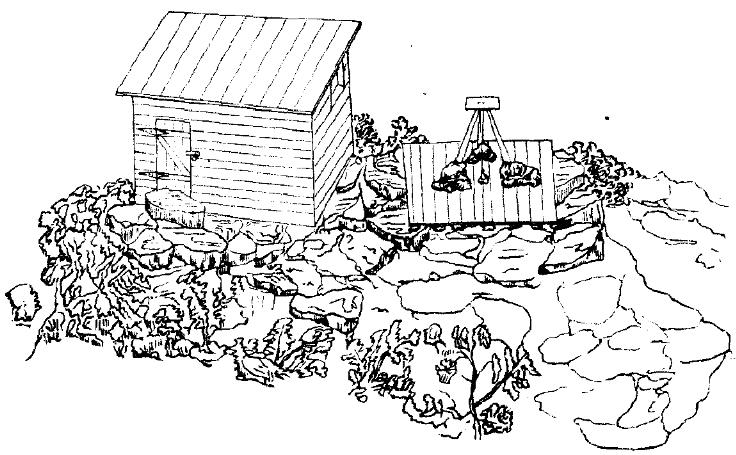
I have mentioned, on page 97, that in 1874 I had fitted up two "student lamps" with reflectors, but that my partial trial with them was not successful. These had been set up at Sugar Loaf Mountain for illumination of our camp in observing nights. The degree of intensity of light from them compared so favorably with that of the French apparatus that I was led to believe the trial in 1874 to have been not altogether a fair one.

On the 10th November, when all observations were nearly completed, I sent Mr. J. B. Boutelle, with one of these lights, to Bull Run Mountain, distant 31.1 miles (50 kms.), to test it. He arrived at the mountain on the 11th, at sunset. I, looking southwest, was barely able to make out the faintest possible outline of Bull Run Mountain, and Mr. Boutelle, looking northeast, could not see anything of Sugar Loaf. But he placed his light upon the heliotrope stand and pointed it at the range-mark used in heliotroping.

To my great surprise and delight, it was at once visible in the telescope at Sugar Loaf, showing clear, bright, small, round, and steady, bearing the full illumination of the cross-hairs, which neither of the French lights would bear. Its brightness was about that of a fourth-magnitude star in the same telescope. Like the magnesium, or any other reflector lamp, the front must be closed by a plane-glass cover on windy nights. A meniscus lens is best, but a box with a pane of glass in front answers very well.

It is cheap, simple, and easily carried. It is capable of manipulation by any person of fair intelligence. That it can be correctly pointed is shown in this case. I think it may be used to advantage wherever the French light can be, or for all distances up to 43.5 miles (70 kms.). Beyond that, it will be safest and cheapest to use the magnesium reflector.

The experience of the season enables me to state with some precision the cost of the magnesium light, so much superior to every other yet tried. The success, in two instances, of burning the light by a time-table, established that method as perfectly practicable. It reduces the time of burning it to 20 minutes per hour, or to 80 minutes for 4 hours of observation. With a delivery of ribbon of 15 inches per minute, the cost will be $2 per night for each light used. The average number of primary stations observed upon at any one station is six, of which three would require the magnesium light, making the expense $6 per night. The nights when observation would be practicable and the lights burned may be taken as averagin three in a week, or seven nights at each station.



View of heliotrope stand and hut from which magnesium light was shown at Mount Marshall.

Of course, an attendant must be paid for where any form of night-signal is used. We have usually paid our heliotropers $1 per day, without subsistence. I found no difficulty last season in employing the same men for night duty at an additional pay of fifty cents per night, or $3 for six stations.

The cost of putting up small huts at each station, like that here shown, and providing material needed, may be estimated at $20 each.

Apart from the first cost of apparatus, we should therefore have as the additional daily cost of night observation for a primary triangulation—

1. Additional pay of six heliotropers	$3 00
2. Additional cost of burning three magnesium lights every other night	3 00
3. Additional cost of kerosene oil for three lamps	20
4. Additional cost of building and supplying six huts, at $20 each, in a surveying season of five months	80
Whole additional daily cost	7 00

To offset this additional party expense there will be—

1. The shortening of time required in occupation of each station by the addition of four observing hours after sunset on each clear day. The average time of observation by day being two hours, this time will be tripled on each clear day and night.

2. Necessity for encamping at many stations may be avoided, where now the probabilities of a long detention and the lack of any decent quarters within a reasonable distance require the transportation and use of equipage.

3. Assuming the present average cost of each primary station to be $1,000, the occupation of only one more station in a season where night signals are used would pay the additional expense, but it is probable that at least three more stations will be occupied, and time, which is money, saved.

Much of this must be matter of estimate and conjecture, but I hope to demonstrate all I assert if I have three more seasons of observations, and am supported by you with the same generous confidence that you gave me last year. Under any circumstances, more time is now spent at every primary station in waiting than in observing. It is probable this must always be the case.

Colonel Peytier says (mémorial du Depot de la Guerre, Vol. 9, p. 389):

"With series observed under bad conditions, we risk altering the mean instead of bettering it. Geodetic stations being usually in high places, often far from villages affording any resources, one can understand in such circumstances the impatience of observers and their desire to finish their stations promptly. Nevertheless, if there is any one quality essential to an observer it is patience. With it and a good instrument he will always succeed in obtaining good results."

I am obliged to differ with M. M. Perrier and Bossot in their condemnation of reflectors and their substitution of "optical collimators." They say, as I have quoted on page 101: "For night signals we have given up the use of reflectors, which could not always be exactly pointed, are difficult to keep in adjustment, and must have considerable dimensions when the sides of triangles are from 40 to 50 kms. (25 to 31 miles) long, and we have adopted the use of optical collimators."

These eminent observers state in reference to reflectors: 1. They cannot always be correctly pointed; 2. They are difficult to keep in adjustment; 3. They require large dimensions when showing upon sides of 40 to 50 kms.

These statements are erroneous, as my experience tends to disprove them. I will, however, take the statement in detail and give evidence that reflectors can be correctly and easily pointed; that they have few and simple adjustments, not easy to put out of order, and that they are visible to the naked eye at 37.3 miles (60 kms.) with a diameter of 3.9 inch ($0^m.1$) when the light of M. Perrier's "optical collimator" with a diameter of 7.9 inches ($0^m.2$) could not be seen in the telescope.

Examining the drawing of the magnesium lamp, a pointer will be noticed under the middle of the reflector. A line is drawn upon the top of the stand placed over the station point in the vertical plane passing through that point and the station to which the lamp is to be shown. The foot-screw behind the clockwork and the pointer under the reflector are placed in this line, and the front face of the reflector is made vertical by the foot-screw. This is all the pointing necessary, and it has not failed to direct the light accurately and render it visible at distances from 31.1 to 65.2 miles (50 kms. to 105 kms.).

None of the reflectors used are true paraboloids; all have more or less divergence of rays. So great is this divergence that the heliotroper at Bull Run complained that he saw the time-signal flashed from Sugar Loaf to Mount Marshall and was confused by it. Looking at the directions on page 105, it will be seen that the angle at Sugar Loaf between Bull Run and Marshall is over 20°. Exact pointing with it is not, therefore, as necessary as it is with the French optical collimator.

The other reflector with the "student lamp" is pointed in an equally simple manner. That it is effective is shown in the account of our experiment with it previously given.

The only adjustments of the magnesium reflector light are to keep it wound up, occasionally to adjust the spring shown at the top of the clockwork, to keep the delivery of the tape at 15 inches (0.38) per minute (which is done by the officer posting the heliotroper), and to keep correctly pointed the direction of the line upon the stand in which the foot-screw and pointer are placed. This can be tested on every clear day with a couple of pins. Also, to keep the time-piece wound up and to set it every night by the time-signal given from the observer's station. The person in charge has then simply to sit by his light and extinguish it at the time given in the time-table for him to "begin" and "stop."

All this has been successfully done at Bull Run, Mount Marshall, and Wolf Stations by uneducated men of ordinary intelligence after a very short training. The apparatus is packed in a box 16 by 14 by 16 inches, with clock, lantern, and other needed accessories, the whole weighing, when packed complete, 40 pounds. The "student lamp" has still simpler adjustments. It is aligned by placing one foot-screw and a pointer under the center of the instrument upon the line on the top of the stand representing the line of sight. The front edge of the reflector is set parallel to the supporting rod and perpendicular to the line of sight, and it is levelled by the foot-screws. It is inclosed in a box having a plane-glass front to keep the flame steady in windy weather, and, being lighted at sunset, rarely requires any further attention up to midnight. Packed in its box for transportation, the whole weighs 25 pounds. From our test of it in very thick weather, at 31.1 miles (50 kms.) distance, I think we may rely upon it in clear weather up to 43.5 miles (70 kms.).

With regard to larger dimensions of reflectors, at distances from 25 to 31 miles (40 to 50 kms.), I have already stated that the magnesium reflector of the same size as the object-glass of the collimator, 7.9 inches or ($0^m.2$), was visible to the naked eye in June, 1877, at distances of 39.1 and 65.2 miles (63 and 105 kms.) in the moonlight. Again, in October, 1877, it was observed for three successive nights at 35.4 and 58.4 miles (57 and 94 kms.), being always visible to the naked eye. From Sugar Loaf Mountain to Bull Run and Wolf Stations the distances are 31.1 and 40.4 miles (50 and 65 kms.). At these stations the aperture of the reflector was diminished to $0^m.1$, but the lights were always visible in the telescope, and often to the naked eye, when the smoke was so dense that the outline of the distant station could not be seen at sunset.

The "student lamp," with a reflector $0^m.2$ diameter, was visible in the telescope at 31.1 miles (50 kms.) distant, when the outline of the mountain was invisible at sunset, and the smoke continued all night.

The French lights as received from France weighed each, packed for transportation in two boxes, 280 pounds. I have already described these lights and their power as I used them. Alterations are now being made by which I hope largely to increase their effective power, while reducing the weight to about 100 pounds, and rendering them more convenient for transportation and use.

I hope after the experience of the coming season to be able to make a decisive report on their use. Any lamp burning coal-oil steadily, with effective power upon long sides, whether reflector or collimator, will be a gain upon the magnesium in point of cost and convenience, but I very much doubt if it can be obtained. But some other and cheaper form of intensified light, equally capable of management by uneducated persons, and equally simple in its details, may very possibly be discovered.

The conclusions to which the experiments and results at Sugar Loaf Mountain have led me may be generally summed up as follows:

1. That night observations are a little more accurate than those by day, but the difference is slight thus far.

2. That the cost of apparatus is less than that of good heliotropes.

3. That the apparatus can be manipulated by the same class of men as those whom we employ as heliotropers; that is, ordinary residents of the locality, of fair intelligence without education.

4. That the average time of observing in clear weather may be more than doubled by observing at night, and thus the time of occupation of a station proportionately shortened; "clear-cloudy" weather when heliotropes cannot show may be utilized at night.

5. That reflector lamps, or optical collimators, burning coal-oil, as already described, may be used to advantage on lines of 43.5 miles (70 kms.) and under. But for longer lines the magnesium light will be best and cheapest, as being most certain.

6. That for the present we should keep up both classes of observations, both by day and night, and that the observers in charge of the various triangulations should be informed of the progress already made, and encouraged and stimulated to improve on the methods and materials thus far employed in night observations.

Sketch showing relative positions of Stations observed from Sugar Loaf Mountain

1879

Statute Miles

Kilometers

Day and Night stations in full lines.

Day stations in broken lines.

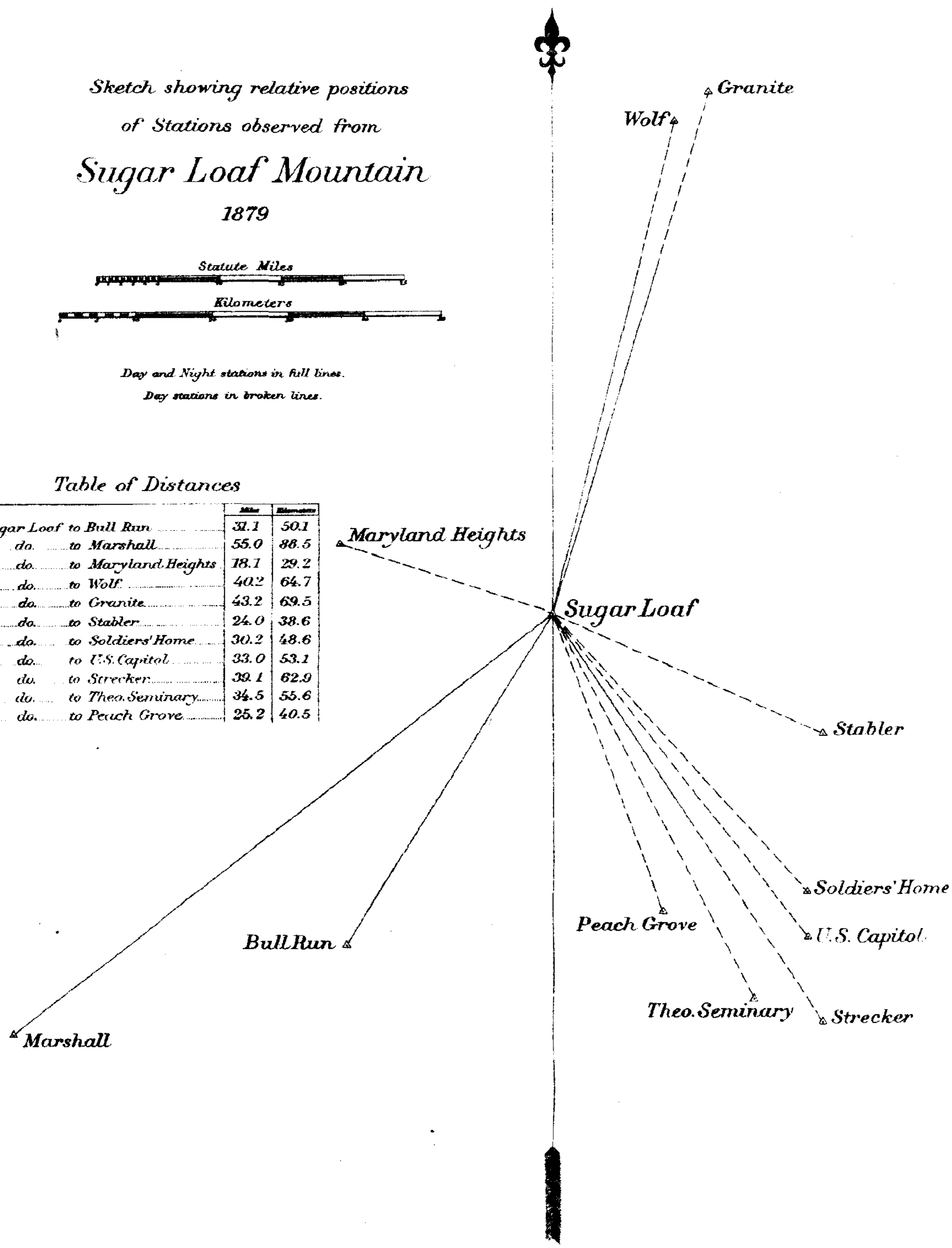
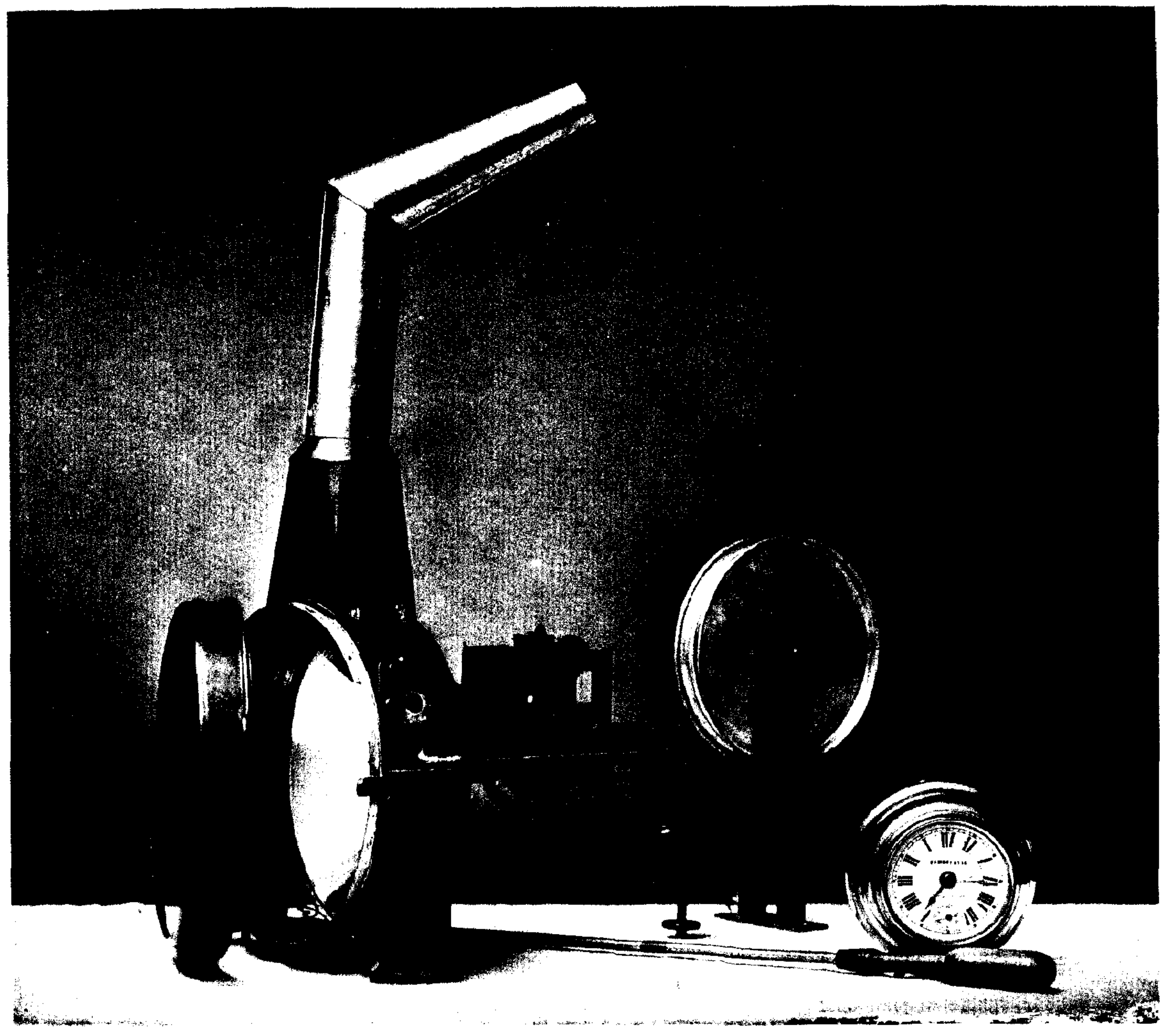


Table of Distances

	Miles	Kilometers
Sugar Loaf to Bull Run	31.1	50.1
do. to Marshall	55.0	88.5
do. to Maryland Heights	18.1	29.2
do. to Wolf	40.2	64.7
do. to Granite	43.2	69.5
do. to Stabler	24.0	38.6
do. to Soldiers' Home	30.2	48.6
do. to U.S. Capitol	33.0	53.1
do. to Strecker	39.1	62.9
do. to Theo. Seminary	34.5	55.6
do. to Peach Grove	25.2	40.5



Magnesium Reflector Light for Geodetic night-signals, as used in 1879.

7. That to carry out (6), five more magnesium lamps and eight more student lamps be fitted up, giving us ten of each, or enough for three parties, that the method may be fairly tested.

The estimated cost would be:

For five magnesium lamps, including clocks, lanterns, and packing boxes...	$250 00
For eight student lamps, with reflectors and foot-screw stands, lanterns, and packing-boxes complete for use........	160 00
Total	410 00

Five pounds of magnesium tape, in tin reels of 2 ounces or 80 yards each, were purchased last season. Of this about two-thirds is still on hand, affording a sufficient supply for two parties for another season.

Yours, respectfully,

CHAS. O. BOUTELLE,
Assistant, United States Coast and Geodetic Survey.

APPENDIX No. 9.

COMPARISON OF THE SURVEYS OF DELAWARE RIVER IN FRONT OF PHILADELPHIA, 1843 AND 1878.

BY H. L. MARINDIN, Assistant.

UNITED STATES COAST AND GEODETIC SURVEY,
Boston, Mass., November 15, 1880.

DEAR SIR: In accordance with your instructions, I have made a comparison of the surveys of the Delaware River in front of Philadelphia, one executed in 1843 by Lieut. G. S. Blake, U. S. N., and the other in 1878, by a party under my charge, in steamer Fathomer.

The comparison extends from Bridesburg to Fort Mifflin, and is contained in the four charts accompanying this report. These charts have been reduced from the original scale of the survey of 1878—1-4800, to a scale of 1-10000. Tracing No. 1 represents the changes in the Delaware River between Bridesburg and Kensington; No. 2, from Kensington to Kaighn's Point; No. 3, from Kaighn's Point to the Horseshoe; and No. 4, from the Horseshoe to Fort Mifflin. (See charts accompanying this report numbered 38, 39, 40, and 41).

The charts contain the following data:

1. The position of the shore, wharf, and low-water lines of 1843.
2. The position of the same lines in 1878.
3. The differences in depth, 1843 to 1878, with the corresponding volumes shoaled or deepened.
4. The position of the line of mid-area, which divides the stream into two parts of equal cross-section.
5. The position of the lines of maximum depth.

This comparison is based on the divisions of 30″ latitude by 30″ longitude; these were again subdivided into small rectangular figures, 2″.5 longitude by 2″.0 latitude, containing 39,426 square feet—something less than one acre. The mean of all the soundings within each small square was obtained for both surveys, and the difference noted, together with the corresponding volume in cubic yards.

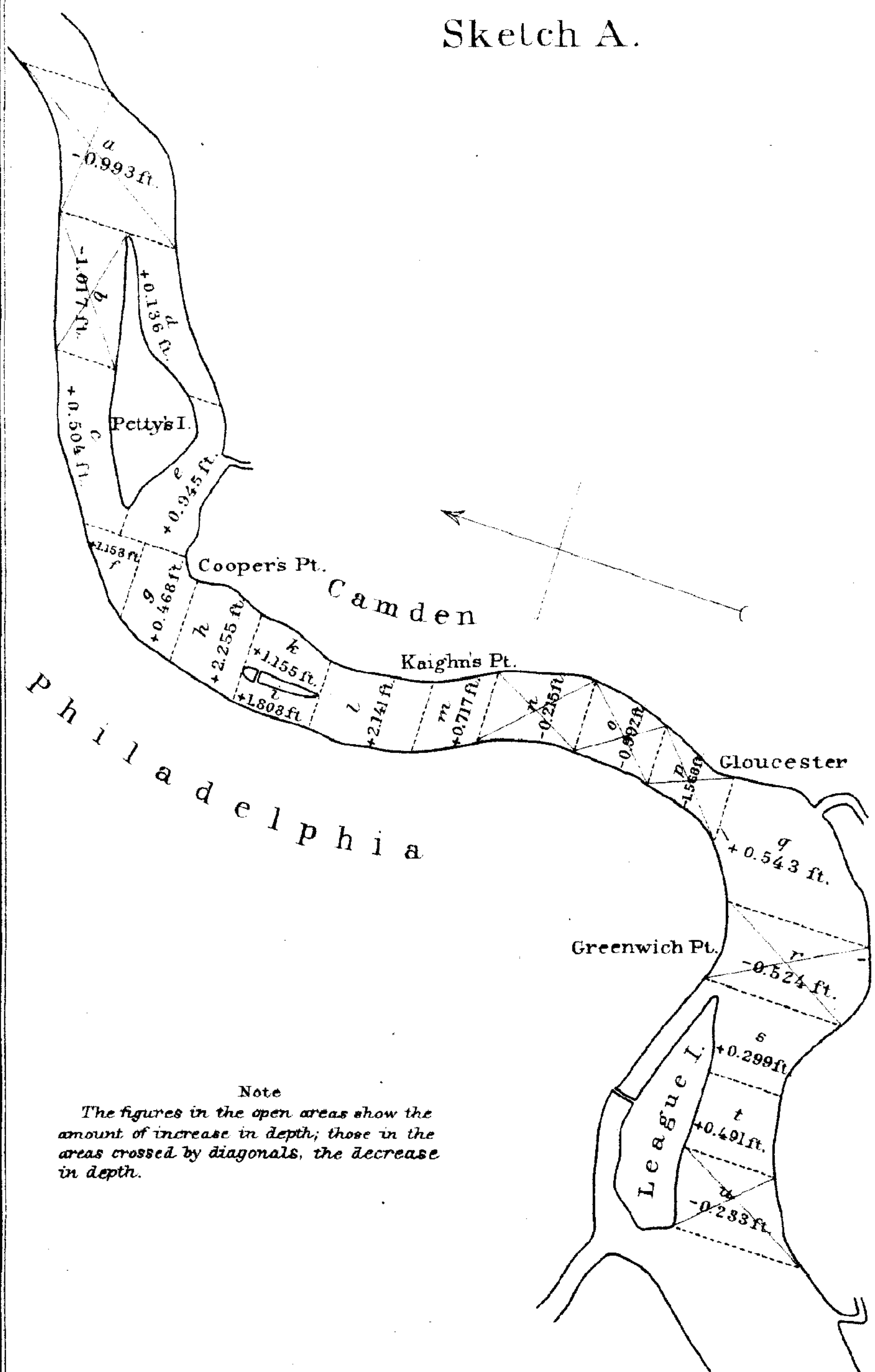
The examination of chart No. 1 shows marked changes, the most important of which is the extension of the shoal from the north channel of Petty's Island up river to Five-mile Point, where it connects with the shore, forming a bulkhead, with only 7 feet of water at mean low tide. Taking the 6-foot curve as a limit for the shoal, I find the extension to have been 4,740 feet in thirty-five years; over this distance, which, in 1843, nearly represented the entrance into Petty's Island (north) Channel from the eastward, there was a series of depths from 6 feet, increasing to 18 and 20 feet—this last depth where now the 6-foot limit of the shoal exists.

There are doubtless many causes which combined to effect this change, but I would suggest, as a reasonable one, the encroachments on the channel-way, at the lower end especially, and along Petty's Island (north) Channel. The current observations of 1878 show this to be a flood-channel mainly; therefore any diminution of the cross-section, obstructing the free admission of the flood current, will have a tendency to effect the change observed.

In sketch A (No. 42) is given the mean amount of shoaling or deepening over short reaches of the river. It will be seen that a large amount of shoaling has taken place in the eastern half of the north channel, and indeed as far as Five-mile Point, whereas the western half of this same channel shows an increase in depth; this is again the effect of the diminution of section by encroachments. The tendency of the current is to restore the cross-section to its just area by deepening the channel; and the power of the flood current, instead of being unimpaired to keep the channel free in its entire length, is now spent in restoring the section to its proper dimensions in the vicinity of the encroachments.

The south channel shows an increase in depth throughout, although not large. Probably the

Sketch A.



Note

The figures in the open areas show the amount of increase in depth; those in the areas crossed by diagonals, the decrease in depth.

gradual closing of the passage into the north channel for the ebb stream must account for part of this amelioration of the south channel.

The blind channel-way between the north and south channel, close to the point of marsh at the eastern extremity of Petty's Island, has increased both in depth and in width, and may in time become the best outlet of the north channel to the eastward.

Chart No. 2 (numbered 39) shows also some changes. Shoaling has taken place along the south side of Petty's Island, between the low-water line and the 12-foot curve, averaging 1.5 feet over this area; but the deeper parts of this half of the south channel have deepened so much as to give a mean increase of depth over the whole of 0.945 foot.

There is a decided decrease of depth over the shoal off the north end of Smith's Island, with an extension of this shoal towards Cooper's Point. This seems, in a great measure, a repetition of the working of the Five-mile Point Shoal. The northern extremity of the Smith's Island shoal, as limited by the 6-foot curve, was 3,100 feet north of the island in 1843; in 1878 I found the northern extremity of this shoal 3,600 feet from the island—an extension of 500 feet in thirty-five years. The channel over the bulkhead at Cooper's Point has been reduced in consequence from 840 feet in width and 11½ feet of water at mean low tide to 230 feet in width and 8 feet depth of water—a decrease of both width and depth.

The mean change, however, over this part of the river as far as Kaighn's Point has been a general increase in depth varying from 0.46 foot to 2.10 feet, as shown in sketch A.

The changes to be noted over the shoal off the south end of Windmill Island show an exception to what seemed to be a rule so far; here I find a decided increase of depth, averaging 3.75 feet within the 12-foot curve as it now stands; the maximum increase over any one acre of area being 9.4 feet and the minimum 0.5 foot. This shoal seems to be effectually wearing away.

The Jersey shore shows some shoaling for a distance off the wharf line as it now exists; here, also, I find the greatest artificial advance of the shore line into the stream, in some cases as much as 1,160 feet. This encroachment on the stream has probably been the means of deepening the channel-way along its entire front from Cooper's Point to Kaighn's Point.

Chart No. 3 (numbered 40), from Kaighn's Point to the Horseshoe, containing nearly the whole of the last-named shoal, shows changes over the Greenwich Point middle ground. There is now 17 feet of water at mean low tide on the shoalest part of the ground, where one sounding of 16¼ feet occurs in the survey of 1843. Taking the 24-foot curve as the limiting line of this shoal, I find a mean increase of depth of 0.37 foot over the area inclosed, with a maximum shoaling of 0.6 foot on any one acre of surface, and a maximum deepening of 2 feet over a similar area. The above-mentioned increase is deduced from a comparison of 63 soundings found within the 24-foot curve. The shoal shows a slight elongation up and down stream with a decrease in its width.

The changes on the Horseshoe Shoal are more marked in its shoalest parts. Taking the 6-foot curve as the limit, with its upper end terminating at the northern extremity of the slough channel, I find a mean shoaling of 2.61 feet over the entire surface inclosed within the limiting curve, with a maximum shoaling of 6.3 feet in any one acre of surface. The slough channel back of the Horseshoe has deepened materially, with a maximum deepening of 5.1 feet in any one acre of surface.

At the lower end of the Horseshoe the shoaling is decided, and extends nearly across the river in the direction of Eagle Point.

Chart No. 4 (numbered 41), from Horseshoe to Fort Mifflin, gives the changes at the western end of the Horseshoe, spoken of above, and such changes as have obtained along the water-front of League Island and at the mouth of the Schuylkill River. An increase of depth can be shown along the larger part of the south side of League Island, but the depths on the Jersey shore seem to have decreased, extending over the shoalest part of the shoal on which Fort Mifflin light-house stands; in examining the depths within the 6-foot curve, I find an average shoaling of 3 feet over the area inclosed.

At the mouth of the Schuylkill River the differences in depth are very large, reaching in some few cases 19 and 22 feet increase. These very large differences must be attributed mainly to the dredging which has been resorted to, to improve this outlet.

In sketch A is given the average shoaling or deepening over limited spaces of the river.

While explaining this sketch I will give some results taken out of tables 1 and 2, in which is given the average change in the depths in a belt 400 feet wide, situated along the line of mid-area (200 feet on each side of the line), and along the lines of maximum depth. The position of these lines is given on the charts 1 to 4, as also the point of intersection with the cross-sections, which points are noted in the tables for purposes of location.

Beginning at Five-mile Point, sketch A shows an average decrease in depth of 0.993 foot as far as the upper end of Petty's Island. Within this space section *a*, the belt along the line of mid-area, shows an increase of depth of 5.3 feet, and along the line of maximum depth, in the Five-mile Point channel, a decrease in depth of 1.02 feet, while the maximum depth belt in the Jersey shore channel gives an increase of 4.86 feet. Going down the north channel, section *b* shows an average shoaling of 1.017 feet in the upper half of this channel, the mid-area belt gives an increase of 1.23 feet, and the maximum depth belt no changes.

The western half of the north channel, section *c*, gives an average increase of 0.504 foot, the mid-area belt an increase of 1.05 feet, and the maximum depth belt an average deepening of 1.53 feet.

The south Petty's Island channel gives for its upper half, section *d*, an average increase of 0.136 foot, for mid-area belt an increase of 0.84 foot, and for maximum depth belt an average deepening of 0.50 foot. The lower half of the channel, section *e*, gives an average deepening of 0.945 foot, for mid-area belt 2.3 feet increase, and for maximum depth belt an average deepening of 1.45 feet.

Off the western end of Petty's Island, sketch A shows a small triangular section, *f*, with an average increase in depth equal to 1.153 feet. This section was cut off from section *g*, the Cooper's Point section, in order to embrace in the latter more specifically the changes which have taken place at Cooper's Point and immediate vicinity. The mid-area belt in section *f* shows an increase in depth of 2.55 feet, and the maximum depth belt an increase of 1.46 feet.

Section *g*, at Cooper's Point, gives an average increase of 0.468 foot, the mid-area belt one of 1.76 feet, while the maximum depth belt on the Philadelphia side gives a large increase of 2.34 feet, and the maximum depth belt over the bulkhead at Cooper's Point an increase of only 0.18 foot. Below this, in section *h*, as far as Smith's Island, I find the largest average deepening of any section of the river, equal to 2.255. feet; the mid-area belt also gives the largest amount of change, equal to an average deepening of 7.31 feet, whereas the maximum depth belt on the Philadelphia side shows an average shoaling of 1.16 feet, and on the Jersey side a large increase of 4.51 feet, so that, of the two channel-ways, the one on the Jersey shore side has had the greatest amelioration.

I have mentioned previously the marked shoaling on the Smith's Island shoal, within this section.

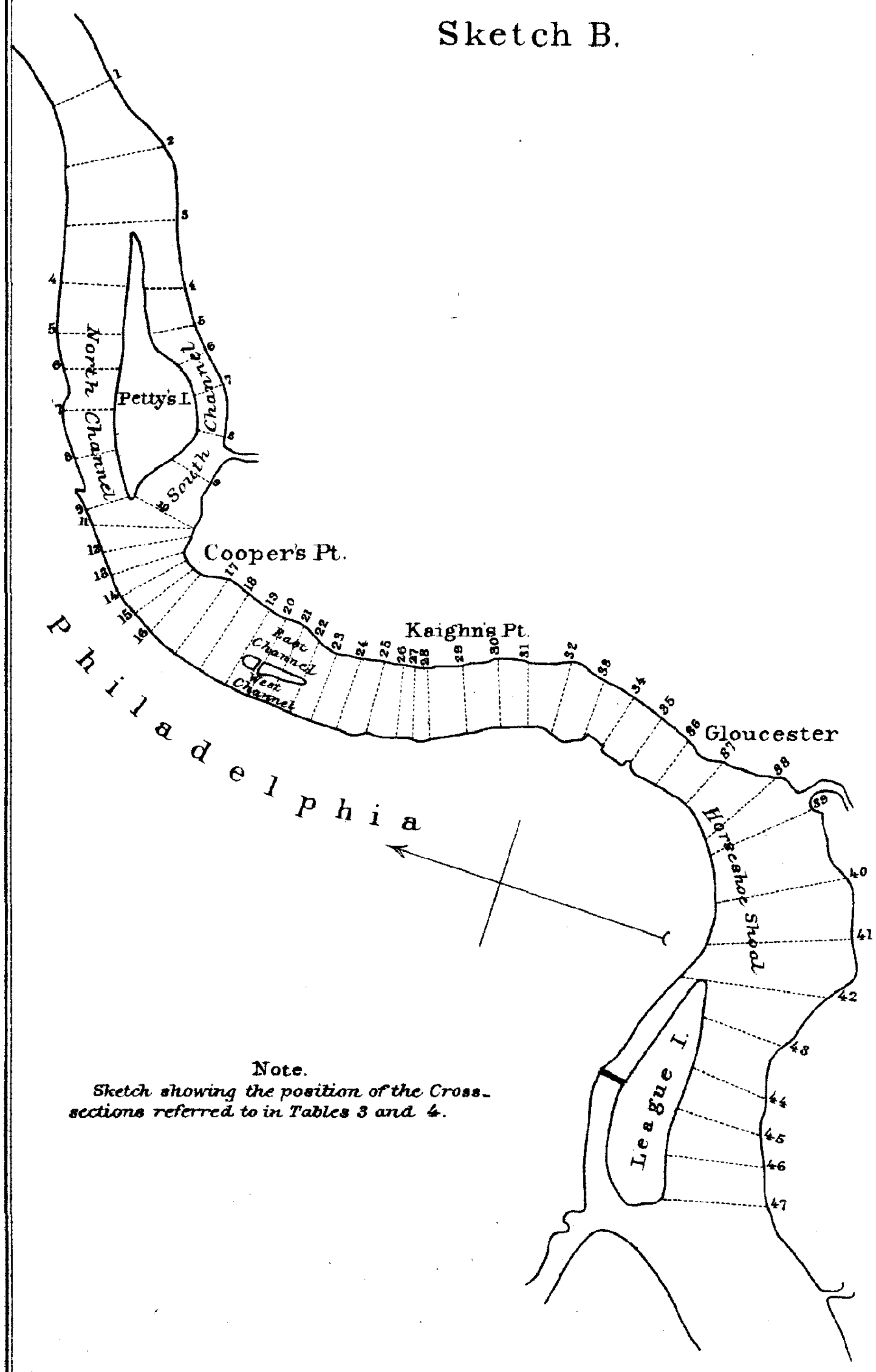
The east and west Windmill Island channels show a decided average increase of depth, respectively, 1.155 feet and 1.808 feet. In the western channel the mid-area belt has deepened 2.3 feet, and the maximum depth belt 3.44 feet. In the eastern channel the mid-area belt has deepened 4.1 feet, and the maximum depth belt 4.72 feet.

From the south end of Windmill Island to Kaighn's Point, section *l*, the average deepening has been large, equal to 2.141 feet. Nearly the entire width of the river shows an improvement. In this section is situated the shoal off the south end of Windmill Island previously mentioned. The mid-area belt shows an increase of 4.7 feet in depth, and the maximum depth-belt on the Philadelphia side gives a deepening of 5.10 feet, and on the Jersey side a similar change of 4.26 feet.

The next section below Kaighn's Point, *m* of sketch A, shows a falling off in the amount of change. This shows an increase of 0.717 foot, with a mid-area belt 3.50 feet deeper, and an increase in the maximum depth-belt on the Pennsylvania side of 1.75 feet, and on the Jersey side an increase of 1.37 feet.

Section *n* is the second section, which shows an average shoaling in the main stream. This shoaling augments as the river becomes narrower, until Gloucester is reached, when it changes again to an increase in the widest part of the river yet observed. In section *n* an average shoaling of 0.215 foot is obtained, while the mid-area belt still shows an increase of depth of 1.96 feet, with a maximum depth belt increase of 1.55 feet on the Pennsylvania side and of 1.84 feet on the Jersey side. These differences show the shoaling to have taken place more particularly on the face of the banks of both shores, reaching in two cases a maximum change of 11.5 feet and 18.8 feet.

Sketch B.



Note.
Sketch showing the position of the Cross-sections referred to in Tables 3 and 4.

In section *o* we have a larger average shoaling, equal to 0.992 foot; the mid-area belt shows scarcely any change, while the maximum depth belt on the Pennsylvania side has an average shoaling of 1.30 feet, and on the Jersey side an increase of depth of 0.44 foot.

Section *p*, off Gloucester, shows a still larger average shoaling, equal to 1.563 feet, with a shoaling in the mid-area belt equal to 0.23 foot; here the maximum depth lines, which have been separate from the starting-place at Five-mile Point, unite, and give an average shoaling of 1.32 feet in this section, so that the shoaling may be said to have been very general across the bed of the river.

We now come to the widest part of the river, section *q*, with an average increase of depth of 0.543 foot; the mid-area belt, however, still gives a shoaling of 0.61 foot, and the maximum depth-belt also a decrease of 0.13 foot. These lines nearly coincide in this section, and run about in the middle of the 24-foot channel; the shoaling within these belts, with a general increase over the whole section, shows that the channel-way has lost what the shore depths have gained. The eastern half of the Horseshoe shoal lies in this section.

The next section, *r*, as far as League Island, indicates an average shoaling of 0.524 foot; the mid-area belt gives a very large shoaling of 4.5 feet, and the maximum depth belt a decrease of 1.17 feet.

The mid-area line, owing to the extensive flats on the Jersey shore, runs almost on the edge of the Horseshoe shoal, where greater changes are found than obtain in the bed occupied by the belt of maximum depth.

The next section, *s*, embraces about one-third of the League Island shore, and shows an average increase of 0.299 foot, while the mid-area belt gives a decrease of 1.75 feet, and the maximum depth belt a shoaling of 0.77 foot.

The section off the middle of League Island gives a larger increase of depth than the previous one, equal to 0.491 foot, with a corresponding increase in the mid-area belt of 1.05 feet, and also in the maximum depth belt equal to 0.66 foot.

Section *u*, the last division off the western end of League Island, once more changes to a general shoaling of 0.233 foot, with a 0.95-foot shoaling in the mid-area belt, and a similar change of 0.35 foot in the maximum depth belt. This section includes a large part of the shoal on which Fort Mifflin Light-house stands, which has previously been shown to have shoaled extensively.

The average change along the entire mid-area belt, from Five-mile Point to the mouth of the Schuylkill River, by way of Petty's Island (north) channel and Windmill Island (west) channel, is an increase of depth of 1.642 feet.

The change in the same belt by way of Petty's Island (south) channel and Windmill Island (east) channel is an increase of 1.759 feet.

The changes in the maximum depth lines from Five-mile Point along the Philadelphia shore to section *p*, in sketch A, where a junction takes place, is an increase of 1.12 feet.

For the belt along the Jersey shore, as far as section *p* in sketch A, there is an increase of 2.33 feet.

From Gloucester, section *p*, the average change in the maximum depth belt, as far as the Schuylkill, shows an average shoaling of 0.29 foot.

The change in the maximum depth belt for the entire distance—Five-mile Point to the mouth of the Schuylkill River, on the Philadelphia shore—is an increase of depth of 0.68 foot, and by way of the Jersey side of the stream, an increase of depth of 1.54 feet.

In the foregoing comparisons I have confined myself to the present limits of the river, as defined by its present shore and wharf lines.

All of which is respectfully submitted.

HENRY L. MARINDIN,
Assistant, Coast and Geodetic Survey.

Hon. CARLILE P. PATTERSON,
Superintendent United States Coast and Geodetic Survey, Washington, D. C.

TABLE 1.—MID-AREA BELT.

Average differences in depth, in belt 400 feet in width, along line of mid-area, 1843 to 1878.

Positions.—Intersections of cross-sections.	Differences in depth. Deepened, + Shoaled, −
Nos. 1 to 3.—*From Five-mile Point to upper end of Petty's Island.*	
	Feet.
At section 1	− 1.1
	− 0.4
	+ 9.4
	+12.3
	+ 7.9
	+ 7.8
At section 2	+ 8.6
	——
	+ 9.6
	+ 8.9
	+ 5.5
	+ 3.9
	+ 2.2
At section 3	+ 4.1
Nos. 4 to 9.—*In Petty's Island north channel.*	
At section 4	+ 0.3
	+ 0.1
	+ 1.1
	——
	+ 1.5
	——
At section 5	+ 0.7
	+ 3.7
	− 1.2
At section 6	+ 0.2
	+ 3.3
	+ 2.3
	+ 1.5
At section 7	+ 0.4
	+ 1.8
	+ 0.9
At section 8	+ 0.9
	+ 1.1
	+ 0.1
At section 9	+ 1.2
Nos. 4 to 10.—*In Petty's Island south channel.*	
At section 4	− 0.7
	+ 1.7
	− 0.1
At section 5	+ 0.6
	− 2.4
Nos. 4. to 10.—*In Petty's Island, south channel*—Continued.	
	Feet.
At section 6	− 1.2
	+ 2.4
	+ 4.9
At section 7	+ 2.5
	+ 0.7
	+ 0.8
	+ 0.3
At section 8	+ 0.6
	± 0.0
	+ 1.8
	+ 6.2
	+ 1.8
	+ 5.2
	——
	+ 3.2
	+ 3.3
At section 10	+ 1.9
Nos. 11 to 19.—*From Petty's Island to Windmill Island.*	
At section 11	+ 0.7
	——
At section 12	+ 1.7
	+ 2.7
At section 13	+ 5.1
	+ 4.2
At section 14	+ 2.3
At section 15	+ 2.9
	+ 0.8
At section 16	± 0.0
	+ 0.4
At section 17	+ 2.8
	+ 4.9
	+ 8.9
At section 18	+12.1
	+ 9.3
At section 19	+ 5.9
Nos. 20 to 22.—*In Windmill Island west channel.*	
At section 20	+ 1.8
	+ 6.3
At section 21	+ 2.2
	+ 0.6
At section 22	+ 0.6
Nos. 20 to 22.—*In Windmill Island, east channel.*	
	Feet.
At section 20	+ 3.9
	+ 4.3
At section 21	+ 3.8
At section 22	+ 4.3
Nos. 23 to 47.—*From Windmill Island to south end League Island.*	
At section 23	+ 2.2
	+ 6.8
	+ 9.4
At section 24	+ 5.2
	+ 6.2
At section 25	+ 4.4
	+ 1.0
	+ 4.0
At section 26	+ 4.2
	+ 2.4
At section 27	+ 6.0
At section 28	——
	+ 3.8
	+ 5.6
At section 29	+ 2.7
	+ 2.2
	+ 2.9
At section 30	+ 3.8
	——
	+ 1.2
	+ 3.5
At section 31	+ 1.6
	+ 3.2
	+ 0.4
At section 32	+ 1.9
	+ [illegible].1
At section 33	+ 0.2
	− 0.4
	− 1.7
At section 34	− 1.1
	+ 0.3
At section 35	+ 2.3
	− 1.2
	+ 0.1
At section 36	+ 0.1
	− 2.2
	+ 0.6
Nos. 23 to 47.—*From Windmill Island to south end League Island*—Continued.	
	Feet.
At section 36	+ 1.0
At section 37	+ 1.2
	− 1.5
	− 0.1
	+ 0.9
At section 38	——
	+ 4.0
	——
	− 1.0
At section 39	——
	+ 1.9
	− 1.2
	− 1.5
	− 1.8
At section 40	− 2.7
	− 4.4
	− 5.8
	− 3.3
	− 5.8
At section 41	− 3.2
	− 4.1
	− 0.6
	− 8.7
At section 42	− 3.2
	− 1.8
	− 5.7
	− 0.6
	± 0.0
At section 43	+ 0.2
	——
	− 1.2
	± 0.0
At section 44	+ 2.2
	+ 1.3
	+ 2.6
	− 0.2
	− 0.1
At section 45	+ 2.0
	+ 0.6
	+ 1.9
	− 0.8
	+ 0.5
At section 46	− 1.7
	− 1.0
At section 47	− 4.6

TABLE 2.—MAXIMUM-DEPTH BELT.

Average differences in depth, in belt 400 feet in width, along the lines of maximum depths, 1843 to 1878.

Positions.—Intersections of cross-sections.	Differences in depth. Deepened, +; Shoaled, −
Nos. 1 to 4.—*From Five-mile Point to Petty's Island, Pennsylvania side.*	
	Feet.
At section 1	+ 7.9
	− 3.2
	− 7.0
	− 1.9
	——
	− 3.9
At section 2	− 1.1
	− 0.8
	− 1.3
	——
	+ 2.1
	− 0.9
At section 3	± 0.0
	+ 2.0
	− 1.5
	− 3.1
	+ 0.5
At section 4	+ 0.3
Nos. 4 to 9.—*In Petty's Island north channel.*	
At section 4	+ 0.3
	+ 0.1
	+ 1.1
	——
	+ 1.5
	——
At section 5	+ 0.1
	——
	− 0.5
At section 6	——
	+ 6.8
	——
	+ 0.3
At section 7	+ 0.2
	+ 0.6
	+ 0.5
At section 8	+ 0.6
	+ 3.4
	+ 1.9
	+ 1.0
At section 9	+ 2.0
Nos. 9 to 19.—*From Petty's Island to Windmill Island, Pennsylvania side.*	
At section 9	+ 2.0
	+ 1.6
At section 11	+ 0.1
	——
At section 12	+ 0.2
	+ 3.2
At section 13	+ 2.0
	+ 1.8
Nos. 9 to 19.—*From Petty's Island to Windmill Island, Pennsylvania side*—Continued.	
	Feet.
At section 14	± 0.0
	+ 2.4
At section 15	+ 4.6
	+ 2.7
At section 16	+ 1.9
	+ 1.5
At section 17	+ 3.3
	− 8.4
	− 0.6
At section 18	+ 2.8
	+ 0.6
At section 19	− 1.5
Nos. 19 to 22.—*In Windmill Island west channel.*	
At section 19	− 1.5
	+ 0.1
	+ 5.3
At section 20	+ 2.0
	+ 5.2
At section 21	+ 4.0
	+ 1.8
At section 22	+ 3.4
Nos. 22 to 36.—*From Windmill Island to Gloucester, along Pennsylvania shore.*	
At section 22	+ 3.4
	+ 2.4
	+ 4.2
At section 23	+ 3.3
	+ 2.5
	+ 4.8
At section 24	+ 5.6
	+ 4.8
At section 25	+ 5.9
	+ 7.5
	+ 5.7
At section 26	+ 5.7
	+ 6.2
At section 27	——
	+ 4.8
At section 28	+ 2.8
	+ 0.4
	− 0.8
At section 29	+ 2.7
	+ 0.6
At section 30	——
	+ 1.4
	+ 3.8
	+ 1.9
At section 31	+ 4.9
	− 1.8
	− 0.3
Nos. 22 to 36.—*From Windmill Island to Gloucester, along Pennsylvania shore*—Continued.	
	Feet.
At section 32	+ 1.0
	− 3.4
At section 33	+ 1.3
	+ 0.5
At section 34	− 0.2
	+ 0.2
	− 1.9
At section 35	− 5.5
	− 5.3
	− 0.9
At section 36	− 1.3
Junction of lines	− 2.2
Nos. 1 to 3.—*From Fisher's Point to Petty's Island, along Jersey shore.*	
At section 1	+ 3.7
	+ 3.0
	+ 2.0
	+ 7.5
	+ 9.3
	+ 7.8
At section 2	+ 8.6
	——
	+ 9.6
	+ 8.3
	+ 6.2
	+ 2.8
	+ 0.7
	− 1.3
At section 3	− 0.1
Nos. 3 to 10.—*In Petty's Island south channel.*	
At section 3	− 0.1
	+ 0.6
	± 0.0
	− 0.7
	− 0.2
	− 0.5
At section 4	− 0.7
	+ 0.2
	+ 0.7
At section 5	+ 0.6
	− 2.4
At section 6	− 1.2
	+ 2.4
	+ 4.9
At section 7	+ 2.5
	+ 1.4
	+ 1.2
	± 0.0
At section 8	− 0.2
	± 0.0
	+ 0.7
Nos. 3 to 10.—*In Petty's Island, south channel*—Continued.	
	Feet.
At section 8	+ 0.9
At section 9	+ 1.8
	+ 1.4
	+ 0.1
	——
	+ 1.8
At section 10	+ 1.9
Nos. 10 to 19.—*From Cooper's Point to Windmill Island, Jersey side.*	
At section 10	+ 1.9
At section 11	+ 4.3
	+ 3.6
At section 12	——
	+ 4.1
At section 13	− 0.5
At section 14	− 5.8
	+ 1.2
At section 15	+ 2.9
At section 16	+ 3.1
	+ 3.3
At section 17	+ 6.9
	+ 6.4
At section 18	+ 3.7
	+ 1.8
At section 19	+ 5.0
Nos. 19 to 22.—*In Windmill Island east channel.*	
At section 19	+ 5.0
	+ 6.0
	+ 3.7
At section 20	+ 3.6
	+ 5.5
At section 21	+ 5.7
	+ 4.0
At section 22	+ 5.1
Nos. 22 to 36.—*From Windmill Island to Gloucester, Jersey side.*	
At section 22	+ 5.1
	+ 4.2
At section 23	+ 4.5
	+ 4.2
	+ 4.2
At section 24	+ 4.2
	+ 5.1
	+ 5.2
At section 25	+ 3.2
	+ 1.9
	+ 3.4
At section 26	+ 6.1
At section 27	+ 4.9

TABLE 2—Continued.

Positions.—Intersections of cross-sections.	Differences in depth. Deepened, + Shoaled, −	*Positions.*—Intersections of cross-sections.	Differences in depth. Deepened, + Shoaled, −	*Positions.*—Intersections of cross-sections.	Differences in depth. Deepened, + Shoaled, −	*Positions.*—Intersections of cross-sections.	Differences in depth. Deepened, + Shoaled, −
Nos. 22 to 36.—*From Windmill Island to Gloucester, Jersey side*—Continued.		Nos. 22 to 36.—*From Windmill Island to Gloucester, Jersey side*—Continued.		From junction of lines to No. 47.—*Gloucester to League Island*—Continued.		From junction of lines to No. 47.—*Gloucester to League Island*—Continued.	
	Feet.		*Feet.*		*Feet.*		*Feet.*
At section 28	——	At section 34	+ 0.1	At section 38	+ 0.6	At section 42	± 0.0
	+ 3.1	At section 35	+ 0.8		− 2.0		——
	+ 1.3		− 0.3		− 1.0	At section 43	+ 2.4
At section 29	+ 2.2		− 2.3	At section 39	——		− 0.4
	+ 1.9	At section 36	− 1.8		+ 1.9		− 0.5
	+ 0.9	Junction of lines	− 2.2		− 1.2		——
At section 30	− 0.5				+ 1.2	At section 44	+ 2.1
	+ 0.7			At section 40	− 0.8		+ 1.5
	+ 3.4	From junction of lines to No. 47.—*Gloucester to League Island.*			− 0.9		+ 2.1
	+ 3.0				− 0.1		− 0.2
At section 31	− 3.6				− 5.9		− 3.5
	+ 3.8				− 3.6	At section 45	+ 2.0
	+ 1.2	Junction of lines	− 2.2		+ 4.6		+ 0.6
At section 32	+ 2.9		+ 1.3	At section 41	+ 1.8		+ 1.9
	+ 2.2	At section 37	− 0.6		− 0.2		− 0.3
At section 33	− 1.1		+ 1.2		− 3.9		− 0.2
	+ 0.8		− 1.5		− 1.0	At section 46	− 0.8
	+ 0.7		− 0.1	At section 42	− 2.2		− 0.2
At section 34	+ 1.4		+ 0.9		− 2.4		——
	+ 0.4	At section 38	——		− 2.3	At section 47	− 2.5

SUPPLEMENT TO REPORT DATED NOVEMBER 15, 1880, ON THE CHANGES IN THE DELAWARE RIVER IN FRONT OF PHILADELPHIA.

BOSTON, MASS., *December* 9, 1880.

In the accompanying tables, Nos. 3 to 10, are given, first, in Table 3, the widths of the stream at high and low water for the years 1843 and 1878. These widths are measured on the cross-sections on which current observations were made in 1878, and the positions of which are accurately described in Professor Mitchell's report, printed in Appendix No. 9 of the Coast and Geodetic Survey Report for 1878. Fifty-six of these cross-sections were measured between Five-mile Point and the mouth of the Schuylkill River, distributed as follows: Thirty-seven sections in the main stream, six in Petty's Island (north) channel, seven in the south channel, and three in each of the Windmill Island channels.*

The mean changes in the width in certain reaches of the river, from Table 3, and the corresponding changes of superficial area, from Table 4, are as follows—(it may be here stated that the areas given in Table 4 were not derived from the measurements given in Table 3, but were measured with a planimeter on the original sheets of the two surveys):

The three cross-sections between Five-mile Point and Petty's Island give an increase of width at high-water of 43 feet, and a mean increase of the same at low-water of 287 feet. This large increase at low-water is mainly due to the measurement on section 1, which happens to pass over a spur of the low-water strand. The areas from Table 4 do not show so large an increase as the above measurements would call for, the high-water stage has increased 449,600 square feet, or 1⅓ per cent., and the low-water only 246,400 square feet, or three-fourths of one per cent.

In Petty's Island (north) channel there has been a diminution of width for both high and low water stages, respectively, 362 feet and 254 feet. The high-water area shows a loss of 1,935,200 square feet, or 7½ per cent., and the low-water a decrease of 223,600 square feet, or slightly in excess of one per cent.

In the south channel of Petty's Island a decrease is given for both stages, 202 feet for high,

* For position of these cross-sections, see Sketch B (No. 43).

and 44 feet for low water width. This is derived from the measurements of ten cross-sections. The high-water area has diminished 431,120 square feet, or 1½ per cent., but the low-water area shows an increase of 36,000 square feet, or one-tenth of one per cent.; the seeming disagreement between the measurements of the sections and the areas as given in table 4 is owing to the fact that the cross-sections are few in number, and fall, in the last case, just where a decrease of width occurs at low-water.

From Petty's Island to Smith's Island, the diminution of width is large and general, varying from 55 feet on cross-section 17 to 1,010 feet on cross-section 15, no case giving an increase of width. The average from nine cross-sections gives 345 feet decrease for high-water and 391 feet for low-water. The areas in this reach of the river show a loss for each stage—for high-water, 2,247,200 square feet, or 8½ per cent. of the original area, and for low-water, 1,911,400 square feet, or 7.6 per cent.; the encroachment has been made chiefly along the New Jersey shore, at and below Cooper's Point.

In the west channel of Windmill Island the high-water stage shows a diminution of width of 120 feet, with a loss of area of 208,000 square feet, or 6½ per cent. The low-water cross-sections give a decrease of width of 74 feet, with a loss of area of 22,400 square feet, or seven-tenths of one per cent. of the superficial area of 1843.

In the east channel of Windmill Island the decrease of width, from the measurement of three cross-sections, is 557 feet for high-water stage, with a loss of superficial area of 1,200,400 square feet, or 17¾ per cent. The measurement of the same sections for low-water stage gives a decrease of width of 450 feet, with a loss of superficial area of 897,200 square feet, or 15¾ per cent.

From the south end of Windmill Island to cross-section No. 37, at Gloucester, the mean width shows a decrease of 594 feet for high-water, and a loss of superficial area of 7,118,880 square feet, or 10¾ per cent. At low-water the decrease in width is 280 feet, with a loss of area of 4,170,680 square feet, or 8¾ per cent.

From Gloucester to the east end of League Island, comprising the whole of the Horseshoe shoal, and the widest part of the river yet examined, there has not been any marked change in width at high-water, the area showing an increase of 407,520* square feet, or about one-half of one per cent. The low-water width has increased considerably, the measurements on cross-sections 38 to 42 giving an average of 284 feet, and the superficial area an increase of 1,272,320 square feet, or 2¾ per cent.

Along the frontage of League Island the width has decreased 33 feet for high-water stage and 71 feet for low-water; this is derived from the measurement of five cross-sections. The area at high-water shows a loss of 54,400 square feet or seven-tenths of one per cent., and at low-water the loss is 409,280 square feet or 1.3 per cent. These last measurements bring the examination to the mouth of the Schuylkill River at cross-section No. 47 of 1878.

The general change over the entire distance from Five-mile Point to the mouth of the Schuylkill, embracing the channels around Petty's and Windmill Islands, as derived from fifty-six cross-sections, is a diminution of width of 312 feet at high-water and a similar change of 155 feet at low-water. The change in superficial area is a loss of 12,337,080 square feet or slightly in excess of 4¼ per cent., and for low-water also a loss of 6,079,840 square feet, or slightly in excess of 2½ per cent.

In Table 5 will be found the changes in the volume of the tidal prism for certain divisions of the river. In making the computation the strand between high and low water was regarded as an inclined plane with a mean depth of 3 feet, but the depth over the low-water area was the full rise of tide equal to 6 feet. The loss in the tidal prism between Five-mile Point and the mouth of the Schuylkill is 56,190,760 cubic feet, or 3½ per cent.

Tables 6 to 10 give comparisons of cross-sections at five points between Bridesburg and Smith's Island. They contain the area of cross-section in 1843 and 1878 with the position of the line of mid-area. In the cross-section off Bridesburg, Table 6, the mid-area line indicates a shift of the whole stream towards the Pennsylvania shore. In the Five-mile Point section, 6,500 feet below the former, the mid-area line indicates a movement of the stream in the opposite direction towards the New Jersey shore.

*This area is a close approximation, as the high-water shore-line is missing for a short distance on the Jersey shore, near Big Timber Creek, survey of 1843.

In Table 8 is a cross-section on a bar in the north channel of Petty's Island off Richmond; the mid-area line indicates a shift of the stream towards Petty's Island.

Table 9 contains a cross-section in the south channel, also, over a bar off the western end of Petty's Island; in this section the mid-area line indicates a movement of the stream of 210 feet towards the Camden shore.

Table 10 gives a cross-section between Cooper's Point and Smith's Island; here the mid-area line indicates a shift of the stream of 108 feet towards the New Jersey shore.

Very respectfully, your obedient servant,

HENRY L. MARINDIN,
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TABLE 3.—*Widths of the Delaware River at high and low water in* 1843 *and* 1878, *from Five-mile Point to the Schuylkill River.*

On cross-section No.—	Width at high-water.		Differences.		Width at low-water.		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	1843.	1878.	Increase.	Decrease.	
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
1	2,500	2,590	90		2,070	2,485	415		At Five-mile Point.
2	5,910	5,960	50		5,530	5,855	325		
3	6,000	5,990		10	5,710	5,830	120		
4	2,810	2,845	35		2,525	2,370		155	
5	2,700	2,650		50	2,510	2,470		40	
6	2,140	1,895		245	1,970	1,790		180	In Petty's Island, north channel.
7	2,450	1,720		730	1,760	1,550		210	
8	2,170	1,350		820	1,700	1,200		500	
9		1,230			1,670	1,230		440	
4	2,340	2,230		110	1,940	1,885		55	
5	2,575	2,730	155		1,900	1,740		160	
6	2,390	2,410	20		1,580	1,740	160		
7	1,945	1,510		435	1,510	1,370		140	In Petty's Island, south channel.
8	1,890	2,080	190		1,270	1,360	90		
9	3,720	2,690		1,030	2,150	2,120		30	
10		2,955			2,700	2,525		175	
11	4,070	3,740		330	4,000	3,740		260	
12	3,380	3,270		110	3,370	3,270		100	
13	3,240	2,970		270	3,030	2,900		130	
14	3,370	3,240		130	3,190	2,960		230	
15	3,380	2,370		1,010	3,270	2,300		970	From west end of Petty's Island to Smith's Island.
16	3,010	2,870		140	3,010	2,870		140	
17	3,840	3,785		55	3,590	3,050		540	
18	3,970	3,630		340	3,600	2,880		720	
19	3,810	3,090		720	3,520	3,090		430	
20	1,050	808		242	1,000	808		192	
21	1,120	1,070		50	1,070	1,070	00	00	In Windmill Island, west channel.
22	1,030	960		70	990	960		30	
20	2,240	1,590		650	2,130	1,590		540	
21	2,750	1,760		990	2,080	1,695		385	In Windmill Island, east channel.
22	2,890	2,860		30	2,105	1,680		425	
23	4,100	2,710		1,390	3,200	2,710		490	
24	3,850	3,740		110	3,000	3,060	60		
25	3,740	2,650		1,090	3,120	2,650		470	At old navy-yard.
26	4,060	2,715		1,345	3,080	2,715		365	At Kaighn's Point.
27	4,880	2,905		1,975	2,980	2,840		140	
28	3,950	3,930		20	3,170	2,700		470	
29	5,260	4,840		420	3,070	2,700		370	
30	4,460	4,140		320	2,970	2,360		610	
31	3,800	2,960		840	2,700	2,560		140	
32	3,430	3,440	10		2,780	2,370		410	
33	3,590	3,330		260	2,500	2,530	30		At Greenwich Point coal wharves.
34	3,410	3,230		180	2,600	2,455		145	

TABLE 3.—*Width of the Delaware River at high and low water, &c.*—Continued.

On cross-section No.—	Width at high-water.		Differences.		Width at low-water.		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	1843.	1878.	Increase.	Decrease.	
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
35	2,820	2,425		395	2,600	2,255		345	
36	2,410	2,425	15		2,130	2,080		50	
37	4,090	4,020		70	2,320	2,230		90	At Gloucester.
38	6,675	6,725	50		3,750	4,090	340		
39		8,860			4,570	5,480	920		
40	7,850	7,830		20	5,585	5,715	130		
41	7,820	7,860	40		5,585	5,790	205		
42	7,500	7,450		50	3,880	4,090	210		At east end of League Island.
43	3,275	3,320	45		3,085	3,220	135		
44	3,450	3,470	20		3,260	3,260	000	000	
45	3,980	3,690		290	3,830	3,495		335	
46	4,305	4,295		10	4,087	3,820		267	
47	4,380	4,450	70		4,100	4,210	110		At west end of League Island.

TABLE 4.—*High and low water areas in the Delaware River from Five-mile Point to the Schuylkill River.*

Locality between cross-sections—	Area at high-water in—		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	
	Square feet.	*Square feet.*	*Square feet.*	*Square feet.*	
1 and 2	12,788,800	13,048,800	260,000		At Five-mile Point.
2 and 3	19,512,000	19,701,600	189,600		
3 and 4	6,014,400	6,203,200	188,800		In Petty's Island north channel.
4 and 5	6,280,000	6,135,200		144,800	
5 and 6	3,601,600	3,539,200		62,400	
6 and 7	3,513,600	2,956,800		556,800	
7 and 8	3,142,400	2,457,600		684,800	
8 and 9	3,040,000	2,364,800		675,200	
3 and 4	5,361,600	5,401,600	40,000		In Petty's Island south channel.
4 and 5	2,946,800	2,846,400		100,400	
5 and 6	2,804,800	2,252,800		552,000	
6 and 7	2,944,000	4,136,480	192,480		
7 and 8	2,916,800	2,846,400		70,400	
8 and 9	4,960,000	5,444,800	484,800		
9 and 10	5,265,600	4,840,000		425,600	
9, 10, and 11	3,420,800	3,184,000		236,800	Petty's Island to Smith's Island.
11 and 12	2,772,800	2,635,200		137,600	
12 and 13	2,849,600	2,608,000		241,600	
13 and 14	2,414,400	2,260,800		153,600	
14 and 15	2,654,400	2,411,200		243,200	
15 and 16	1,817,600	1,449,600		368,000	
16 and 17	3,521,600	3,238,400		283,200	
17 and 18	3,636,800	3,471,200		165,600	
18 and 19	3,606,400	3,188,800		417,600	
19 and 20	1,192,000	1,060,800		131,200	Windmill Island west channel.
20 and 21	1,128,000	1,148,800	20,800		
21 and 22	872,000	774,400		97,600	
19 and 20	2,720,000	2,148,800		571,200	Windmill Island east channel.
20 and 21	2,308,200	1,705,600		602,600	
21 and 22	1,718,400	1,692,800		25,600	
22 and 23	4,105,600	4,115,200	9,600		
23 and 24	4,924,800	4,330,400		594,400	
24 and 25	3,923,200	3,340,000		583,200	
25 and 26	4,820,800	3,281,120		1,539,680	Off Kaighn's Point.
26 and 27	3,208,000	1,648,000		1,560,000	

TABLE 4.—*High and low water areas in the Delaware River, &c.*—Continued.

Locality between cross-sections—	Area at high-water in—		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	
	Square feet.	*Square feet.*	*Square feet.*	*Square feet.*	
27 and 28	3, 148, 800	3, 092, 800		56, 000	
28 and 29	6, 894, 400	6, 475, 200		419, 200	
29 and 30	5, 107, 200	4, 748, 800		358, 400	
30 and 31	6, 470, 400	5, 603, 200		867, 200	
31 and 32	4, 393, 600	4, 342, 400		51, 200	
32 and 33	2, 976, 000	2, 907, 200		68, 800	
33 and 34	4, 104, 000	3, 948, 800		155, 200	Off Greenwich Point coal wharves.
34 and 35	3, 670, 400	2, 990, 400		680, 000	
35 and 36	3, 486, 400	3, 462, 400		24, 000	
36 and 37	4, 232, 000	4, 060, 800		171, 200	Off Gloucester.
37 and 38	10, 219, 200	10, 389, 600	170, 400		
38 and 39		15, 372, 800			
39 and 40		15, 182, 400			Over the Horseshoe Shoal.
40 and 41	14, 096, 000	14, 213, 120	117, 120		
41 and 42	12, 139, 200	12, 259, 200	120, 000		
42 and 43	7, 942, 400	7, 982, 400	40, 000		
43 and 44	4, 960, 000	5, 051, 200	91, 200		
44 and 45	6, 822, 400	6, 633, 600		188, 800	Off League Island shore.
45 and 46	8, 016, 000	7, 912, 000		104, 000	
46 and 47	4, 656, 000	4, 763, 200	107, 200		

Locality between cross-sections—	Area at low-water in—		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	
	Square feet.	*Square feet.*	*Square feet.*	*Square feet.*	
1 and 2	12, 160, 000	12, 564, 000	404, 000		At Five-mile Point.
2 and 3	18, 876, 800	18, 719, 200		157, 600	
3 and 4	5, 467, 200	5, 700, 000	233, 800		
4 and 5	5, 854, 400	5, 553, 600		300, 800	
5 and 6	3, 168, 000	3, 249, 600	81, 600		In Petty's Island north channel.
6 and 7	2, 590, 400	2, 694, 000	103, 600		
7 and 8	2, 392, 000	2, 304, 000		88, 000	
8 and 9	2, 390, 400	2, 137, 600		252, 800	
3 and 4	5, 109, 200	5, 156, 800	47, 600		
4 and 5	2, 492, 400	2, 307, 200		185, 200	
5 and 6	1, 931, 200	2, 008, 800	77, 600		
6 and 7	2, 753, 600	2, 865, 600	112, 000		In Petty's Island south channel.
7 and 8	1, 942, 400	1, 998, 400	56, 000		
8 and 9	3, 712, 000	3, 654, 400		57, 600	
9 and 10	4, 139, 200	4, 124, 800		14, 400	
9, 10, and 11	3, 278, 400	3, 134, 400		144, 000	
11 and 12	2, 753, 600	2, 635, 200		118, 400	
12 and 13	2, 798, 400	2, 596, 800		201, 600	
13 and 14	2, 344, 000	2, 235, 200		108, 800	
14 and 15	2, 600, 000	2, 411, 200		188, 800	Petty's Island to Smith's Island.
15 and 16	1, 792, 000	1, 449, 600		342, 400	
16 and 17	3, 369, 600	3, 033, 600		336, 000	
17 and 18	3, 280, 200	2, 864, 800		415, 400	
18 and 19	2, 892, 800	2, 836, 800		56, 000	
19 and 20	1, 107, 200	1, 060, 800		46, 400	
20 and 21	1, 064, 000	1, 148, 800	84, 800		Windmill Island west channel.
21 and 22	835, 200	774, 400		60, 800	
19 and 20	2, 389, 000	2, 022, 400		366, 600	
20 and 21	1, 964, 200	1, 699, 900		265, 000	Windmill Island east channel.
21 and 22	1, 315, 200	1, 049, 600		265, 600	
22 and 23	3, 278, 400	3, 001, 800		276, 600	
23 and 24	3, 630, 400	3, 525, 600		104, 800	
24 and 25	3, 209, 600	3, 069, 600		140, 000	

TABLE 4.—*High and low water areas in the Delaware River, &c.*—Continued.

Locality between cross-sections—	Area at low water in—		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	
	Square feet.	*Square feet.*	*Square feet.*	*Square feet.*	
25 and 26	3, 801, 600	3, 281, 120	....	520, 480	Off Kaighn's Point.
26 and 27	1, 798, 400	1, 648, 000	....	150, 400	
27 and 28	2, 249, 600	2, 006, 400	....	243, 200	
28 and 29	4, 049, 600	3, 587, 200	....	462, 400	
29 and 30	3, 356, 800	2, 858, 400	....	498, 400	
30 and 31	4, 592, 000	4, 102, 400	....	489, 600	
31 and 32	3, 400, 000	3, 030, 400	....	369, 600	
32 and 33	2, 257, 600	2, 060, 800	....	196, 800	
33 and 34	3, 001, 600	3, 043, 200	41, 600	....	Off Greenwich Point coal wharves.
34 and 35	3, 179, 200	2, 777, 600	....	401, 600	
35 and 36	3, 190, 400	3, 008, 000	....	182, 400	
36 and 37	2, 880, 000	2, 704, 000	....	176, 000	Off Gloucester.
37 and 38	5, 884, 800	6, 216, 000	331, 200	....	Over the Horseshoe Shoal.
38 and 39	8, 486, 400	9, 083, 200	596, 800	....	
39 and 40	10, 926, 400	11, 395, 200	468, 800	....	
40 and 41	12, 153, 600	12, 059, 520	....	94, 080	
41 and 42	8, 372, 800	8, 342, 400	....	30, 400	
42 and 43	6, 396, 800	6, 672, 320	275, 520	....	Off League Island shore.
43 and 44	4, 668, 800	4, 880, 000	211, 200	....	
44 and 45	6, 425, 600	6, 203, 200	....	222, 400	
45 and 46	7, 606, 400	6, 916, 800	....	689, 600	
46 and 47	4, 406, 400	4, 422, 400	16, 000	....	

TABLE 5.—*Changes in the tidal prism*, 1843 *to* 1878, *between Five-mile Point and the mouth of the Schuylkill River.*

Position between cross-sections, numbers—	Total tidal prism.		Differences.		Remarks.
	1843.	1878.	Increase.	Decrease.	
1 and 3	190, 012, 800	191, 100, 800	1, 088, 000	....	Five-mile Point to Petty's Island.
3 and 9	142, 363, 200	135, 886, 800	....	6, 476, 400	North channel Petty's Island.
3 and 10	150, 838, 800	149, 653, 440	....	1, 185, 360	South channel Petty's Island.
9, 10, and 19	155, 410, 200	142, 934, 400	....	12, 475, 800	Petty's Island to Smith's Island.
19 and 22	18, 595, 200	17, 904, 000	....	691, 200	West channel Windmill Island.
19 and 22	37, 185, 000	30, 955, 200	....	6, 229, 800	East channel Windmill Island.
22 and 37	340, 022, 400	306, 153, 720	....	33, 868, 680	Windmill Island to Gloucester.
37 and 42	338, 500, 800	343, 540, 320	5, 039, 520	....	Gloucester to League Island.
42 and 47	185, 702, 400	184, 311, 360	....	1, 391, 040	Front of League Island.

Depth of tidal prism, 6 feet.

TABLE 6.—*Cross-section off Bridesburg, 200 feet below wharf.*

Dist. from bulkhead.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
0	....	....	....	....	*High-water bulkhead in 1878.*
48	....	....	....	....	High-water in 1843.
80	....	....	....	....	Low-water in 1843.
100	1.0	0.0	....	1.0	
200	6.5	6.0	....	0.5	
300	9.0	10.5	1.5	....	Area of section in 1843 = 43,710 square feet.
400	11.7	12.5	0.8	....	Area of section in 1878 = 44,860 square feet.
500	13.0	13.0	0.0	0.0	*Increase of section* = 1,150 square feet.
600	13.0	13.2	0.2	....	
700	15.0	15.5	0.5	....	Mid-area line from origin:
800	16.0	18.0	2.0	....	In 1843 = 1,371 feet.
900	19.5	19.5	0.0	0.0	In 1878 = 1,350 feet.
1,000	21.5	24.0	2.5	....	
1,100	26.5	31.0	4.5	....	
1,200	32.0	30.5	....	1.5	
1,300	29.5	30.0	0.5	....	
1,400	26.0	28.0	2.0	....	
1,500	23.0	25.0	2.0	....	
1,600	18.0	18.0	0.0	0.0	
1,700	13.0	12.0	....	1.0	
1,800	9.2	7.5	....	1.7	
1,900	8.0	5.5	....	2.5	
2,000	9.0	5.2	....	3.8	
2,100	9.0	5.2	....	3.8	
2,200	9.0	7.0	....	2.0	
2,300	10.0	9.2	....	0.8	
2,400	11.5	10.2	....	1.3	
2,500	14.0	12.7	....	1.3	
2,600	15.7	14.5	....	1.2	
2,700	14.0	15.2	1.2	....	
2,800	10.5	15.0	4.5	....	
2,900	9.0	12.0	3.0	....	
3,000	8.0	8.7	0.7	....	
3,100	6.0	8.0	2.0	....	
3,200	1.0	6.0	5.0	....	
3,240	0.0	....	....	....	Low-water in *1843.*
3,300	....	0.0	....	....	Low-water in 1878.

TABLE 7.—*Cross-section at Five-mile Point, 500 feet below Harrison's wharf.*

Dist. from Pa. side.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
0	....	....	....	....	At levee of 1878.
25	....	....	....	....	High-water shore line, 1843.
40	....	0.0	....	....	Low-water of 1878.
100	0.0	3.0	3.0	....	Low-water of 1843.
200	2.5	9.2	6.7	....	
300	5.5	12.0	6.5	....	
400	10.2	11.0	0.8	....	Area of section in 1843 = 46,060 square feet.
500	13.5	8.5	....	5.0	Area of section in 1878 = 44,460 square feet.
600	13.5	6.2	....	7.3	Loss of section = 1,600 square feet.
700	13.5	5.2	....	8.3	
800	13.0	5.5	....	7.5	Mid-area line from origin:
900	11.5	3.2	....	8.3	In 1843 = 1,696 feet.
1,000	14.0	2.5	....	11.5	In 1878 = 1,780 feet.
1,100	17.0	6.0	....	11.0	

TABLE 7.—*Cross-section at Five-mile Point, 500 feet below Harrison's wharf*—Continued.

Dist. from Pa. side.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
1,200	17.0	14.0	....	3.0	
1,300	17.0	20.0	3.0	....	
1,400	19.2	21.0	1.8	....	
1,500	22.0	22.2	0.2	....	
1,600	28.0	27.0	....	1.0	
1,700	30.0	32.0	2.0	....	
1,800	35.0	35.5	0.5	....	
1,900	37.0	36.5	....	0.5	
2,000	39.0	38.2	....	0.8	
2,100	35.0	37.0	2.0	....	
2,200	20.0	26.5	6.5	....	
2,300	17.0	19.0	2.0	....	
2,400	12.0	15.0	3.0	....	
2,500	8.5	11.0	2.5	....	
2,600	5.0	6.0	1.0	....	
2,700	3.0	4.0	1.0	....	
2,800	2.0	3.5	1.5	....	
2,900	1.0	2.2	1.2	....	
2,910	0.0	....	....	....	Low-water of 1843.
2,940	....	....	....	....	High-water of 1843.
2,970	....	0.0	....	....	Low-water of 1878.
3,080	....	....	....	....	High-water of 1878.

TABLE 8.—*Cross-section on Richmond Bar, in north channel of Petty's Island.*

Dist. from Pa. side.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
0	6.0	9.5	3.5	....	At wharf on Pennsylvania side.
100	11.0	12.2	1.2	....	
200	11.5	12.5	1.0	....	
300	12.5	10.7	....	1.8	Area of section in 1843 = 32,390 square feet.
400	12.5	10.5	....	2.0	Area of section in 1878 = 29,980 square feet.
500	10.5	11.0	0.5	....	
600	13.5	14.2	0.7	....	Loss of area = 2,410 square feet.
700	16.7	14.0	....	2.7	Mid-area line from origin:
800	19.0	13.2	....	5.8	In 1843 = 1,132 feet.
900	18.5	13.2	....	5.3	In 1878 = 1,192 feet.
1,000	18.5	13.2	....	5.3	
1,100	18.0	14.7	....	3.3	
1,200	17.2	13.5	....	3.7	
1,300	16.5	14.0	....	2.5	
1,400	15.5	13.2	....	2.3	
1,500	16.0	14.0	....	2.0	
1,600	15.5	14.6	....	0.9	
1,700	14.5	15.7	1.2	....	
1,800	16.5	16.7	0.2	....	
1,900	15.5	17.0	1.5	....	
2,000	14.5	16.5	2.0	....	
2,100	12.5	13.5	1.0	....	
2,200	4.5	7.0	2.5	....	
2,260	0.0	0.0	....	....	Low-water in 1843 and 1878.
2,460	....	....	....	....	High-water.

TABLE 9.—*Cross-section at west end of Petty's Island, south channel.*

Dist. from bulkhead on Petty's Island.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
0	− 1.5	− 2.5	....	1.0	Bulkhead, 1878, on Petty's Island.
100	− 0.5	− 1.7	....	1.2	
200	+ 0.5	− 0.5	....	1.0	
300	1.5	+ 2.5	1.0	....	Area of section in 1843 = 21,390 square feet.
400	3.0	4.7	1.7	....	Area of section in 1878 = 24,330 square feet.
500	4.5	4.7	0.2	....	
600	4.7	4.7	0.0	0.0	Increase of area = 2,940 square feet.
700	8.0	5.0	....	3.0	Mid-area line from origin:
800	11.7	5.7	....	6.0	In 1843 = 1,386 feet.
900	14.5	7.0	....	7.5	In 1878 = 1,596 feet.
1,000	15.2	9.5	....	5.7	
1,100	14.5	11.2	....	3.3	
1,200	12.5	13.5	1.5	....	
1,300	12.5	14.7	2.2	....	
1,400	12.2	15.7	3.5	....	
1,500	12.0	15.7	3.7	....	
1,600	11.5	15.5	4.0	....	
1,700	11.5	15.5	4.0	....	
1,800	11.0	15.2	4.2	....	
1,900	10.5	15.0	4.5	....	
2,000	8.0	13.0	5.0	....	
2,100	6.5	11.5	5.0	....	
2,200	5.5	10.0	4.5	....	
2,300	5.5	9.5	4.0	....	
2,400	7.5	9.0	1.5	....	
2,500	6.5	9.5	3.0	....	
2,600	2.0	4.0	2.0	....	
2,700	1.0	1.0	0.0	....	
2,760	....	0.0	....	....	Low-water, 1878.
2,800	0.2	....	....	....	High-water, 1878.
2,850	0.0	....	....	....	Low-water, 1843.
2,950	....	....	....	....	High-water, 1843, Jersey side.

TABLE 10.—*Cross-section No. 17 of 1878, below Cooper's Point.*

Dist. from bulkhead.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
0	....	....	....	....	Bulkhead of 1843; same in 1878.
100	33.5	....	....	....	Above outer end of wharf of 1843.
200	42.0	24.5	....	17.5	Origin of section No. 17 of 1878.
300	43.0	55.9	12.9	....	
400	59.0	54.4	....	4.6	
500	46.0	46.5	0.5	....	Area of section in 1843 = 49,610 square feet.
600	42.0	39.6	....	2.4	Area of section in 1878 = 48,140 square feet.
700	27.0	30.8	3.8	....	Loss of area = 1,470 square feet.
800	21.5	25.7	4.2	....	
900	20.5	21.1	0.6	....	Mid-area line from origin:
1,000	16.5	19.2	2.7	....	In 1843 = 648 feet.
1,100	10.5	18.9	8.4	....	In 1878 = 756 feet.
1,200	7.5	16.4	8.9	....	
1,300	5.5	7.9	2.4	....	
1,400	4.5	0.5	....	4.0	
1,500	3.5	0.0	....	3.5	
1,600	3.0	4.3	1.3	....	
1,700	3.5	8.4	4.9	....	
1,800	5.0	11.8	6.8	....	

TABLE 10.—*Cross-section No.* 17 *of* 1878, *below Cooper's Point*—Continued.

Dist. from bulkhead, Pa. side.	Depth at low-water.		Differences.		Remarks.
	1843.	1878.	Deepened.	Shoaled.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
1,900	7.5	13.4	5.9	....	
2,000	7.5	13.9	6.4	....	
2,100	7.5	14.0	6.5	....	
2,200	8.5	12.3	3.8	....	
2,300	9.5	10.0	0.5	....	
2,400	10.5	8.2	....	2.3	
2,500	11.5	9.2	....	2.3	
2,600	12.5	9.0	....	3.5	
2,700	9.5	7.9	....	1.6	
2,800	8.5	6.8	....	1.7	
2,900	6.5	3.0	....	3.5	
3,000	5.5	0.0	....	5.5	Low-water of 1878.
3,100	4.0	− 0.9	....	4.9	
3,200	3.5	− 1.5	....	5.0	
3,300	2.5	− 2.2	....	4.7	
3,400	2.5	− 2.5	....	5.0	
3,500	1.3	− 2.9	....	4.2	
3,600	0.0	− 2.9	....	2.9	Low-water of 1843.
3,700	....	− 3.2	....	....	
3,770	....	....	....	....	High-water of 1878.
3,800	....	....	....	....	
3,850	....	....	....	....	High-water line of 1843.

APPENDIX No. 10.

REPORT ON COMPARISON OF SURVEYS OF MISSISSIPPI RIVER IN THE VICINITY OF CUBITT'S GAP BY H. L. MARINDIN, ASSISTANT.

BOSTON, MASS., *April* 22, 1880.

SIR: A comparison of surveys of that part of the Mississippi River lying between the head of the Passes, Louisiana, and a line across the river about 4,000 feet above the north point of "Cubitt's Gap," has just been completed, and I have the honor to forward it in accordance with your call of April 12, 1880.

Beginning at a line 4,000 feet above the north point of "Cubitt's Gap," to a line across the river at the south point, we have two surveys for comparison, both by the Coast Survey—one in 1872, by Assistant Granger, and the other in 1876 by a party under my charge. This comparison shows a shoaling on both banks of the stream and a marked deepening along the center of the river and towards the right bank (west shore). Taking the whole area under consideration there has been a deepening of 1.7 feet in the four years, or 0.4 foot per year, in that part of the river above the "Gap," and a mean shoaling of 0.5 foot in the same time, or 0.12 foot per year, in that part of the river directly in front of the "Gap."

A noticeable feature in front of the "Gap," and one which, in a great measure, must be traced to it as its cause, is the formation of a flat on the west bank, as shown by the deep contours—the 24-foot curve more especially—starting at a point on the west shore, 3,000 feet above the "Gap," where all the curves run parallel to the shore, and where the 24-foot curve is 260 feet from the 3-foot curve, which I have taken as the reference, for convenience, being smoother than the shore-line, although running parallel to it. The 24-foot curve abruptly juts out towards the center of the river, till, opposite the north point of the "Gap," it is 820 feet from the 3-foot curve; then, following down stream, and opposite the south point, it is 920 feet; then, after passing the opening of "Cubitt's Gap," it retreats towards the shore-line, so that about 2,000 feet below the south point it is 760 feet, 4,000 feet below it is 720 feet off, and 8,000 feet below the "Gap" it is only 500 feet off, notwithstanding the gradual expansion of the Mississippi, which at the upper limit is 3,720 feet in width, and at the lower limit, 8,000 feet below the "Gap," it is 4,815 feet in width, as measured between the 3-foot contour of each bank.

From the south point, for a distance of about 1,300 feet down stream, the two surveys compared are one of 1866 and the other of 1876, which give a mean shoaling of 1.6 feet in ten years, or 0.16 foot per year.

From the above-mentioned limit, 1,300 feet below the south point of "Gap," to Cubitt's house, we have two surveys for comparison, one executed by Assistant Gerdes, and the other by my party in 1877, giving an interval of eleven years; over this space there has been a mean shoaling of 3.9 feet, or 0.35 foot per year.

From Cubitt's house to the Head of the Passes, including all the space now covered by the works for the imprevement of the channel-way into South Pass, we have two surveys again—one of 1866, by Assistant Gerdes, and one done under my direction in 1875, by Subassistant Braid; these surveys show a decrease in depth of 3.6 feet in nine years, or 0.4 foot each year. Where, however, the present jettied channel into South Pass is located, there has been a decided deepening.

The accompanying Table 1 gives the comparison of the different surveys in detail, by dividing the surface of the river into squares of 10″ latitude by 10″ longitude, and giving the mean depth in that area as obtained by the sum of all the soundings over this space.

Table 2 gives the position of the flat in front of "Cubitt's Gap," as delineated by the 24-foot contour, with a reference also to the width of the river at that place.

Table 3 gives a cross-section of the river at the south point of "Cubitt's Gap." This section begins at the west shore and follows one of the sounding-lines of the survey of 1866, and is compared with the survey of 1876. It lies somewhat diagonally across the stream. The comparison shows an average shoaling of 1.2 feet in ten years, or 0.12 foot per year, a decrease in depth of 3 per cent.

Table 4 gives a cross-section of the river about 1¾ miles below "Cubitt's Gap." This shows a mean shoaling between 1866 and 1877 of 3.4 feet, or 0.31 foot per year, a decrease of 10 per cent.

Table 5 gives another section across the wide part of the river at the Head of Passes, at a point below "Cubitt's house." It begins at the west shore and runs on a line of soundings of the survey of 1866, and is compared with the survey of 1875; the section ends at the east shore, near the south end of the Mississippi Base. This section shows a decrease in depth of 4.4 feet in nine years, or 0.43 foot per year, a decrease of nearly 17 per cent.

There is no change in the width of the river between "Cubitt's Gap" and the Passes, as shown by the 3-foot and 6-foot curves, although the bed of the stream shows a slight bodily shift to the eastward.

In all cases, during this comparison, where the soundings of the earlier surveys—which are not as numerous as in the more recent surveys—fell between close lines of soundings, the comparative depth was obtained by grouping the surrounding soundings of the later survey.

A sketch of the locality, showing the areas covered by the comparison, is appended.

Respectfully submitted.

HENRY L. MARINDIN,
Assistant, Coast and Geodetic Survey.

Hon. CARLILE P. PATTERSON,
Superintendent Coast and Geodetic Survey, Washington, D. C.

MISSISSIPPI RIVER.

TABLE 1.—*Comparison of surveys at Head of Passes, Louisiana, of* 1866, 1872, 1875, 1876, 1877.

Area limits.						Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.			Longitudes.			1866.	1875.	Shoaled.	Deepened.		
°	′	″	°	′	″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29	08	40 50	89	14	10 20	25.7	20.6	− 5.1	....	−19	At head of Pass à l'Outre.
29	08	40 50	89	14	20 30	25.0	19.7	− 5.3	....	−21	
29	08	40 50	89	14	30 40	14.6	12.0	− 2.6	....	−18	
29	08	40 50	89	14	40 50	14.7	14.2	− 0.5	....	−03	
29	08	40 50	89	15	50 00	12.5	14.8	....	+ 2.3	+18	
29	08	40 50	89	15	00 10	14.0	14.9	....	+ 0.9	+06	
29	08	40 50	89	15	10 20	31.4	23.5	− 7.9	....	−25	
29	08	40 50	89	15	20 30	34.7	33.1	− 1.6	....	−04	
29	08	40 50	89	15	30 40	16.0	15.0	− 1.0	....	−06	Head of Southwest Pass, west shore.
29	08 09	50 00	89	14	10 20	31.0	27.0	− 3.0	....	−09	At head of Pass à l'Outre.
29	08 09	50 00	89	14	20 30	26.0	19.0	− 7.0	....	−27	
29	08 09	50 00	89	14	30 40	22.6	17.8	− 4.8	....	−21	
29	08 09	50 00	89	14	40 50	22.5	16.5	− 6.0	....	−26	
29	08 09	50 00	89	15	50 00	17.6	16.6	− 1.0	....	−06	
29	08 09	50 00	89	15	00 10	27.0	22.2	− 4.8	....	−18	
29	08 09	50 00	89	15	10 20	30.6	26.0	− 4.6	....	−15	
29	08 09	50 00	89	15	20 30	30.2	27.9	− 2.3	....	−07	
29	08 09	50 00	89	15	30 40	....	....	....	....	....	At west shore.

TABLE 1.—*Comparison of surveys at Head of Passes, &c.*—Continued.

Area limits.						Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.			Longitudes.			1866.	1875.	Shoaled.	Deepened.		
°	′	″	°	′	″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29	09	00 10	89	14	10 20	32.4	26.9	− 5.5	....	−17	At head of Pass à l'Outre.
29	09	00 10	89	14	20 30	33.1	23.4	− 9.7	....	−29	
29	09	00 10	89	14	30 40	24.2	18.6	− 6.6	....	−27	
29	09	00 10	89	14	40 50	25.5	21.1	− 4.4	....	−17	
29	09	00 10	89	15	50 00	27.7	21.7	− 6.0	....	−21	
29	09	00 10	89	15	00 10	27.0	22.0	− 5.0	....	−18	
29	09	00 10	89	15	10 20	30.5	27.1	− 3.4	....	−11	
29	09	00 10	89	15	20 30	26.8	27.0	....	+ 0.2	+01	
29	09	00 10	89	15	30 40	22.1	21.3	− 0.8	....	−03	
29	09	00 10	89	15	40 50	....	....	....	....	....	At west shore.
29	09	10 20	89	14	10 20	23.8	22.2	− 0.6	....	−02	At east shore.
29	09	10 20	89	14	20 30	29.2	25.8	− 3.4	....	−11	
29	09	10 20	89	14	30 40	29.6	23.8	− 5.8	....	−19	
29	09	10 20	89	14	40 50	24.3	22.6	− 1.7	....	−07	
29	09	10 20	89	15	50 00	29.9	23.2	− 6.7	....	−23	
29	09	10 20	89	15	00 10	33.8	26.7	− 7.1	....	−21	
29	09	20 30	89	14	20 30	18.7	17.1	− 1.6	....	−09	At east shore.
29	09	20 30	89	14	30 40	25.4	25.4	− 0.0	+ 0.0	....	
29	09	20 30	89	14	40 50	29.5	26.0	− 3.5	....	−12	
						1866.	1877.				
29	09	10 20	89	15	10 20	33.9	27.6	− 6.3	....	−18	
29	09	10 20	89	15	20 30	31.2	26.5	− 4.7	....	−15	
29	09	10 20	89	15	30 40	....	....	....	....	....	
29	09	10 20	89	15	40 50	....	....	....	....	....	At west shore.
29	09	20 30	89	14 15	50 00	28.7	26.9	− 1.8	....	−06	
29	09	20 30	89	15	00 10	37.4	28.6	− 8.8	....	−23	
29	09	20 30	89	15	10 20	37.0	28.6	− 8.4	....	−22	
29	09	20 30	89	15	20 30	33.0	27.6	− 5.4	....	−16	
29	09	20 30	89	15	30 40	31.6	25.9	− 5.7	....	−18	
29	09	20 30	89	15	40 50	16.3	8.8	− 7.5	....	−45	At west shore.
29	09	30 40	89	14	30 40	18.7	17.9	− 0.8	....	−04	At east shore.
29	09	30 40	89	14	40 50	29.0	26.6	− 2.4	....	−08	
29	09	30 40	89	15	50 00	28.5	27.3	− 1.2	....	−04	
29	09	30 40	89	15	00 10	34.4	29.2	− 5.2	....	−15	
29	09	30 40	89	15	10 20	39.7	31.1	− 8.6	....	−21	

TABLE 1.—*Comparison of surveys at Head of Passes, &c.*—Continued.

Area limits.		Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.	Longitudes.	1866.	1877.	Shoaled.	Deepened.		
° ′ ″	° ′ ″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29 09 30 40	89 15 20 30	38.0	29.3	− 8.7	....	−22	
29 09 30 40	89 15 30 40	....	....	....	....	....	
29 09 30 40	89 15 40 50	....	....	....	....	....	At west shore.
29 09 40 50	89 14 30 40	....	....	....	....	....	At east shore, near Cubitt's house.
29 09 40 50	89 14 40 50	23.9	24.2	....	+ 0.3	+01	
29 09 40 50	89 15 50 00	33.2	27.5	− 5.7	....	−17	
29 09 40 50	89 15 00 10	34.9	31.2	− 3.7	....	−10	
29 09 40 50	89 15 10 20	41.1	34.4	− 6.7	....	−16	
29 09 40 50	89 15 20 30	42.7	32.2	−10.5	....	−24	
29 09 40 50	89 15 30 40	33.4	28.3	− 5.1	....	−15	
29 09 40 50	89 15 40 50	28.4	23.5	− 4.9	....	−17	
29 09 40 50	89 16 50 00	....	....	....	....	....	At west shore.
29 09 50 10 00	89 14 40 50	....	....	....	....	....	
29 09 50 10 00	89 15 50 00	27.0	25.4	− 1.6	....	−06	
29 09 50 10 00	89 15 00 10	33.7	31.2	2.5	....	−07	
29 09 50 10 00	89 15 10 20	40.3	35.5	− 4.8	....	−11	
29 09 50 10 00	89 15 20 30	43.5	36.4`	− 7.1	....	−16	
29 09 50 10 00	89 15 30 40	....	....	....	....	....	
29 09 50 10 00	89 15 40 50	30'.0	27.2	− 2.8	....	−09	
29 09 50 10 00	89 16 50 00	....	....	....	....	....	At west shore.
29 10 00 10	89 14 50 15 00	25.0	25.0	− 0.0	+ 0.0	....	At east shore.
29 10 00 10	89 15 00 10	27.0	27.0	− 0.0	+ 0.0	....	
29 10 00 10	89 15 10 20	40.5	33.0	− 7.5	....	−18	
29 10 00 10	89 15 20 30	43.7	38.2	− 5.5	....	−12	
29 10 00 10	89 15 30 40	45.3	35.3	−10.0	....	−22	
29 10 00 10	89 15 40 50	33.4	28.7	− 4.7	....	−13	
29 10 00 10	89 16 16 00	25.5	22.0	− 3.5	....	−13	At west shore
29 10 10 20	89 15 00 10	28.4	28.1	− 0.3	....	−01	At east shore.
29 10 10 20	89 15 10 20	36.5	32.5	− 4.0	....	−11	
29 10 10 20	89 15 20 30	39.2	38.2	− 1.0	....	−02	
29 10 10 20	89 15 30 40	46.7	40.3	− 6.4	....	−13	
29 10 10 20	89 15 40 50	42.0	32.0	−10.0	....	−23	
29 10 10 20	89 16 50 00	32.0	26.4	− 6.6	....	−20	At west shore.
29 10 20 30	89 15 10 20	29.6	30.5	....	+ 0.9	+03	At east shore.
29 10 20 30	89 15 20 30	40.0	38.0	− 2.0	....	−05	

TABLE 1.—*Comparison of surveys at Head of Passes, &c.*—Continued.

Area limits.		Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.	Longitudes.	1866.	1877.	Shoaled.	Deepened.		
° ′ ″	° ′ ″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29 10 20/30	89 15 30/40	45.4	42.0	− 3.4	....	−07	
29 10 20/30	89 15 40/50	47.0	39.0	− 8.0	....	−17	
29 10 20/30	89 16 50/00	38.0	30.1	− 7.9	....	−20	
29 10 20/30	89 16 00/10	28.2	21.2	− 7.0	....	−24	At west shore.
29 10 30/40	89 15 10/20	21.8	24.0	....	+ 2.2	+10	At east shore.
29 10 30/40	89 15 20/30	33.5	34.6	....	+ 1.1	+03	
29 10 30/40	89 15 30/40	....	....	....	....	....	
29 10 30/40	89 15 40/50	48.0	45.3	− 2.7	− 0.5	−05	
29 10 30/40	89 16 50/00	45.4	36.0	− 9.4	− 2.0	−20	
29 10 30/40	89 16 00/10	34.9	24.1	−10.8	− 3.0	−30	At west shore.
29 10 40/50	89 15 20/30	24.0	29.9	....	+ 5.9	+24	At east shore.
29 10 40/50	89 15 30/40	39.0	38.6	− 0.4	....	−01	
29 10 40/50	89 15 40/50	45.6	46.0	....	+ 0.4	+01	
29 10 40/50	89 16 50/00	46.1	43.1	− 3.0	....	−06	
29 10 40/50	89 16 00/10	39.6	29.6	−10.0	....	−25	
29 10 40/50	89 16 10/20	31.6	23.0	− 8.6	....	−27	At west shore.
29 10 50/11 00	89 15 30/40	32.6	34.7	....	+ 2.1	+06	At east shore.
29 10 50/11 00	89 15 49/50	43.0	43.8	....	+ 0.8	+02	
19 10 50/11 00	89 16 50/00	47.0	48.0	....	+ 1.0	+06	
29 10 50/11 00	89 16 00/10	....	....	....	....	....	
29 10 50/11 00	89 16 10/20	34.0	25.0	− 9.0	....	−26	At west shore.
29 11 00/10	89 15 30/40	17.7	25.3	....	+ 7.6	+42	At east shore.
29 11 00/10	89 15 40/50	35.8	38.7	....	+ 2.9	+07	
29 11 00/10	89 16 50/00	44.8	47.7	....	+ 2.9	+06	
29 11 00/10	89 16 00/10	47.6	45.5	− 2.1	....	−04	
29 11 00/10	89 16 10/20	36.0	25.6	−10.4	....	−28	
29 11 00/10	89 16 20/30	24.0	14.8	− 9.2	....	−38	At west shore.
29 11 10/20	89 15 40/50	27.5	33.0	....	+ 5.5	+20	At east shore.
29 11 10/20	89 16 50/00	41.0	45.0	....	+ 4.0	+09	
29 11 10/20	89 16 00/10	44.0	51.5	....	+ 7.5	+17	
29 11 10/20	89 16 10/20	45.6	35.2	−10.4	....	−22	
29 11 10/20	89 16 20/30	32.6	22.5	−11.1	....	−34	
29 11 10/20	89 16 30/40	26.0	15.3	−10.7	....	−41	At west shore.

TABLE 1.—*Comparison of surveys at Head of Passes, &c.*—Continued.

Area limits.						Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.			Longitudes.			1866.	1876.	Shoaled.	Deepened.		
°	′	″	°	′	″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29	11	20 30	89	15 16	50 00	....	....	....	....	....	At east shore.
29	11	20 30	89	16	00 10	43.5	48.2	....	+ 4.7	+10	
29	11	20 30	89	16	10 20	41.1	49.3	....	+ 8.2	+20	
29	11	20 30	89	16	20 30	40.2	29.8	—10.4	....	—25	
29	11	20 30	89	16	30 40	27.8	17.8	—10.0	....	—36	At west shore, opposite "Cubitt's Gap."
						1872.	1876.				
29	11	30 40	89	15 16	50 00	32.4	33.4	....	+ 1.0	+03	East shore, below south Point of "Cubitt's Gap."
29	11	30 40	89	16	00 10	44.5	47.0	....	+ 2.5	+05	
29	11	30 40	89	16	10 20	43.3	50.3	....	+ 7.0	+16	
29	11	30 40	89	16	20 30	45.0	48.0	....	+ 3.0	+06	
29	11	30 40	89	16	30 40	38.0	33.0	— 5.0	....	—13	
29	11	30 40	89	16	40 50	....	....	....	....	....	At west shore.
29	11	40 50	89	16	00 10	....	....	....	....	....	Near edge of "Cubitt's Gap."
29	11	40 50	89	16	10 20	....	....	....	....	....	
29	11	40 50	89	16	20 30	49.3	53.5	....	+ 4.2	+08	
29	11	40 50	89	16	30 40	43.2	39.0	— 4.2	....	—09	
29	11	40 50	89	16	40 50	26.5	22.7	— 3.8	....	—14	West shore.
29	11 12	50 00	89	16	10 20	48.3	51.6	— 3.3	....	—06	At edge of "Cubitt's Gap."
29	11 12	50 00	89	16	20 30	55.0	55.0	+ 0.0	+ 0.0	....	
29	11 12	50 00	89	16	30 40	....	....	....	....	....	
29	11 12	50 00	89	16	40 50	42.0	37.1	— 4.9	....	—11	
29	11 12	50 00	89	16 17	50 00	....	....	....	....	....	West shore, opposite north point of "Gap."
29	12	00 10	89	16	20 30	....	....	....	....	....	Above north point of "Gap," east shore.
29	12	00 10	89	16	30 40	50.4	53.0	....	+ 2.6	+05	
29	12	00 10	89	16	40 50	....	....	....	....	....	
29	12	00 10	89	16 17	50 00	....	....	....	....	....	At west shore.
29	12	10 20	89	16	20 30	48.0	45.3	— 2.7	....	—05	At east shore.
29	12	10 20	89	16	30 40	57.0	55.2	— 1.8	....	—03	
29	12	10 20	89	16	40 50	48.0	47.3	— 0.7	....	—01	
29	12	10 20	89	16 17	50 00	36.7	38.8	....	+ 2.1	+05	
29	12	10 20	89	17	00 10	25.2	23.0	— 2.2	....	—08	At west shore.
29	12	20 30	89	16	20 30	27.0	39.0	....	+12.0	+44	At east shore.
29	12	20 30	89	16	30 40	51.0	54.0	....	+ 3.0	+05	
29	12	20 30	89	16	40 50	56.6	58.3	....	+ 1.7	+03	

TABLE 1.—*Comparison of surveys at Head of Passes, &c.*—Continued.

Area limits.						Mean depth.		Mean amount.		Per cent. of depth.	Remarks.
Latitudes.			Longitudes.			1872.	1876.	Shoaled.	Deepened.		
°	′	″	°	′	″	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
29	12	20 30	89	17	50 00	43.6	49.2	....	+ 5.6	+12	
29	12	20 30	89	17	00 10	32.8	31.5	— 1.3	....	—04	
29	12	20 30	89	17	10 20	....	....	....	....	....	At west shore.
29	12	30 40	89	16	30 40	....	....	....	....	....	At east shore.
29	12	30 40	89	16	40 50	55.5	57.6	....	+ 2.1	+03	

TABLE 2.—*Outline of flat opposite "Cubitt's Gap," as shown by the 24-foot curve of west shore.*

Distance along 3-ft. curve of west shore.	Distance of 24-ft. curve from 3-ft. curve.	Width of river.	Remarks.
Feet.	*Feet.*	*Feet.*	
0	260	3,720	24-foot curve parallel to shore, 3,000 feet above "Gap."
2,000	535	3,870	
4,000	820	....	Opposite to "Cubitt's Gap."
6,000	920	4,050	Opposite to south point of "Gap," nearly.
8,000	760	4,110	About 1,700 feet below "Gap."
10,000	720	4,215	
12,000	520	4,485	
14,000	500	4,815	

NOTE.—The 3-foot curve running parallel to the shore-line but much smoother, was taken as the base from which the ordinates to the 24-foot curve were measured.

MISSISSIPPI RIVER.

TABLE 3.—*Section from right bank (west shore) to east bank below south point of "Cubitt's Gap," in 1866 and* 1876, *A to B.*

Distance from shore-line.	Depth in feet at low-water.		Amount shoaled or deepened.		Remarks.
	1866.	1876.	In 10 years.	Ratio to depth.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	
0	4	0	— 4	—100	Latitude 29° 11′ 21″.7, longitude 89° 16′ 40″.0; shore-line of 1876 at west shore.
150	11	1	—10	— 90	
350	15	20	+ 5	+ 33	
500	36	22	—14	— 38	The section begins at west shore and runs somewhat diagonally downward across the stream on a line of soundings of survey of 1866, and ends about 960 feet below the south point of "Cubitt's Gap."
720	37	23	—14	— 37	
920	40	23	—17	— 42	
1,080	30	24	— 6	— 20	
1,200	36	25	— 9	— 25	
1,360	43	30	—13	— 29	
1,530	46	35	—11	— 24	
1,720	46	40	— 6	— 13	
1,950	42	38	— 4	— 09	
2,100	39	49	+10	+ 25	
2,230	36	50	+14	+ 39	
2,425	40	51	+11	+ 27	
2,610	40	51	+11	+ 27	
2,810	43	49	+ 6	+ 14	
2,970	42	47	+ 5	+ 12	

TABLE 3.—*Section from right bank (west shore) to east bank, &c.*—Continued.

Distance from shore-line.	Depth in feet at low-water.		Amount shoaled or deepened.		Remarks.
	1866.	1876.	In 10 years.	Ratio to depth.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	
3, 150	42	49	+ 7	+ 18	
3, 340	45	50	+ 5	+ 11	
3, 470	46	46	± 0	± 00	
3, 640	45	44	− 1	− 02	
3, 790	32	41	− 1	− 02	
3, 920	39	39	± 0	± 00	
4, 050	34	38	+ 4	+ 12	
4, 190	30	31	+ 1	+ 03	
4, 310	17	18	+ 1	+ 05	
4, 425	1	0	− 1	−100	Latitude 29° 11′ 35″.1, longitude 89° 15′ 53″.6; shore-line of 1876 at east shore.

MISSISSIPPI RIVER.

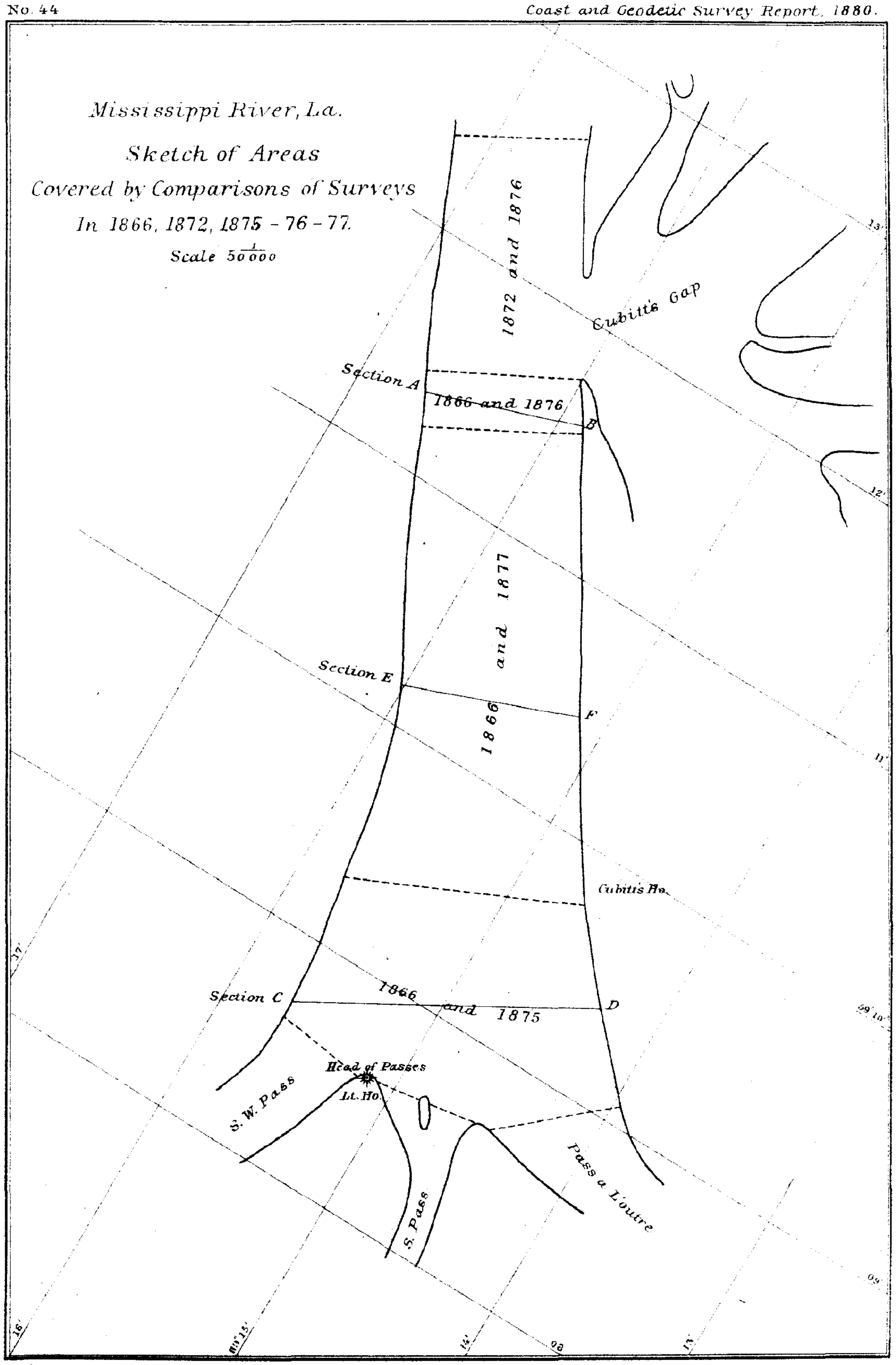
TABLE 4.—*Section from right to left bank, about 1¾ miles below "Cubitt's Gap," La., E to F.*

Distance from shore-line.	Depth in feet at low-water.		Amount shoaled or deepened.		Remarks.
	1866.	1877.	In 11 years.	Ratio to depth.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	
0	....	....	....	....	Latitude 29° 10′ 10″ 9 longitude 89° 16′ 03 .8 shore-line of 1877, west shore.
130	1	1	± 0	....	
250	5	6	+ 1	+ 20	
380	25	22	− 3	− 12	
540	31	23	− 8	− 25	
770	33	24	− 9	− 27	
950	34	26	− 8	− 23	
1, 110	33	29	− 4	− 12	
1, 310	39	29	−10	− 25	
1, 470	43	32	−11	− 25	
1, 620	45	33	−12	− 26	
1, 830	45	34	−11	− 24	
1, 970	46	36	−10	− 21	
2, 170	48	38	−10	− 20	
2, 375	49	39	−10	− 20	
2, 580	48	39	− 9	− 19	
2, 770	46	42	− 4	− 08	
2, 950	43	43	± 0	....	
3, 220	42	41	− 1	− 02	
3, 455	40	40	± 0	....	
3, 660	39	36	− 3	− 07	
3, 850	36	36	± 0	....	
4, 070	36	34	− 2	− 06	
4, 290	34	34	± 0	....	
4, 540	33	31	− 2	− 06	
4, 750	29	29	± 0	....	
4, 900	22	28	+ 6	+ 27	
5, 100	13	27	+14	+108	
5, 230	3	14	+11	+366	Latitude 29° 10′ 25″.7, longitude 89° 15′ 05″.5; shore-line of 1877, east shore.
5, 400	0	....	....	....	

MISSISSIPPI RIVER.

TABLE 5.—*Section at Head of Passes, about 2,342 feet above Head of Passes light-house, west shore to east shore, C to D.*

Distance from shore-line.	Depth in feet at low-water.		Amount shoaled or deepened.		Remarks.
	1866.	1875.	In 9 years.	Ratio to depth.	
Feet.	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	
0	....	....	....	....	Latitude 29° 08′ 45″.1, longitude 89° 15′ 41″.0; shore-line of 1875 at west shore.
144	2	2	± 0	± 00	
308	4	3	− 1	− 25	
436	5	5	± 0	± 00	This section follows one of the cross-section sounding lines of survey of 1846, starting on west shore and ending at east shore, near south end of Mississippi base.
580	9	12	+ 3	+ 33	
698	27	27	± 0	± 00	
862	31	27	− 4	− 13	
1,007	34	28	− 6	− 17	
1,175	33	29	− 4	− 12	
1,328	33	29	− 4	− 1	
1,502	34	28½	− 5½	− 1	
1,673	31	28½	− 3½	− 11	
1,847	33	28½	− 4½	− 13	
2,040	30	27	− 3	− 10	
2,224	31	27½	− 3½	− 11	
2,402	31	26	− 5	− 16	
2,575	31	26	− 5	− 16	
2,756	33	26	− 7	− 21	
2,953	33	27	− 6	− 18	
3,126	31	24	− 7	− 22	
3,297	30	23	− 7	− 23	
3,477	29	24	− 5	− 17	
3,655	27	22	− 5	− 18	
3,871	27	22	− 5	− 18	
4,052	27	23	− 4	− 15	
4,193	28	22	− 6	− 21	
4,380	30	20½	− 9½	− 31	
4,600	30	21	− 9	− 30	
4,796	30	21	− 9	− 30	
4,973	30	21½	− 8½	− 28	
5,170	28	21	− 7	− 26	
5,348	28	21	− 7	− 26	
5,521	27	22	− 5	− 18	
5,685	26	22	− 4	− 15	
5,905	23	22½	− 0½	− 02	
6,050	28	23	− 4	− 15	
6,220	27	23	− 5	− 18	
6,398	30	23	− 7	− 23	
6,549	31	23	− 8	− 25	
6,732	31	25	− 6	− 20	
6,890	31	26	− 5	− 16	
7,038	31	25	− 6	− 20	
7,172	31	25½	− 5½	− 17	
7,326	27	25½	− 1½	− 05	
7,529	33	24½	− 9	− 27	
7,690	31	26	− 5	− 16	
7,808	27	21	− 6	− 22	
7,979	7	14	+ 7	+100	
8,123	4	5	+ 1	+ 25	
8,242	2	1¾	− 0¼	− 12	
8,350	0	0	0	0	Latitude 29° 09′ 24″.8, longitude 89° 14′ 18″.4; shore-line of 1875, east shore.


Mississippi River, La.
Sketch of Areas
Covered by Comparisons of Surveys
In 1866, 1872, 1875 - 76 - 77.
Scale 1/50000
1872 and 1876
Cubitt's Gap
Section A
1866 and 1876
B
1866 and 1877
Section E
F
Cubitt's Ho.
Section C
1866 and 1875
D
Head of Passes
Lt. Ho.
S. W. Pass
S. Pass
Pass a Loutre
13'
12'
11'
59' 10'
09'
08
14'
13'
89° 15'
16'
17'

APPENDIX No. 11.

REPORT ON GEODESIC LEVELING ON THE MISSISSIPPI RIVER.

BY ANDREW BRAID, ASSISTANT.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, D. C., April 5, 1881.

DEAR SIR: In accordance with your instructions of September 28, 1880, I proceeded to Baton Rouge, where the schooner Quick was fitted out and a party organized.

The previous season's work terminated at Fort Adams, Miss., but on account of the unsatisfactory results of the river crossing at Red River Landing, it was deemed advisable to re-run the portion of the work between those two places.

Work was therefore commenced at Red River Landing November 10, but instead of following the same course as last year, the line was continued along the west bank of the river until nearly opposite Fort Adams, where a better place for the crossing was found. The width of the river at this point was 790 meters instead of 1,370 meters, as in the previous crossing. The lower stage of the river, moreover, giving the line of sight an elevation of over 15 feet above the surface of the water was highly advantageous, as was also the cloudy weather with which we were favored. Simultaneous observations were made in opposite directions by Mr. Isaac Winston and myself, and then the observers exchanged stations and repeated observations.

The following tabulation of results I quote from my November (1880) report. Stations A and B (in the accompanying illustration) are the positions of the instruments, the former on the west bank and the latter on the east bank:

	m.	
"Station A, Level No. 1, A. B., observer	= 0.0248	mean of 5 sets.
"Station B, Level No. 36, I. W., observer	= 0.0226	mean of 4 sets.
"Station B, Level No. 1, A. B., observer	= 0.0221	mean of 5 sets.
"Station A, Level No. 36, I. W., observer	= 0.0347	mean of 4 sets.
"Mean = B. M. 158 higher than 157	= 0.0260	

"The tide-gauge method on the contrary, assuming the water to have the same level on both sides, would indicate B. M. 157 to be the higher by $0^{m}.0297$, a difference of $5\frac{1}{2}$ centimeters from the result by spirit-leveling. The spirit leveling result is in this case undoubtedly correct, and the discrepancy, therefore, is due to the difference of level of the surfaces of the water at T and T′. This becomes evident when we examine the currents and find them running in opposite directions, there being a strong eddy on the eastern side. The surface of the water on that side must therefore be the higher. An inequality of the same kind must have existed at the crossing of last May at Red River Landing, for upon connecting with the terminal B. M. (XLIX) of last season, I find its height to be nearly 9 centimeters ($0.^{m}0893$) less than then computed." (A revision of computations with correction for inequality of pivots applied gives $0^{m}.0907$, which is practically the same.) "The former computation depends entirely on the tide-gauge results of the May crossing, the spirit-leveling observations being rejected on account of their wide range." I now find, however, that the latter, notwithstanding their discordance, give a mean result nearer the truth than the adopted one.

If we take the observations of May 8, 10, and 11 (days on which observations in both directions were obtained), we will have four sets in each direction, each set consisting of 10 to 12 repetitions. Their mean result is:

	m.
B. M. *a* lower than 127	0.0195
Tide-gauge result is B. M. *a* higher than 127	0.0718
Difference	0.0913

This makes the result at the terminal B. M. (XLIX) agree very clearly with this season's result, but under the circumstances I consider such close agreement accidental, as the means for the different days are all different, and have a range of 15 centimeters. . . . . "The bench-marks of the east side of the river, from Red River to Fort Adams, can be corrected by subtracting $+0^m.0907$ from their computed heights, as we know their relation to B. M. XLIX, the height of which has been re-determined.

"The following is a list of the bench-marks thus affected, with their heights (as per office computation) and corrections applied thereto:

B. M. XLVI = $+13^m.6412 - 0^m.0907 = +13^m.5505$.
B. M. XLVII = $+12^m.3812 - 0^m.0907 = +12^m.2905$.
B. M. XLVIII = $+21^m.2670 - 0^m.0907 = +21^m.1763$.

B. M. XLIX = $+18^m.1017 - 0^m.0907 = +18^m.0110$, result as re-determined.

As these bench-marks now form no part of the main line, they may be treated as a branch line or discarded entirely." This subject was fully treated in my November report, but for convenience of reference I have reproduced the essential portions here.

The weather during the season was unusually bad, and the roads consequently very bad also, which made the progress of the work both slow and laborious.

A junction was effected with Mr. Weir at a point about 4 miles south of Saint Joseph's, Tensas Parish, Louisiana, January 19, after which, in accordance with instructions, the vessel was taken to Algiers and laid up. Mr. C. A. Snow was left on board as ship-keeper, he having served in the same capacity when the vessel was laid up at Baton Rouge.

The distance surveyed during the season, including the branch to the Fort Adams bench-mark, is 170½ kilometers (106 miles), and the total distance of the junction B. M. (LXXIII) (*exclusive* of branch to Fort Adams), from Carrollton, is 470.7 kilometers, or 292 miles. Its height above B. M. I at Carrollton is $18^m.8250$, and the final disagreement of lines A and B = 5.4^{mm}.

A complete list of the bench-marks of this season, with their relative heights and distances, will accompany this report.

The permanent or "primary" bench-marks are indicated by the Roman numerals, and the temporary ones by the Arabic. The primary marks are usually granite or marble posts set in the ground, with their tops projecting three or four inches above the surface and bearing the inscription—

U. S.
B □ M
1880 or 1.

The instrument used is the same as heretofore used by me on the Mississippi River work, and also on the trans-continental line of levels, viz, Geodesic Micrometer-level, No. 1.

This instrument, originally made by Wurdemann, has been much improved at the Coast and Geodetic Survey Office. The accompanying illustrations (Nos. 46 and 47) will render clear the following brief description:

The telescope is mounted in rings, and can be turned about its optical axis. A vertical micrometer-screw is mounted so that the eye-end of telescope can be elevated or depressed, thus measuring the small angle between the horizon and target. The center of motion is below the object end Y of instrument. The eccentricity thus produced would prevent the use of the micrometer for the measurement of angles of any considerable size, on account of the variable value of a turn, but in practice the angle measured seldom exceeds five to ten divisions (22″ to 44″) of the screw, so that the effect of the eccentricity is inappreciable. The striding level is loose and reversible, thus admitting of elimination of level adjustment error.

One division of level = 5″.29; one division of micrometer screw = 4″.43; magnifying power of telescope = 26; focal distance, 16 inches, and aperture, $1\frac{3}{8}$ inches. The diaphragm carries one vertical and 4 horizontal spider lines arranged as in Fig. 1, illustration No. 47.

The angular distance from central line to *a* is 16′ 54″.5, and from central line to *c* is 16′ 35″.7. The central line and line *a* only are used in distance readings, and the extra line *b* is only inserted as a means of distinguishing *a* and *c* from each other.

The latest determination of inequality of pivots from observations made in December, 1880, and January and March, 1881, gives object-end pivot larger by 1″.6 than eye-end pivot. The linear value corresponding to this (depending on the distance) is, therefore, to be *added* to each rod reading.

Whole revolutions of the micrometer are shown on the steel scale shown in Fig. 2. The head of micrometer is graduated into 100 parts or *divisions*, and tenths of divisions are read by estimation.

The whole instrument is mounted on a substantial tripod with "open-work" legs, thus combining stability and portability, two essential requirements of a field instrument. The weight of instrument and stand, exclusive of striding level, is 23 pounds.

The levelling-rods, two in number, and marked A and B, are of wood, and over 3 meters long. They are made so as to avoid warping, and a transverse section will be a Maltese cross. The face of rod is graduated to centimeters, and a brass scale also graduated to centimeters is inserted in the side. The target, which is rectangular and bears a white central line bounded by black spaces, and these again by white edges, moves by an endless chain, and is secured when in position by a clamping screw. The target carries over the brass scale an ivory scale graduated to millimeters. Tenths of millimeters are read by estimation. A circular level is attached to each rod so that it may always be held in a vertical position, and a thermometer is also inlaid by the side of the brass scale, so that temperature may be noted each time the rod is read.

The rods are graduated from below upwards, but the zero of scale is some distance above the foot of rod.

The index error for rod A is $0^{m}.0762$.

The index error for rod B is $0^{m}.0801$.

The foot of rods is of brass and convex, fitting into concavity in foot-plates.

The foot-plates are of cast iron and furnished with teeth on their under surface so that they may be firmly fixed to the ground.

METHOD OF OBSERVING.

Various methods have been tried, such as running the line forward and then backward, reading the bubble of level instead of micrometer head, using the latter simply as a pointer, &c.; but the method finally adopted as combining the greatest accuracy with the least outlay of time is as follows:

Two lines are run simultaneously, with the rods usually at different distances from the instrument, and to prevent the gradual accumulation of error, supposed to be due to running constantly in one direction, alternate sections are run in opposite directions. Each station of the instrument therefore contains two backsights and two foresights. In stations 1, 3, 5, &c., rod A, backsight, is invariably read first, then rod B, backsight, then rod A, foresight, and, finally, rod B, foresight. In stations 2, 4, 6, rod B takes precedence of A in both back and fore sights. If 4 rods could be used the mean time of observation of backsights could be made to agree with that of foresights by observing one backsight, then both foresights, and, finally, second backsight; and at the next station the order could be reversed so as to begin and end with a foresight. This would undoubtedly be the most perfect system: it would necessitate two extra rodmen, but something would be gained in accuracy and also in time. To attempt to carry this method out with only 2 rods would involve a great loss of time, as the rodmen would have to walk over the whole distance several times. Moreover, the changes in refraction during the extra time consumed at a station would probably introduce sufficient error to more than counterbalance any benefits derived from the system.

Each fore and back sight contains four readings of "horizon," and four of "target," which are derived as follows, the instrument, of course, being first adjusted and leveled, and the target placed approximately in the horizontal plane of the telescope:

1st. The eye end of bubble is brought to a given scale division (the selection of which depends on length of bubble, which should be nearly central) by means of micrometer screw, and the micrometer reading is recorded in column "horizon."

2d. By means of micrometer, bisect central white line of target and record micrometer reading in column "target."

3d. Reverse level. Repoint on target and record as before in "target" column.

4th. By means of micrometer screw bring *object* end of bubble to the same scale division as before, and record micrometer reading in column "horizon."

5th. Invert telescope about its optical axis and repeat step 4th.

6th. Bisect target and record reading in "target" column.

7th. Reverse level to original position and repoint on target, recording as before in "target" column.

8th. Repeat step 1st and record in "horizon" column.

The following diagram shows graphically the order of the observations. *E* and *I* indicate *erect* and *inverted* positions of the telescope, and *D* and *R direct* and *reverse* positions of the striding level.

		Horizon.	Target.
E	D	1	2
E	R	4	3
I	R	5	6
I	D	8	7

The distance is derived by observing the number of scale divisions of rod included between the middle and outer cross-hairs, the angular distance of said cross-hairs being known. The height of the target on the rod is read by the rodman from the brass and ivory scales before mentioned, and his reading checked by the observer or his aid. The temperature is also noted.

The mean of the four "target" readings, minus the mean "horizon" reading, gives the value in terms of the micrometer screw of the inclination or deviation of the target from the true horizontal line. This is reduced to linear measurement and applied as a correction to the rod reading. The other corrections to be applied are for inequality of pivots, curvature, and refraction and temperature. Resulting heights are, of course, derived by the usual formulae Backsight—foresight.

The following is a specimen of the record showing the complete observations at one station of the instrument:

[Left-hand page.]

BACK SIGHT.

Number of station.	Telescope.	Level.	Micrometer. Horizon.	Micrometer. Target.	Distance wire.	Upper and lower edge of target.	Rod reading and temperature.
May 22, 1880.							
Running from B. M. 137 to primary B. M. XLIX at Fort Adams, Miss.							
Rod A.							
11	E	D	40.611	40.600	1.734	1.93	1.9544
		R	590	600	....	1.98	
	I	R	590	580	....	....	82°
		D	590	578	....	....	
Means			40.595	40.589	22.0		
			−0.6				
Rod B.							
11	I	D	40.590	40.590	2.171	1.925	1.9505
		R	581	591	....	1.975	
	E	R	580	600	....	....	81°
		D	590	600	....	....	
Means			40.585	40.595	22.0		
			+1.0				

[Right-hand page.

FORE SIGHT.

Number of station.	Telescope.	Level.	Micrometer. Horizon.	Micrometer. Target.	Distance wire.	Upper and lower edge of target.	Rod reading and temperature.
Rod A.							
11	E	D	40.472	40.460	....	....	
		R	470	463	....	....	
	I	R	470	489	0.272	0.09	0.1174
		D	489	490	....	0.14	
Means			40.475	40.475	15.5		82°
			0.0				
Rod B.							
11	I	D	40.520	40.449	0.270	0.09	0.1144
		R	480	491	....	0.14	
	E	R	480	460	....	....	82°
		D	470	461	....	....	
Means			40.488	40.478	15.6		

Rods on primary B. M. XLIX at Fort Adams, on premises of J. R Matthews.

PROBABLE AND MEAN ERRORS.

The probable and mean errors of the season's work have been computed by the same method as heretofore employed.

The formula for mean error per kilometer for a single levelling is $K = \sqrt{\frac{1}{n}\left[\frac{2\,v^2}{s}\right]}$ and for two levellings $= \sqrt{\frac{1}{2\,n}\left[\frac{2\,v^2}{s}\right]}$

The formula for mean error for the whole distance is $\mu = \sqrt{\frac{[s]}{2\,n}\left[\frac{2\,v^2}{s}\right]}$

Probable error = mean error × .67 The probable error per kilometer is found to be $0^{mm}.9$, and for the whole distance ± $11mm.6$ The following, from the "Präcisions-nivellement der Elbe," explains the derivation of the above formulæ.

"Let $v, v_1, v_2, \ldots \ldots v_m$ represent the differences between the results of a number (m) of separate levellings from their arithmetical mean, then

$$\text{The square of the mean error of a single levelling} = \frac{[vv]}{m-1}$$

$$\text{The square of the mean error of the arithmetical mean} = \frac{[vv]}{m\,(m-1)}$$

In the case before us we have two levellings, so that $vv = v_1, v_1$, and the above expressions will reduce to $2\,vv$ and $\frac{2\,vv}{2}$ respectively.

Let s represent the length of the line of levelling (expressed in kilometers), for which the errors are sought, then by the assumption that the squares of the errors are to each other as the distances, we get:

The square of the mean error per kilometer for a single levelling $= \frac{2\,vv}{s}$

And

The square of the mean error per kilometer for two levellings $= \frac{1}{2}\,\frac{2\,vv}{s}$

Let there be n distances for whose total length the errors are to be found, and taking the $s, s_1, s_2, \ldots s_n$ as equal, or so nearly equal, that the weights of the $\frac{2\,vv}{s}$ and $\frac{1}{2}\,\frac{2\,vv}{s}$ may be taken as equal, then the arithmetical means of all the $\frac{2\,vv}{s}$ and $\frac{1}{2}\,\frac{2\,vv}{s}$ will give the most probable value of the squares of the mean errors, *i. e.*: The square of the mean error per kilometer, derived from n distances for a single levelling $= \frac{1}{n}\left[\frac{2\,vv}{s}\right]$

The square of the mean error per kilometer for the mean of two levellings $= \frac{1}{2\,n}\left[\frac{2\,vv}{s}\right]$

Finally assuming that the errors increase as the square root of the distance, we find that the square of the mean error of the difference in height for one levelling $= \frac{[s]}{n}\left[\frac{2\,vv}{s}\right]$ and for a double measurement $= \frac{[s]}{2\,n}\left[\frac{2\,vv}{s}\right]$

The formulæ will therefore be expressed thus:

$$\text{Mean error per kilometer for single levelling} = K = \sqrt{\frac{1}{n}\left[\frac{2\,v^2}{s}\right]}$$

$$\text{Mean error per kilometer for double levelling} = \sqrt{\frac{1}{2\,n}\left[\frac{2\,v^2}{s}\right]}$$

$$\text{Mean error of mean of two levellings over whole distance} = \mu = \sqrt{\frac{[s]}{2\,n}\left[\frac{2\,v^2}{s}\right]}$$

Abstract of results.

	Distance in kilometers.	Rod A.	Rod B.	Mean.	Diff.
		m.	*m.*	*m.*	*mm.*
B. M. I to 127	305.140	+13.0474	+13.0386	*±13.0637	8.8
127 to 148	1.068	− 4.1266	− 4.1231	− 4.1348	3.5
148 to 147	.123	− 1.5952	− 1.5955	− 1.5954	0.3
147 to 146	.457	− 1.0326	− 1.0322	− 1.0324	0.4
146 to 145	.044	+ 1.2495	+ 1.2489	+ 1.2492	0.6
145 to 149	2.122	+ 3.2480	+ 3.4267	+ 3.4273	1.3
149 to 150	2.113	− 0.0507	− 0.0555	− 0.0531	4.8
150 to 151	1.286	+ 0.5487	+ 0.5492	+ 0.5490	0.5
151 to 152	3.081	+ 1.2950	+ 1.2972	+ 1.2961	2.2
152 to L	2.076	+ 0.5557	+ 0.5583	+ 0.5570	2.6
127 to L	12.370	+ 0.2718	+ 0.2740	+ 0.2729	2.2
I to 127*	*305.140			*+13.0637	*8.8
I to L	317.510			+13.3366	6.6
L to 153	.671	− 0.3123	− 0.3121	− 0.3122	0.2
153 to LI	1.426	+ 0.3507	+ 0.3543	+ 0.3525	3.6
L to LI	2.097	+ 0.0384	+ 0.0422	+ 0.0403	3.8
I to L*	*317.510			*+13.3366	*6.6
I to LI	319.607			+13.3769	2.8

* Office computation.

Abstract of results—Continued.

	Distance in kilometers.	Rod A.	Rod B.	Mean.	Diff.
		m.	*m.*	*m.*	*mm.*
LI to 154	.736	+ 1.0168	+ 1.0205	+ 1.0186	3.7
154 to 155	1.594	− 0.8590	− 0.8603	− 0.8596	1.3
155 to 156	.203	− 3.9110	− 3.9097	− 3.9104	1.3
156 to 157	.077	− 4.6428	− 4.6428	− 4.6428	0.0
157 to 158	.838	+ 0.0260	+ 0.0260	+ 0.0260	0.0
158 to XLIX	1.618	+13.0019	+13.0027	+13.0023	0.8
LI to XLIX	5.066	+ 4.6319	+ 4.6364	+ 4.6341	4.5
I to LI*	*319.607	....	....	*+13.3769	*2.8
I to XLIX	324.673	....	....	+18.0110	1.7
LI to 154	.736	+ 1.0168	+ 1.0205	+ 1.0186	3.7
154 to 155	1.594	− 0.8590	− 0.8603	− 0.8596	1.3
155 to 159	1.201	− 2.0816	− 2.0744	− 2.0780	7.2
159 to 160	2.665	+ 1.1113	+ 1.1118	+ 1.1116	0.5
160 to 161	2.601	− 0.4593	− 0.4615	− 0.4604	2.2
161 to LII	3.180	+ 2.2651	+ 2.2669	+ 2.2660	1.8
LI to LII	11.977	+ 0.9933	+ 1.0030	+ 0.9982	9.7
I to LI*	*319.607	....	....	*+13.3769	*2.8
I to LII	331.584	....	....	+14.3751	6.9
LII to 162	5.508	− 1.8425	− 1.8339	− 1.8382	8.6
162 to LIII	.141	+ 0.5752	+ 0.5759	+ 0.5755	0.7
LII to LIII	5.649	− 1.2673	− 1.2580	− 1.2627	9.3
I to LII*	*331.584	....	....	*+14.3751	*6.9
I to LIII	337.233	....	....	+13.1124	16.2
LIII to 163	5.606	− 5.2620	− 5.2580	− 5.2600	4.0
163 to 164	1.611	+ 1.7394	+ 1.7401	+ 1.7398	0.7
164 to 165	2.237	+ 3.3864	+ 3.3846	+ 3.3855	1.8
165 to 166	.746	− 0.7938	− 0.7928	− 0.7933	1.0
166 to 167	3.354	− 0.3597	+ 0.3604	+ 0.3600	0.7
167 to 168	2.920	+ 1.6530	+ 1.6549	+ 1.6540	1.9
168 to LIV	1.019	+ 0.3487	+ 0.3446	+ 0.3446	4.1
LIII to LIV	17.493	+ 1.4314	+ 1.4338	+ 1.4326	2.4
I to LIII*	*337.233	....	....	*+13.1124	*16.2
I to LIV	354.726	....	....	+14.5450	18.6
LIV to 169	3.447	− 0.8702	− 0.8713	− 0.8707	1.1
169 to 170	3.806	+ 0.5805	+ 0.5738	+ 0.5771	6.7
170 to 171	1.204	− 0.2154	− 0.2204	− 0.2179	5.0
171 to LV	3.038	+ 0.2667	+ 0.2661	+ 0.2664	0.6
LIV to LV	11.495	− 0.2384	− 0.2518	− 0.2451	13.4
I to LIV*	*354.726	....	....	*+14.5450	*18.6
I to LV	366.221	....	....	+14.2999	5.2
LV to 176	.171	+ 0.2787	+ 0.2776	+ 0.2781	1.1
176 to 175	2.477	− 1.1423	− 1.1459	− 1.1441	3.6
175 to 174	1.578	− 0.6933	− 0.6894	− 0.6914	3.9
174 to 173	.888	+ 0.3258	+ 0.3250	+ 0.3254	0.8
173 to 172	1.445	+ 0.4119	+ 0.4130	+ 0.4125	1.1
172 to 178½	2.092	+ 2.4298	+ 2.4272	+ 2.4285	2.6
178½ to LVI	.835	+ 0.1425	+ 0.1455	+ 0.1440	3.0
LV to LVI	9.486	+ 1.7531	+ 1.7530	+ 1.7530	0.1
I to LV*	*366.221	....	....	*+14.2999	*5.2
I to LVI	375.707	....	....	+16.0529	5.1

*Office computation.

Abstract of results—Continued.

	Distance in kilometers.	Rod A.	Rod B.	Mean.	Diff.
		m.	*m.*	*m.*	*mm.*
LVI to 178½	.835	− 0.1425	− 0.1455	− 0.1440	3.0
178½ to 178	1.183	− 0.8995	− 0.9020	− 0.9007	2.5
178 to 177	3.228	+ 0.2249	+ 0.2290	+ 0.2269	4.1
177 to LVII	.158	− 0.0179	− 0.0170	− 0.0175	0.9
LVI to LVII	5.404	− 0.8350	− 0.8355	− 0.8353	0.5
I to LVI*	*375.707			*+16.0529	*5.1
I to LVII	381.111			+15.2176	4.6
LVII to 179	3.174	− 0.8579	− 0.8574	− 0.8577	0.5
179 to 180	2.418	+ 2.0092	+ 2.0103	+ 2.0098	1.1
180 to LVIII	.847	− 2.6947	− 2.6954	− 2.6950	0.7
LVII to LVIII	6.439	− 1.5434	− 1.5425	− 1.5429	0.9
I to LVII*	*381.111			*+15.2176	*4.6
I to LVIII	387.550			+13.6747	5.5
LVIII to 181	4.059	+ 2.9912	+ 2.9864	+ 2.9888	4.8
181 to LIX	1.298	− 0.2397	− 0.2442	− 0.2420	4.5
LVIII to LIX	5.357	+ 2.7515	+ 2.7422	+ 2.7468	9.3
I to LVIII*	*387.550			*+13.6747	*5.5
I to LIX	392.907			+16.4215	3.8
LIX to LX	.773	+ 0.3138	+ 0.3154	+ 0.3146	1.6
I to LIX*	*392.907			*+16.4215	*3.8
I to LX	393.680			+16.7361	2.2
LX to 182	3.395	− 0.5412	− 0.5430	− 0.5421	1.8
182 to 183	3.445	+ 0.6307	+ 0.6295	+ 0.6301	1.2
183 to 184	1.544	− 0.8060	− 0.8073	− 0.8066	1.3
184 to 185	2.283	− 0.2041	− 0.2002	− 0.2022	3.9
185 to LXI	2.650	+ 0.1107	+ 0.1129	+ 0.1118	2.2
LX to LXI	13.317	− 0.8099	− 0.8081	− 0.8090	1.8
I to LX*	*393.680			*+16.7361	*2.2
I to LXI	406.997			+15.9271	0.4
LXI to 186	1.985	+ 0.6065	+ 0.6049	+ 0.6057	1.6
186 to LXII	.089	− 0.0548	− 0.0543	− 0.0545	0.5
LXI to LXII	2.074	+ 0.5517	+ 0.5506	+ 0.5512	1.1
I to LXI*	*406.997			*+15.9271	*0.4
I to LXII	409.071			+16.4783	1.5
LXII to LXIII	.948	− 0.6510	− 0.6472	− 0.6491	3.8
I to LXII*	*409.071			*+16.4783	*1.5
I to LXIII	410.019			+15.8292	2.3
LXIII to 189	1.439	+ 1.7348	+ 1.7347	+ 1.7348	0.1
189 to LXIV	1.335	− 0.6526	− 0.6453	− 0.6490	7.3
LXIII to LXIV	2.774	+ 1.0822	+ 1.0894	+ 1.0858	7.2
I to LXIII*	*410.019			*+15.8292	*2.3
I to LXIV	412.793			+16.9150	9.5
LXIV to 188	1.344	+ 0.6462	+ 0.6443	+ 0.6453	1.9
188 to 187	2.398	− 1.2349	− 1.2432	− 1.2391	8.3
187 to LXV	.221	+ 1.6754	+ 1.6751	+ 1.6752	0.3
LXIV to LXV	3.963	+ 1.0867	+ 1.0762	+ 1.0814	10.5
I to LXIV*	*412.793			*+16.9150	*9.5
I to LXV	416.756			+17.9964	1.0

* Office computation.

Abstract of results—Continued.

	Distance in kilometers.	Rod A.	Rod B.	Mean.	Diff.
		m.	*m.*	*m.*	*mm.*
LXV to 190	2.406	− 0.2826	− 0.2833	− 0.2830	0.7
190 to 189½	1.716	+ 0.2030	+ 0.2035	+ 0.2033	0.5
189½ to 191	1.917	− 0.3407	− 0.3348	− 0.3377	5.9
191 to 192	1.825	− 1.6180	− 1.6223	− 1.6202	4.3
192 to 193	1.027	+ 0.0796	+ 0.0838	+ 0.0817	4.2
193 to 196	1.882	+ 2.6052	+ 2.6000	+ 2.6026	5.2
196 to LXVI	.117	− 1.8288	− 1.8295	− 1.8291	0.7
LXV to LXVI	10.890	− 1.1823	− 1.1826	− 1.1824	0.3
I to LXV*	*416.756			*+17.9964	*1.0
I to LXVI	427.646			+16.8140	1.3
LXVI to 196	.117	+ 1.8288	+ 1.8295	+ 1.8291	0.7
196 to 195	1.072	− 0.4446	− 0.4430	− 0.4438	1.6
195 to 194	1.597	− 1.7330	− 1.7323	− 1.7326	0.7
194 to 197	1.865	+ 1.9742	+ 1.9758	+ 1.9750	1.6
197 to 198	2.207	+ 0.4514	+ 0.4443	+ 0.4479	7.1
198 to 199	2.873	− 1.3314	− 1.3362	− 1.3338	4.8
199 to 212	.785	− 0.0666	− 0.0646	− 0.0656	2.0
212 to LXVII	.224	− 0.1942	− 0.1912	− 0.1927	3.0
LXVI to LXVII	10.740	+ 0.4846	+ 0.4823	+ 0.4835	2.3
I to LXVI*	*427.646			*+16.8140	*1.3
I to LXVII	438.386			+17.2975	3.6
LXVII to 212	.224	+ 0.1942	+ 0.1912	+ 0.1927	3.0
212 to 211	2.125	+ 1.3774	+ 1.3788	+ 1.3781	1.4
211 to 205	1.852	− 0.4472	− 0.4436	− 0.4454	3.6
205 to 204	2.189	+ 0.7175	+ 0.7243	+ 0.7209	6.8
204 to LXVIII	2.616	− 0.8380	− 0.8332	− 0.8356	4.8
LXVII to LXVIII	9.006	+ 1.0039	+ 1.0175	+ 1.0107	13.6
I to LXVII*	*438.386			*+17.2975	*3.6
I to LXVIII	447.392			+18.3082	10.0
LXVIII to 203	1.584	+ 0.6387	+ 0.6418	+ 0.6402	3.1
203 to LXIX	.439	+ 0.0729	+ 0.0707	+ 0.0718	2.2
LXVIII to LXIX	2.023	+ 0.7116	+ 0.7125	+ 0.7120	0.9
I to LXVIII*	*447.392			*+18.3082	*10.0
I to LXIX	449.415			+19.0202	10.9
LXIX to LXX	1.915	− 1.1632	− 1.1611	− 1.1622	2.1
I to LXIX*	*449.415			*+19.0202	*10.9
I to LXX	451.330			+17.8580	13.0
LXX to 202	1.265	+ 1.6265	+ 1.6278	+ 1.6271	1.3
202 to 201	2.573	+ 0.3206	+ 0.3167	+ 0.3186	3.9
201 to 200	1.798	− 0.7174	− 0.7175	− 0.7174	0.1
200 to LXXI	.069	− 1.4117	− 1.4117	− 1.4117	0.0
LXX to LXXI	5.705	− 0.1820	− 0.1847	− 0.1834	2.7
I to LXX*	*451.330			*+17.8580	*13.0
I to LXXI	457.035			+17.6746	10.3
LXXI to 200	.069	+ 1.4117	+ 1.4117	+ 1.4117	0.0
200 to 207	1.666	+ 1.2320	+ 1.2216	+ 1.2268	10.4
207 to 206	2.279	− 0.2691	− 0.2714	− 0.2702	2.3
206 to LXXII	1.855	− 0.7622	− 0.7605	− 0.7614	1.7
LXXI to LXXII	5.869	+ 1.6124	+ 1.6014	+ 1.6079	11.0
I to LXXI*	*457.035			*+17.6746	*10.3
I to LXXII	462.904			+19.2815	0.7

*Office computation.

Abstract of results—Continued.

	Distance in kilometers.	Rod A.	Rod B.	Mean.	Diff
		m.	*m.*	*m.*	*mm.*
LXXII to 210	2.493	+ 1.4229	+ 1.4326	+ 1.4277	0.3
210 to 209.............	1.519	+ 0.0347	+ 0.0276	+ 0.0312	7.1
209 to 208..............	1.783	− 0.0399	− 0.0479	− 0.0439	8.0
208 to LXXIII	1.965	− 1.8719	− 1.8712	− 1.8715	0.7
LXXII to LXXIII...	7.760	− 0.4542	− 0.4589	− 0.4565	4.7
I to LXXII*	*462.904	....	....	*+19.2815	*0.7
I to LXXIII	†470.664	....	....	+18.8250	5.4

* Office computation. † Distance exclusive of branch to Fort Adams.

Probable error per kilometer = 0.9 mm.
Probable error for whole distance = 11.6 mm.

No. 1

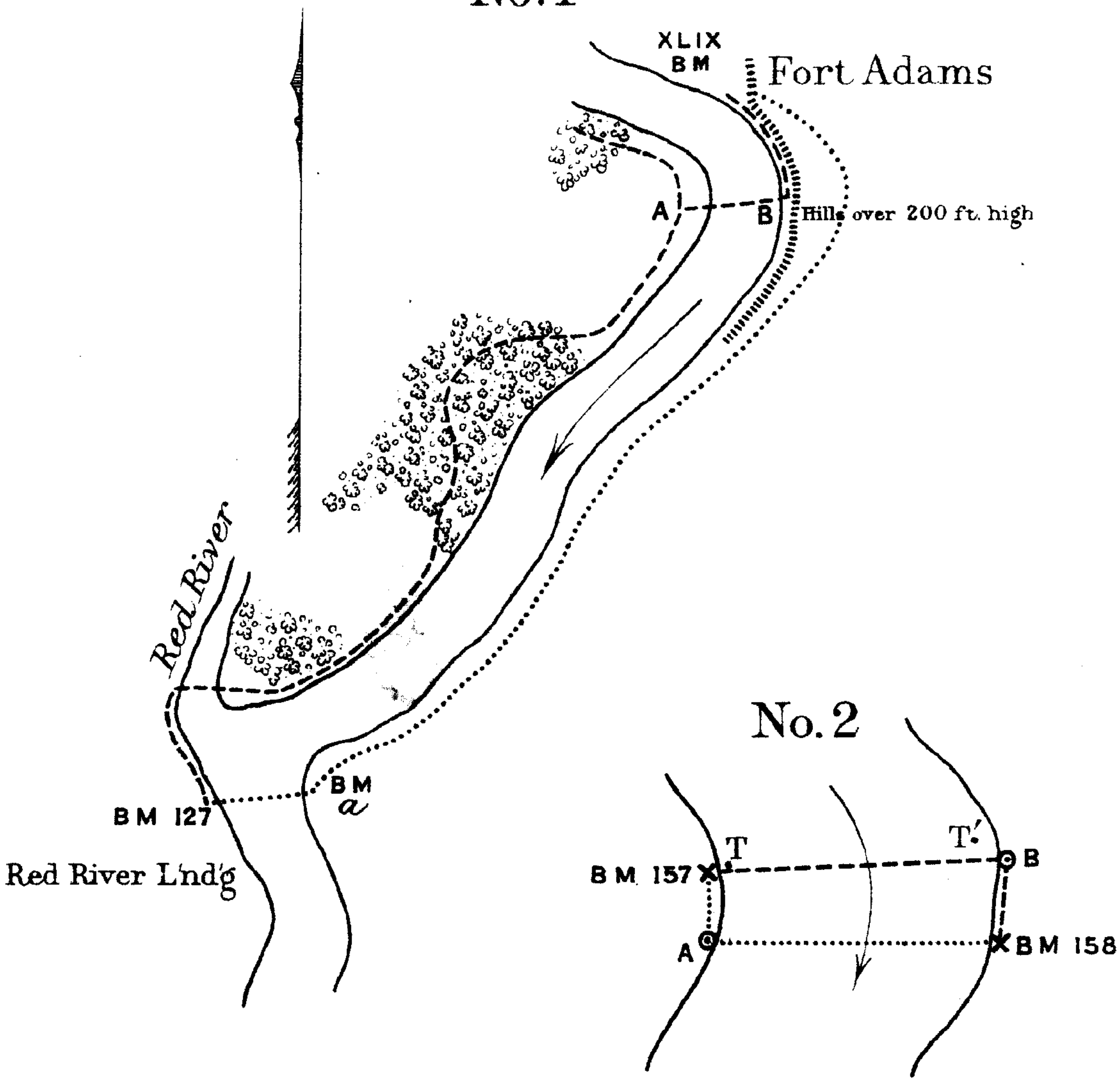
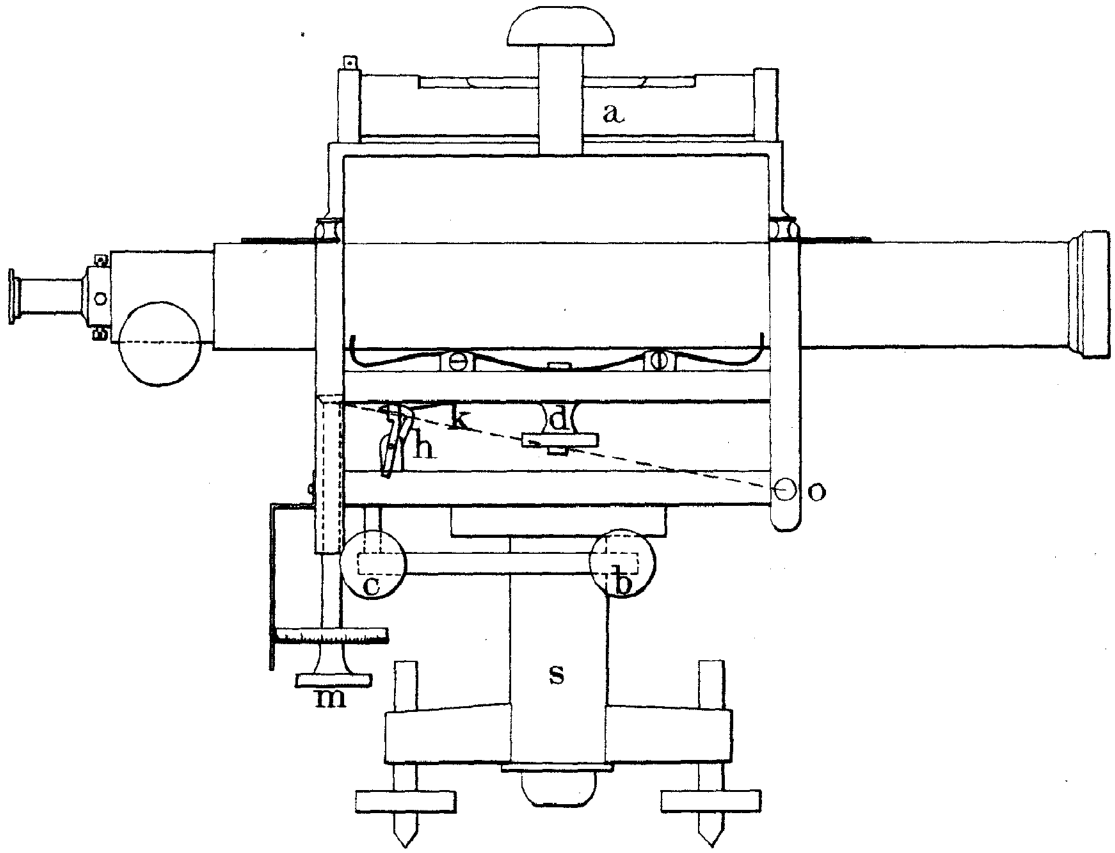


FIG. No. 1 – *The dotted line shows course of line of levels from Red River Ld'g to Ft. Adams, May 1880; while line drawn in dashes shows the route followed this season.*

FIG. No. 2 – A & B *are positions of instruments, and the dotted and broken lines the sights observed from each to connect* B.M.s 157 & 158. T & T' *are tide gauges.*

Fig. 1



SIDE VIEW OF

GEODESIC MICROMETER LEVEL No. 1

a represents striding level; b, the clamping screw; c, the tangent screw; m, the micrometer screw; d, a screw for raising telescope in the Y's; o, center of motion imparted by micrometer screw, and broken line, k-d-o, the radius (variable). The whole instrument can be revolved about s. When carrying the instrument from station to station, the pressure is entirely removed from the micrometer screw by means of the hook h, which is held in place by the spring k.

Fig. 2

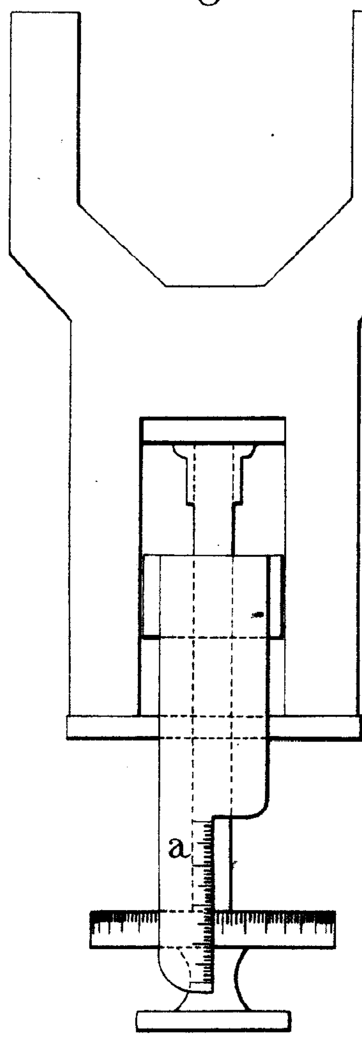
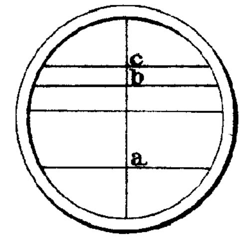


fig. 1



FRONT VIEW OF

MICROMETER SCREW

GEODESIC MICROMETER LEVEL No. 1

The steel scale a is graduated to indicate whole turns of the micrometer, and at the same time its edge serves as reading mark for the graduated micrometer head.

APPENDIX No. 12.

REPORT ON THE BLUE CLAY OF THE MISSISSIPPI RIVER.

By GEORGE LITTLE, Ph. D.

ATLANTA, GA., *July* 4, 1880.

DEAR SIR: In accordance with your letter of instructions, I have made, during the months of February, March, and December of last year, a "study and report on the so-called 'blue-clay' problem of the Mississippi River." As you have expressed the special question to be, "Is this formation one antedating geologically the present river, and into which the river has dug a bed, or is it a deposit by the river itself, in which it has formed its own bed, as in the case of the 'Passes'?" I have made a careful examination of the geological formations from Memphis to New Orleans, and present herewith sections (thirty-three in number) of all the prominent exposures or outcrops either made by myself or by competent observers. viz:

Sir Charles Lyell; second visit to the United States.

David Dale Owen, State Geologist of Arkansas.

Eugene W. Hilgard, State Geologist of Mississippi.

James M. Safford, State Geologist of Tennessee.

Eugene A. Smith, State Geologist of Alabama.

F. V. Hopkins, State Geologist of Louisiana.

For a more thorough knowledge of the river and its history, I have studied the—

Report on the Mississippi River. Humphreys and Abbot, 1876.

Report on the Mississippi and Ohio Rivers. Chas. Ellet.

Geological Description of Louisiana. Wm. Darby.

Géologie Pratique de Louisiane. R. Thomassy.

Silliman's Journal. E. W. Hilgard (March, April, May, 1871), on Geology of the Delta and Mud-Lumps of the Passes.

Report on the Rock-Salt Deposit of Petit Anse of the American Bureau of Mines, by Chas. Goessman.

Smithsonian Contributions to Knowledge, No. 248; on the Geology of Lower Louisiana. Eugene W. Hilgard.

Reports upon the specimens obtained from borings made in 1874, between the Mississippi River and Lake Borgne, to Engineer Department United States Army, by Prof. E. W. Hilgard and Dr. F. V. Hopkins, 1878.

The Physics of the Gulf of Mexico and of its Chief Affluent, the Mississippi River, by Caleb G. Forshey. New Orleans, La., 1878.

Improvement of the Mississippi River and its Alluvial Lands. H. Mis. Doc. No. 13, Forty-fifth Congress, third session. Memorial of John Cowdon, January, 1879.

Dr. W. J. Carroll's New Theory in that Branch of Natural Science known as River Hydraulics. Natchez, 1878.

Official Register, Louisiana State University, 1870, 1871, 1872, 1877, in which reports are made by Profs. F. V. Hopkins and S. H. Lockett.

Special Report of the Board of State Engineers to the Governor of Louisiana on the Mouth of Red River and the Falls at Alexandria. January 23, 1874; New Orleans; by E. H. Angamar and M. Jeff. Thompson.

Reconnaissance of Mississippi River from Cairo to New Orleans; to accompany Third Subdivision, Mississippi Route to the Seaboard. Act of Congress of June 23, 1874. By Maj. Chas. R. Suter.

Map of Mississippi River between mouths of the Illinois and Ohio Rivers, 1870, by Col. James H. Simpson, U. S. A.

Map of Mississippi River between Cairo and New Orleans.

Report on Geology of Missouri. G. C. Swallow.

Report on Geology of Arkansas. D. D. Owen.

Report on Geology of Tennessee. J. M. Safford, 1869.

Report on Geology of Mississippi. B. L. C. Wailes, 1854.

Report on Geology of Mississippi. E. W. Hilgard, 1860.

Report on Geology of Louisiana. F. V. Hopkins, 1870, 1871, 1872, 1877.

Report on Geology of Alabama. M. Tuomey, 1850, 1858.

Report on Geology of Illinois. A. C. Worthen.

Report on Geology of Iowa. C. A. White.

The history of the Mississippi River affords an epitome of the history of that portion of the continent embraced within the United States. Its headwaters rise in the oldest Azoic rocks, near the line of British America, from the springs and lakes of Minnesota, and its affluents drain the western slope of the Appalachian water-shed as well as the eastern side of the Rocky Mountains.

It has excavated its bed through the Paleozoic rocks of Wisconsin, Iowa, Illinois, Missouri, and Kentucky. Its banks in these States are mostly composed of sandstone and limestone, which have confined the waters to a comparatively narrow channel. But, below the mouth of the Ohio, in latitude 36° 58′, and indeed above, at Cape Girardeau, in latitude 37° 20′, softer material allows the stream greater latitude, and we find that as soon as the Cretaceous and Tertiary rocks begin to appear, the river has at different times spread out over much wider area.

From Cairo, in latitude 37° 00′, to the Gulf of Mexico, in latitude 29° 00′, the successive elevations of the continent have brought to the surface the rocks of different periods in Mesozoic and Caenozoic times in regular arrangement, with the mouth of the Mississippi River as a center, in approximately concentric circles, or perhaps more accurately stated as the sides of a triangle whose apex is near Cairo, in latitude 37° 00′, and whose base is the Gulf shore, in about latitude 29° 00′. Thus we find the *Cretaceous* rocks extending from the vicinity of Cairo, southeastward to Alabama and Georgia, where they terminate on the east side of the Mississippi, and through Arkansas to and through Texas on the west side.

The *Tertiary* rocks extend next to these on both sides of the river, and border the Mississippi bottom or lands subject now to overflow as far south as Chicot, La., in latitude 33° 00′ on the west, and Fort Adams, Miss., in latitude 31° 05′ on the east side of the river.

The Quaternary clays border the Gulf from these points southward, and are said to extend some distance beneath the waters of the Gulf as sea bottom before the deep water sets in.

Immediately beneath these clays, but overlying the Cretaceous and Tertiary rocks, we find an extensive deposit of sand and pebbles, extending from Cairo to the Gulf, which corresponds in geological time with the great Drift period of the States north of the Ohio, and which probably resulted from the melting of the glaciers which strewed the bowlders and deposited the clays and sands over the surface of the Northern States.

The rounded forms of these pebbles and sand grains indicate their removal by a rapidly flowing current. By their grinding action, as well as the force of the current which bore them along, a deep basin has been cut out in the rocks of Cretaceous and Tertiary age, from Cairo to the Gulf, and this basin has afterwards been filled above the gravel and pebbles which covered its bottom by two distinct materials—the lower one a stiff clay formed in still water, the upper a fine silt, which shows no evidence of stratification, and must have been deposited from water free from any appreciable current.

While the clay has only been recognized as far north as Columbus, Ky., in latitude 36° 47′, the silt or loess has been traced as far as Sioux City, Ia., in latitude 42° 33′, and nearly to Fort Pierre, Dak., in latitude 44° 23′, of uniform texture and chemical composition, and with physical features so similar, that specimens from Sioux City cannot be distinguished by the eye from those found in the bluff at Fort Adams, in latitude 31° 05′, or Baton Rouge, in latitude 30° 27′, where this stratum terminates to the southward.

While the Mississippi River was filling up with calcareous silt, the wide bed eroded by the glacial stream, there was forming around the coast of the Gulf a marshy deposit of blue clay, which is now exposed at Port Hudson, on the Mississippi River, in latitude 30° 40′, and eastward to Mobile, and westward from Chicot to Victoria, Tex. These seem to have been closely related, though successive deposits, from the fact that, at the characteristic outcrop at Port Hudson, the calcareous silt is replaced by a yellowish, sandy hardpan, with no perceptible line of separation, while lower down, at Garig's ferry, on the Amite River, near the junction of the Comite, the hardpan becomes whitish and more clayey, and lower down again passes gradually into a light blue, sandy clay, which represents the blue clay found in the banks of the Mississippi, and as far eastward as Woodville, about twenty miles from Fort Adams.

In the sections made between Lake Borgne and the Mississippi River an alternation of sands and clays takes place, just such as we see now during a single season of high and low water on the river; sands and clays deposited alternately, according to the rapidity or slowness of the current.

A subsequent elevation of the southern portion of the Mississippi Valley has caused the river to make a new bed, cutting down into the silt, and in the course of ages it has removed again this light material, excepting a narrow strip along the bluff now bordering the "bottom" from Memphis, in latitude 35° 09′, along the edge of the Yazoo "bottom" to Vicksburg, Natchez, and Baton Rouge, in latitude 30° 27′ on the west, and Crowley's Ridge from the Missouri line, in latitude 36° 00′ to Helena, in latitude 34° 32′, and some isolated spots, such as Sicily Island, in Louisiana. The river has diminished in volume until at present it only occupies a bed about one mile in width, which is constantly changing, and may have moved its location from one side to the other of its basin, originally forty miles in width at Memphis. The melting of the snow on the Rocky Mountains, together with the accumulated water from the winter rains, causes it to overflow its present banks, and there is an annual deposit of alluvium extending from the banks across to the bluffs or highlands, which border what is known as the "Mississippi Bottom." This alluvial deposit varies with the materials brought down by the current, but is generally sand or clay. The clay is sometimes blue, sometimes green, and again, as along Red River and below, it is red.

Although there is so great a difference in the tenacity of the clay and the sand, the power of the current of the river is such that it seems to cut them with equal ease, in changing its bed, by washing out the lower strata of sand, and undermining the banks, so that acres often fall into the stream at once.

Within the last twenty years, under my own observation, the river has cut away a mile of one bank, and made a deposit of a mile on the opposite side, now overgrown with willow and poplar.

At Rodney, in latitude 31° 52′, where I landed from a steamer by a plank into a store in 1860, a sand bar has formed, making the landing two miles from the same store in 1880. Not many years have passed since boats landed at the foot of the bluff on which Vicksburg stands; last year the city had two miles' travel between it and the river landing, and a batture formed in front of the old landing fully a mile in width.

At another point I have seen a small ditch dug across a narrow neck of land half a mile wide, which connected the points at which the river had approached itself at the extremes of a bend 27 miles in length, and during one overflow the current began passing through this ditch, and before the river fell again a passage had been formed large enough to carry the largest steamers. This is now the main bed of the river, while the two ends of the bed have been silted up so as to form a lake 25 miles in length and crescent-shaped. Similar changes have happened repeatedly within the recollection of those now living, so that we may easily believe that if the bed has been changed 9 miles from west to east in ten years it may have moved 40 in any half century, and thus passed from one side of the "bottom" to the other. The materials of the banks from Memphis southward are mostly the clays and marls of the Tertiary until we reach Vicksburg, on the eastern side, where a bed of Tertiary limestone has checked the current; and again at Grand Gulf, in latitude 32° 02′, we find a Grand Gulf sandstone, which has caused another curve in the course of the river.

At Fort Adams, in latitude 31° 05′, a claystone has again offered an obstacle to its free flow and turned it westward. On the west side it has had free course, unless the limestone outliers of the Cretaceous ridge extending from Northern Louisiana to the Five Islands on the Gulf may have offered an obstruction. The whole Mississippi bottom appears at present to be uniform in its composition, consisting of alternating deposits of sand, where the currents were swift, and of beds of clay which have filled the low places when the current was sluggish or in eddies. The Alluvium in this respect resembles the other groups of the Quaternary period, as may be seen by the sections exposed in Alabama, as described by Tuomey; in Tennessee, as described by Safford, in Mississippi by Hilgard, in Arkansas by Owen, and by Hopkins in Louisiana.

SOUTHERN DRIFT.

The stratum marking the division between the ancient history of the Mississippi and the modern is that composed of sand and pebbles which is found all along the banks from the mouth of the Ohio, where we may suppose the old river entered the sea at the close of the Carboniferous time to the mouth at the Gulf of the Atchafalaya, where the new bed was cut out at the time the coast of the Gulf of Mexico had acquired nearly its present outline. While we find this stratum along the present course of the river, and along the border of the Carboniferous rocks, both east and west of the river, made up of pebbles of various sizes, the general surface of the Cretaceous and Tertiary is covered mostly by fine sand. Tuomey, in his first report on Alabama, 1850, described these deposits on the edge of the Carboniferous, and southward, as "superficial beds," as follows, page 159:

"I have in the preceding pages referred to beds of loose materials composed of pebbles, sand, clay, and loam, that are found scattered over the State, often completely hiding the underlying rocks. These may be studied to great advantage around Tuscaloosa, where they are fairly displayed on the slope of the hill towards the river, affording a striking illustration of the causes that are daily modifying the earth's surface. The upper bed is composed of red loam, and is underlaid by yellow and white sand, showing oblique lamination. These beds alternate with deposits of coarse quartzose pebbles of various colors; among these are often found agate, jasper, hornstone, and other varieties of quartz. The largest of the pebbles rarely exceed four inches in diameter. Occasionally rounded fragments of the sandstone of the coal measures may be detected, and, in a few instances, I have found pieces of the millstone grit much larger than the pebbles. But the most interesting portion of these materials consists in the cherty pebbles, having an oolitic structure, that give intelligence of the origin of the beds in which they are contained. I have stated that in the lower group of Carboniferous rocks there are beds of chert that are in structure oolitic. It is the ruins of these that have furnished the oolitic pebbles. Hornstone and agate also occur in these beds, and are doubtless the origin of the pebbles of these minerals. The degradation of the conglomerate of the millstone grit of the valley has also contributed quartz and other silicious materials. But we are not left altogether to infer from identity of mineral composition that the loose materials that cover the surface around Tuscaloosa have travelled from north to south from 100 to 150 miles, for we can trace the very path they travelled by the monuments they have left behind them on their journey. Along Jones's Valley beds of pebbles may be traced in spots beyond the influence of any cause now in operation that could place them there. And almost in the streets of Elyton Dr. Earle directed my attention to a low and narrow ridge composed of these materials; add to this that I have found at Tuscaloosa in these beds fossil corals, and among them a species of *strombodes*, a carboniferous fossil, and I think there can be but little risk in stating that the materials of these beds have traveled at least from the lower edge of Blount County, a distance of 70 miles. Within a very few years they have again taken up their line of march and are fast hastening on their downward course from Tuscaloosa. Tons are transported to the river by every shower of rain, and the only wonder is, that the navigation of the Warrior has not long ago been impeded by this vast accumulation that is taking place in its bed. * * * I am obliged to conclude that the beds around Tuscaloosa are newer than the Eocene Tertiary of the State."

Again, in his second report, p. 144, 1858, he says:

"They are found on the highest elevations, and are strewed along the valleys. Across the middle of the State and north of the verge of the Cretaceous rocks they are found in greatest force. Tuscaloosa stands upon these beds, as do the cities of Columbia, S. C., Petersburg and Richmond, Va. Washington and Baltimore have also their foundations on these strata."

The deposits everywhere show the action of water; they are often obliquely laminated, and sometimes beds of clay occur between the strata of sand and pebbles, indicating a short period of repose in the agitated waters. North of the paper-mill at Tuscaloosa, a bed of swamp-mud 4 feet thick outcrops at the base of a bank, in a ravine covered by a stratum 20 or 30 feet in thickness, of the usual material of these beds. The remains of grass, charred wood, compressed stems of woody plants, and the elytræ of insects, are found abundantly. I have elsewhere mentioned that these are among the newest beds of the State, excepting the alluvial, now in process of formation, but I hesitated about referring them to any particular period. I now think that they belong to the *drift*, although having but few points of resemblance to that formation at the north. *There*, considerable deposits are thrown together containing large, angular, and rounded masses of rock that could scarcely have resulted from the action of water alone; *here*, the largest of the rounded fragments seldom, if ever, exceed 6 inches in diameter, and there are no angular masses, excepting in the instances that I have mentioned, and the action of water in motion is everywhere impressed upon one as the sole transporting force. A remarkable feature in the distribution of this formation is its appearing in greatest force parallel with the Tertiary plane of the United States, and crossing the rivers at their falls. These beds are indeed scattered farther south, but their greatest accumulation takes place here, the thickness being often 100 feet.

If the southern drift be at all connected with that of the north, it may be explained by supposing that the northern glaciers suddenly melted, and that the water thus liberated in immense volume took a southern direction, carrying with it the débris torn from the surface over which it passed, until it met the Tertiary sea, upon the shores of which its burden was deposited. It is difficult to suppose that any force acting upon hard silicious fragments for so short a time as that necessary for their transportation from north to south would so completely round and polish them, and if we suppose these materials to have been already water-worn and scattered over the surface, and that they were merely brought together by this force, still one would suppose that a very considerable quantity of angular fragments would also be torn up and transported with the rest, which is not the case. But after all, we know too little of the grinding force that may be exerted by a mass of loose materials 100 feet in thickness, when in motion. This theory would sufficiently well account for that enormously long ridge of drift extending parallel with the Atlantic coast; for, the moment the current entered the Tertiary sea, its velocity would be checked, and the greater part of the transported detritus deposited. It can be demonstrated that this accumulation took place at a time when, if our southern rivers existed at all, they did not occupy their present beds, for they have almost all cut through the drift, after its deposition. In supposing that the drift was deposited on the margin of the Tertiary sea, the difficulty meets us that in the southern drift we have no marine remains, nor in truth organic remains of any sort beyond the silicified wood already mentioned, and yet beds of clay and fine sand are deposited in a manner that indicated a period of repose, and conditions favorable to the preservation of organic remains, if any organism existed in the sea. The only way by which I can account for this absence of every vestige of life in a sea that once teemed with life, is by supposing that, before the drift period, the bottom of this sea had been elevated and converted into dry land, and that at the commencement of the drift period a depression of the land took place; that the time between the influx of the sea and the deposition of the drift was too short for marine animals even to have commenced a colonization; and that the land was again elevated into its present position and subjected to long-continued denudation, which produced its present configuration; that after this elevation the rivers excavated their present channels. It must obviously be very difficult to assign the limits of the southern drift, for it is found scattered over the States, the materials becoming smaller as we proceed south, till they mingle with the sands on the coast, from which they cannot be distinguished. The remains of the mastodon are found on the surface, or are washed out by the streams.

BLUFF OR LOESS.

Prof. G. C. Swallow, in Geological Survey of Missouri, p. 69, says:

"The geological position of this formation in the series of Missouri rocks is easily determined. That it is newer than the drift is satisfactorily proved by the fact that it rests upon the latter formation, when both are present and undisturbed. It caps nearly all the bluffs of the Missouri and Mississippi within our State, forming the very highest deposits skirting their valleys. Thus while the bottom prairie occupies a higher geological horizon, the bluff is usually several hundred feet above it in the topographical.

"This formation when well developed usually presents a fine, pulverulent, obsolitely stratified mass of light grayish buff, silicious, and slightly indurated marl. Its color is usually variegated with deeper brown stains of oxide of iron. The bluff formation is often penetrated by numerous tubes or cylinders, about the size or thickness of pipe stems, some larger and others smaller. They are composed of clay, carbonate of lime, and oxide of iron, being argillo-calcareous oxide of iron, or calcareous clay ironstone."

These he attributes to the decayed roots of oak trees and other plants, and states further that, "These phenomena have been thus minutely investigated, not merely as interesting scientific facts, but also as one of the most useful agricultural features of this pre-eminently valuable formation; for upon it, and sustained by its absolutely inexhaustible fertilizing resources, rest the very best farms of the Mississippi and Missouri valleys. These tubes and holes also constitute the most thorough system of drainage imaginable."

A specimen of this deposit collected at Hannibal, Mo., gave Dr. Litton, in 100 parts, dried at 212° Fahr.:

Silica	77.02
Alumina and peroxide of iron	12.10
Lime	3.25
Magnesia	1.63
Carbonic acid	2.83
Water	2.43
Total	99.26

According to Bischoff's Chemical Geology, the loess of the Rhine, supposed by some to be identical with our bluff, gives the following results from two analyses:

	I.	II.	IV.
Silicic acid	58.97	81.04	62.43
Alumina	9.97	9.75	7.51
Peroxide of iron	4.25	6.67	5.14
Lime	0.02	....	....
Magnesia	0.04	0.27	0.21
Potash	1.11 }	2.27	1.75
Soda	0.84 }		
Carbonate of lime	20.16	....	17.63
Carbonate of magnesia	4.21	....	3.02
Loss by ignition	1.37	....	2.31
	99.94	100.00	....

"These analyses show a striking coincidence in the composition of these widely separated formations."

David Dale Owen, in Arkansas Geological Report of 1860, p. 412, in the description of Phillips County, says:

"Crowley's Ridge, which runs through Greene, Craighead, Poinsett, and Saint Francis Counties, forming the divide between the waters of the Saint Francis and White Rivers, terminates in Phillips County, just below the city of Helena. The top of this ridge, throughout its entire extent in Arkansas, is composed for the most part of silicious clay and marl of Quaternary date, usually resting on a bed of water-worn gravel."

The counterpart of Crowley's Ridge may be seen on the opposite side of the Mississippi River, at Memphis, thence running northward through the State of Tennessee and a part of Kentucky, crossing the Ohio River at Caledonia, in Illinois. In Tennessee this ridge reaches the river at the first, second, third, and fourth Chickasaw Bluffs. In Kentucky, at Hickman, Columbus, and

Jefferson's Bluff. The fourth Chickasaw Bluff, upon which Memphis is built, has an elevation of some 70 feet above low-water, and is entirely composed of yellowish marly clay, belonging to the Quaternary. At Randolph, on the second Chickasaw Bluff, the elevation is 200 feet above low-water, and for the sake of comparison, the following section obtained at that place is here given—

	Feet.
Quaternary:	
Sandy soil and subsoil, yellowish marly clay	85
Tertiary:	
Purplish pink clay	½
Yellowish sand and gravel	10
Brown silicious and lignitic clay shale	20
Upper bed of lignite	2
Ash-colored clay with fossil leaves	11
Lower bed of lignite	2½
Space—ash-colored silicious clay (?), to low-water Mississippi River	70
Aggregate	201

The yellow sand and gravel bed at the junction of the Quaternary and Tertiary is very variable in its character, but marks a distinct horizon through a district of country many miles in width; and, so far as known, extends in length from the southern part of Arkansas, running with a northeasterly strike through the eastern part of that State, the western part of Mississippi, Tennessee, Kentucky, and terminating in the southern part of Illinois. It is this member, cemented into a hard ferruginous conglomerate, which crosses the Ohio River at New Caledonia, in Illinois, and forms the Grand and Little chain on that stream.

Prof. B. L. C. Wailes, in his Report on the Geology of Mississippi in 1854, page 213, describes the

Loess or loam.

"A prominent and interesting feature, which distinguishes the counties bordering upon the Mississippi below the Yazoo, is found in that considerable deposit superimposed on the diluvial gravel, and which enters into the more easterly range of counties only along the margins of the Homochitto, Big Black, and Yazoo Rivers. Its average width, on the east side of the Mississippi, does not exceed 12 miles, and it is not met with at all on the western side, at least below the high lands of Arkansas. In the escarpment of the Mississippi bluffs, and in other natural sections, it is seen frequently of the thickness of 50 or 60 feet, thinning out as you recede from the river, until it is lost, and the red sands and pebbles on which it rests appear upon the surface. European geologists describe it, under the name of Loess or Lehm, as an 'alluvial, tertiary, sedimentary deposit, consisting of very fine, well-washed, yellow, calcareous loam, occurring over considerable tracts, and found reposing on every rock from the granite of Heidelberg to the gravel on the plains of the Rhine.' Here it has not the character of a local alluvium, and is probably due to the same causes that have spread the gravel and pebble deposits so widely over our surface.

"In March, 1846, being desirous of drawing the attention of M. Lyell, then on a visit to this State (Mississippi), to this peculiar and interesting deposit, he accompanied me on an excursion to one of the large ravines in Adams County, where it is exposed to the depth of at least 50 feet. Speaking of the result of this examination, in his travels, subsequently published, he remarks that the 'resemblance between this loam and the fluviatile silt of the valley of the Rhine, generally called loess, is most perfect.' Its embedded fossils are chiefly bleached helices or snail-shells together with mammalian remains. At every bluff on the Mississippi, from Fort Adams to the Yazoo, and in the hills in the rear, this loam is seen, and the roads leading into the interior cut into it deeply, and expose it on every hand."

Again, on page 283, he remarks:

"In the lake-marl, which occupies the lacustrine beds of the Drift period, we find a few fossil Testacea, such as lymnea, succinea, cyclas, two species of planorbis, and a very small paludina. One species of the planorbis, a very minute one, and the paludina mentioned, are not now found living in our waters; the others belong to existing species. The Testacea of the loess, or loam, referred to the same period, are, on the contrary, all terrestrial, embracing several species of helices or snails, all of which, it is believed, are yet found living in different parts of the continent, although some of them seem to have disappeared, or to have now no living representative in the fauna of this region. Among the species most numerous may be enumerated the *Helix albolabris, alternata, concara, elevata, fraterna, perspectiva, profunda, thyroides, tridentata*, &c. The great bone-bed of the Mississippi, or the depository of the extinct mammalia, is also found in the loess, the limits of which have already been defined. Throughout its extent the remains of the mastodon have been discovered."

Mastodon bones have been obtained in Bayou Sara, near Pinckneyville, in Wilkinson County; in various localities in Adams County; in Jefferson County, near the former town of Greenville; and in Warren County, in the deep cut of the railroad at Vicksburg; and in the vicinity of Big Black River, near the eastern line of the county.

In a few localities, such as the accompanying Testacea would indicate to have been the beds of fresh-water ponds or marshes, considerable portions of the skeleton have been found together, as if the animal may have perished there, and in such cases the bones are frequently in contact with considerable masses of a black, fatty earth, entirely dissimilar from the surrounding marl, and which may reasonably be supposed to have resulted from the decomposition of the viscera and the other perishable animal matter; but most usually the bones appear detached, as if drifted into their present position, and consequently it is not unusual to find a tusk, or a molar, a bone of the leg, or a joint of the vertebra, where no other vestiges are seen.

The most prolific locality of these remains is in Adams County, on Pine Ridge, in townships 7 and 8, range 3 west, about 6 miles north of Natchez, where a large and deep ravine has extended its ramifications over an area of several miles, and which, in its undermining progress of denudation, has been constantly exposing these remains for more than forty years, or from a period coeval with the first cultivation of the country through which it has its course. The bones generally lie from 10 to 20 feet below the general surface, and in the ravine on Pine Ridge, the remains of other animals have been found with them.

Among these may be enumerated those of the megalonyx and the tapir. Besides these the teeth of the fossil horse and ox are frequently found. Those of the bos are referred by Dr. Leidy to the *Bison latifrons* (fifth volume Smithsonian Contrib.). I am indebted to Dr. Leidy for the following list of mammalia:

Felis atrox.	*Tapir americanus* and *fossilis.*
Ursus americanus (*fossilis*).	*Megalonyx jeffersonii.*
Ursus amplidens.	*Magalonyx dissimilis.*
Equus americanus.	*Mylodon harlanii.*
Cervus virginianus.	*Ereptedon priscus.*
Bootherium cavifrons.	*Mastodon giganteus.*
Elephas primigenius.	

In the report of Captain Marcy of exploration of the Red River in 1852, Appendix D, page 183, the statement is made that "Dr. Shumard found on the Red River, 26 miles from Fort Washita, a deposit of ash-colored loam, 25 feet thick, containing terrestrial and fluviatile shells of the genera *Lymnea, Physa, Planorbis, Pupa*, and *Helix*, the whole resembling species found in the loam at New Harmony, Indiana, and elsewhere in the Mississippi Valley. This formation along the Mississippi constitutes what are known as the "Bluffs," and is a fluviatile accumulation laid down by the river when the region was at a lower level. In other words, it is an ancient alluvion. Its thickness and known extent along the Mississippi render it very probable that it will be found along most of the principal tributaries of that river. A similar deposit is found along the valley of the Rhine. Its thickness is from 200 to 300 feet, and it is a yellowish gray loam, consisting chiefly of clay, combined with sand and carbonate of lime. The same deposit is found along most of the principal valleys or tributaries of the Rhine, it evidently having been contemporaneously deposited. It is known in Germany under the name of loess. The occurrence of a formation along the Red River similar to those described leads me to believe that it will be found along most of the rivers which are tributary to the Mississippi, and it is quite probable that in the environs of Preston, and even over broad tracts of that region, there are extensive superficial alluvial deposits, which afford a soil that can scarcely be surpassed for its richness and fertility. (Extracted from reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War in 1853–'54. Vol. II, Thirty-third Congress, third session, Ex. Doc. No. 91.)

Prof. J. M. Safford describes the condition of things in Tennessee as follows (p. 119, Report on Tennessee, 1869):

THE MISSISSIPPI BOTTOM OR BOTTOMS.

Much of the area is covered with swamps and lakes; much, too, is wild and dark with heavy forests, even yet the retreat of the deer and other wild animals. Other portions, confined for the most part to a belt bordering the river, are in a good state of cultivation. The undeveloped agricultural resources of the division (of the State) as a whole are great, and, in proportion to its area, may make it, some day when its lands shall have been reclaimed, the wealthiest part of the State.

This magnificent valley plain (or bottom valley) is altogether, including the delta of the river, which is but the extension of the plain into the Gulf of Mexico, about 600 miles long. Mr. G. W. R. Bayley, a civil engineer of Louisiana, thus defines its limits. "The head of the alluvial plain or delta of the Mississippi may be assumed as occurring where rock *in situ* forms both shores, or at a point some 30 miles above the mouth of the Ohio, known as "The Chains." The entire alluvion, extending thence to the sea, comprises an area of about 40,000 square miles, and presents a front upon the Gulf of Mexico of 260 miles, 85 miles north, and 175 miles west of the river's mouth.

Sir Charles Lyell says of the valley plain, it is very variable in width from east to west, being near its northern extremity, or at the mouth of the Ohio, 50 miles wide, at Memphis 30, at the mouth of White River 80, and contracting again farther south, as at Grand Gulf, to 33 miles.

Taking high-water level as that of the great plain, the latter attains at the mouth of the Ohio an elevation of 320 feet above the Gulf. Considering the distance, the slope seaward is, therefore, very gradual. The valley plain proper is bounded on the east and west respectively by two ranges of highlands, approximately parallel and rising from 50 to 200 feet above the plain. These highlands generally present steep slopes or faces towards the plain, but preserve, for the most part, their elevation in the opposite direction, extending off as table lands. The Mississippi has probably during past ages occupied successively all parts of the area. At one day it may have washed the base of Crowley's Ridge. The valley plain as a whole is of great antiquity. It has apparently, however, been washed out of another more ancient and extensive alluvial plain, the remains of which are seen at a higher elevation in the slopes and cliffs of the highlands on each side (as, for example, in the bluffs of Tennessee and in the slopes of Crowley's Ridge in Arkansas). These highlands have a corresponding elevation. They present, too, along their opposing faces the same vertical succession of formations. The strata of loam, gravel, sand, and clay, whose edges now crop out upon their slopes, once extended across from side to side in continuous layers, forming the more ancient and higher plain. It has been the work of the river to carve out of this greater plain its great valley of "bottoms." The eastern bluff and the western ridge are at this day the limits of its lateral movements, and remain, moreover, as monuments of the great changes that have occurred.

It is the opinion of Sir Charles Lyell that an extensive region, including the valley plain of the Mississippi, has been subjected to a great oscillation of level. This at first depressed the region, or rather the more inland portion of it, about 200 feet below its present level, and then restored it again to its former position. During the first part of this oscillation and at the period of greatest depression the materials of strata, the remnants of which are now seen in the bluffs and slopes of the highlands, were deposited during overflows very much as alluvial matter is now. But when the movement was reversed and the region was slowly upraised, the river carved out its valley "through the horizontal and unconsolidated strata as they rose, sweeping away the greater portion of them, and leaving mere fragments in the shape of terraces, skirting 'the newly formed alluvial plain' as monuments of the changes in level."

The Bluff loam (Safford), p. 433.—This, the topmost of the bluff formations, is generally a mass of silicious loam, somewhat calcareous and usually of a light ashen yellowish or buff color, but sometimes lacking the yellow tinge. It is distinctly stratified, contains land and fresh-water shells, and frequently oddly shaped calcareous concretions. It has, in Tennessee, a maximum thickness of about 100 feet, ranging generally, however, from 30 to 80. In the bluff at Memphis it is from 40 to 60 feet thick, and presents in its lower part, along a well marked horizon, and in a vertical position, earthy ferruginous casts or molds of what may have been the long tapering roots of some tree.

The loam rests directly upon the bluff gravel.

The following species of shells have been collected from this formation:

1. *Helix appressa*, Memphis.
2. *Helix hirsuta*, Memphis.
3. *Helix monodon*, Memphis.
4. *Helix solitaria*, Dyer County.
5. *Helix profunda*, Hickman, Ky.
6. *Planorbis bicarinata*, Memphis.
7. *Cyclos*, Sp.? Memphis
8. *Amnicola lapidaria*, Memphis.
9. *Lymnea*, Sp.?
10. *Succinea*, Sp.?

Dr. Wyman has published a "Notice of fossil bones from the neighborhood of Memphis," which he states are representatives of the genera, Mastodon, Megalonyx, Castor, and Castoroides, and that they are "from, as is supposed, the diluvium of the Mississippi." The geological position as given here is very indefinite. I think it, however, more than probable that the bones came from the bluff loam.

The bluff gravel (p. 432).—This bed varies in thickness from 10 to 50 feet. It consists generally of coarse yellow and orange sands, with everywhere more or less coarse gravel, and has usually a layer of white or variegated clay at its base. The gravel is generally the most conspicuous portion. This is sometimes cemented by oxide of iron (occasionally by calcareous matter) into great blocks of coarse conglomerate. It consists of water-worn pebbles from the size of a man's fist down to that of a pigeon's egg. The pebbles have been derived mostly from carboniferous chert. The bluff gravel is remarkable for its extent in a general direction parallel with the river. It is seen along the face of the Mississippi Bluff from the Mississippi line to Kentucky, and both ways much beyond these limits.

Its eastern outcrop is not well marked. It appears to extend from 15 to 20 miles eastward, from a straight line drawn through the most westerly parts of the bluff.

At Memphis the highest part of the bluff is about 100 feet above low water. The lower part of the section at this point belongs to the bluff gravel, and consists of alternating layers of yellow, orange, and white sands, containing toward its base more or less gravel. It also contains a few seams of whitish clay. At some points also masses of ferruginous conglomerate occur, as well as thin plates and scrolls of red sandstone. In a branch back from the river a bed of coarse gravel was observed.

I have given the foregoing full statements of the principal observers of the Quaternary formations to show in the first place the identity of the southern drift in point of time with the northern drift, which north of the Ohio has had such an important agency in modifying the surface of the States bordering on the Upper Mississippi. Secondly, to show that the glacial forces were sufficient to erode the original wide bed of the Mississippi, forty miles wide between Memphis, Tenn., and Madison, Ark.

The facts given also show that this bed has been refilled by the loess which immediately overlies the drift as far south as Memphis. We come now to consider the features of the Port Hudson hardpans and clays.

My attention was first called to a blue clay in Cole's Creek, Mississippi, in 1860, underlying the loess and overlying the drift.

In Hilgard's Report on the Geology of Mississippi, printed in 1860, but published in 1866, I found a description of blue clay on the Chickasawkay River, near Winchester, referred by him to the Tertiary, which contained roots and trunks of Cupuliferae, Coniferae, and Palmea.

On examination of this stratum, and making further explorations in southwest Mississippi, in which the same clay was found on Buffalo Creek and other creeks in that region, containing bones and teeth of the Mastodon, and on comparing these deposits again with the exposure at Port Hudson and its clays, I came to the conclusion that they were all of the same age, and formed a group which was intermediate between the bluff and the drift, and that there had been a more or less continuous stratum over the whole Mississippi bottom, and in the valleys of some of the rivers which had been removed in parts of the bottom by the action of the river.

Dr. E. A. Smith, at that time my assistant in the Mississippi survey, was directed to examine the Yazoo bottom, and his observations showed that in digging wells, after passing through the alluvium, a blue clay stratum, as much as 40 feet in thickness in places, was uniformly penetrated before reaching water, which was found in the underlying sands and pebbles of the drift. The observations made during the last year confirm the opinion that this stratum has been continuous from Memphis to New Orleans, but has in many portions of the bottom been removed by the river, and its place supplied by the newer alluvial deposits which now, as a general thing, form the banks of the river, and are being constantly removed, so that the levees, which have been built at enormous expense, require constant care for their preservation or frequent renewal.

PORT HUDSON.

In a paper read before the American Association for the Advancement of Science, at Indianapolis, in 1871, and published in the proceedings for that year, Dr. E. W. Hilgard speaks thus of the Port Hudson group, as laid down on the accompanying map (illustration No. 48):

"The next formation laid down on the map is the Port Hudson group, of which, however, the outcropping littoral portion only is here represented. Properly speaking, it should be shown as occupying also most of the space colored as alluvial, since it underlies everywhere not only the marine alluvium and a portion of the Gulf itself, but also that of the Mississippi and its chief tributaries, at least as high up as Memphis, and on Red River nearly, if not quite, up to Shreveport. It seems to exist equally in the valleys of other large rivers tributary to the Gulf, notably in that of the Pascagoula, up to 100 miles, in a direct line, from the coast.

"Having discussed this formation somewhat in detail in papers recently published, I will merely state that it embraces a group of partly littoral and estuarian, partly swamp, lagoon, and fluviatile deposits, whose thickness and location are manifestly dependent upon the topographical features of the continent, then (during the 'Champlain' period) in progress of slow depression—as shown by the nature of the deposits, and the numerous superimposed generations of large cypress stumps, embedded in laminated clays, exhibiting the yearly fall of leaves. These beds overlie those of the orange sand, or stratified drift, while they themselves are overlaid by not only the river alluvium, but also by the loess or bluffs ilt, or its equivalents, as well as, where this is absent, by the yellow loam of the surface. It would seem that here, also, during the latter portion of the drift period, most of the larger river-channels were already impressed upon the surface, though not always coincident with the present immediate valley, as Newberry has observed in relation to some of the northern rivers. A depression of the land would gradually transform these channels into inlets filled with more or less stagnant fresh water down to a greater or less distance from the then-existing coast-line, and thus opportunity would be afforded for the formation of the swamp and lagoon deposits, into which both the Mississippi and Red Rivers have subsequently cut their channels. The banks of the Red River, as well as—outside the present alluvial area—those of the many lakes and bayous which border that stream, exhibit strata absolutely identical in character with those observed near the coast, yet, of course, totally different from either the alluvial deposits of the present time or the adjoining Tertiaries. The same holds true, more or less, of the Mississippi and its mighty 'bayous.' According to the observations of Dr. E. A. Smith, in the Yazoo bottom, and my own in that of the Tensas, not only do the clays with calcareous concretions (as characteristic of the Port Hudson age as they are foreign to the alluvium of to-day) frequently crop out in the beds of the streams, but much of the best lands of the 'buckshot' kind, now situated above overflow, have clearly been formed by simple disintegration of these strata, altogether independently of the river alluvium.

"These results fully confirm, therefore, the statement made by General Humphreys, that the Mississippi does not, as a rule, flow in a bed formed from its own deposits, but has excavated it in an older geological formation. Wells exceeding 15 or 20 feet ordinarily strike these clays throughout the bottom as they do in the delta, and the analogy has been completed by the repetition of the phenomena, observed in driven wells at New Orleans, at a point about 50 miles above Vicksburg (General Wade Hampton's plantation), where a tube well has furnished a copious flow of combustible gas undiminished for many months. The swamp clays form, however, only the lower portion of the Port Hudson beds. Higher up, as shown at the Port Hudson bluff, there lie yellow or whitish silts, and 'hard pans.' These form also a level terrace some miles in width bordering the Tensas bottom, while high above it on the hill-tops of Sicily Island, on the Washita, lie the remnants of the Loess formation, the main body of which has succumbed to the erosive influence of the Terrace epoch elevation. It has, however, left a belt a few miles wide on the eastern side of the valley, as shown on the map. It would thus seem that during the latter portion of the period of depression the rate of sinking became at times too rapid to allow of the accumulation of swamp deposit. The indurate silts are mostly devoid of fossils of any kind, but are occasionally traversed by fluviatile beds with pebbles, driftwood, &c. Then there is a recurrence of the swamp deposits; then, again, silts; and finally, the calcareous, silty loam of the bluff formation, with its numerous terrestrial fossils and 'loess puppets' ends the deposits clearly referable to the epoch of depression.

"The loess differs little from its equivalent farther north, save in being utterly devoid of stratification as well as of any fluviatile organisms. It is not easy to imagine the *modus operandi* by which a deposit of this kind, sometimes 70 feet thick, and of dead uniformity from top to bottom, could be produced. Its equivalents farther north exhibit very distinctly the structure resulting when deposition takes place in (gently) flowing water; at the south it was probably substantially stagnant, save as regards the tidal flow. Perhaps the latter may serve to explain both the absence of fluviatile as well as marine life, and the uniform intermixture without any semblance of arrangement of material varying from the finest silt to pebbles half an inch in diameter. A strong tidal wave running up a deep inlet of this kind would naturally sweep away in its periodical rushes many members of the terrestrial fauna, whose remains are in a marked degree the more abundant the nearer we approach to the edge of the formation. Overlying the loess we find, wherever opportunity is afforded, a stratum of yellow loam or brick clay, which, near the larger valleys, is often as much as 15 or 20 feet in thickness. It is altogether devoid of stratified structure, as well as of fossils, and forms the surface layer, and in most cases the subsoil, of the Gulf States. If, as I am inclined to believe, its presence, as a connected though very undulating sheet on all but the most elevated uplands of these States, necessitates the assumption of submergence, however brief, to the highest level at which it occurs, the changes of level heretofore alluded to would be shown to have exceeded by 600 to 700 feet the estimate given above.

"The succeeding (Terrace) epoch of elevation has not, so far as I am aware, left any marks in the way of beach lines or terraces, unless the second bottoms or 'hommocks' be accounted as such. They, however, belong to a very modern epoch, for they occur on streams no larger than what is usually called a 'creek,' and are most marked on the smaller rivers while apparently absent from those of the largest size, such as the Mississippi, Red, and Arkansas rivers. The elevation at which, on the very Gulf shore, we find deposits of the Port Hudson age (180 feet at the Five Islands on Vermilion Bay) shows nevertheless that a stupendous amount of erosion was accomplished during the time that the Mississippi occupied in scooping out its channel to a depth which even below the northern boundary of Louisiana cannot be estimated at less than 500 feet. As regards the modern epoch, I will remark that while in the axis of the ancient embayment the Mississippi River, through the singular instrumentality of mudlumps upheaval, is rapidly pushing out the land into the Gulf waters, the latter are nevertheless gaining ground on almost the entire coast of Mississippi and Alabama, and the same is true of a portion of Vermilion Bay. Yet, on the whole, the coast of Louisiana, as well as that of Texas and Florida, is more than holding its own, and the shallowness of the water, even where encroachment does take place, will necessarily restrict the latter within narrow limits hereafter."

At the same meeting of the association Dr. E. A. Smith, assistant in the Mississippi geological survey, read the following paper:

"It has generally been assumed that the formation underlying the Mississippi bottom was exclusively of alluvial character. (See Lyell's Principles of Geology, tenth edition, ch. XIX, vol. 1.) On the other hand, it has been suggested by General Humphreys (Report on the Mississippi River, p. 99), that the river is flowing through it (the delta region) in a channel belonging to a geological epoch antecedent to the present. On page 84: 'From McNutt, in latitude 33° 40′, to Sunflower River, in latitude 34° 22′, underlying the vegetable mold and alluvion is a stratum of dark, heavy clay, which, where exposed, is called "buckshot" land by the settlers from its fancied resemblance to leaden balls when it has been baked and cracked by the sun.'

"Dr. Hilgard remarks (American Journal of Science, January, 1869), 'The stump stratum No. 1 (Port Hudson profile), however, as appears from numerous data collected by myself, or contained in Humphrey's and Abbot's Report, exists at about the same level (*i. e.*, near that of tide-water), not only over all the so-called delta plain of the Mississippi, but also higher up, perhaps as far as Memphis.'

"Observations made by myself in the Yazoo bottom during the last year lead to the conclusion that the true river deposits of any considerable thickness are mostly confined to narrow strips of land, lying on each side of the Mississippi, and of the bayous and creeks that form a network of streams throughout the bottom, and to ancient channels since filled up, while a large proportion of the superficial area of the bottom, including some of the most fertile lands, is derived from the clays of older formations, into which the beds of these streams have been excavated.

"The high or 'front land,' on the immediate banks of the streams, is at present rarely overflowed. It is usually a sandy loam of various colors, and of various degrees of fertility. It supports a growth of sweet gum, honey locust, swamp chestnut, oak, water-oak, pecan, and cane. The growth varies with the locality and character of the loam, as may be seen better hereafter in the remarks preceding the analyses. These high lands seem to represent the true river alluvium. From the 'front land' there is a gradual slope down towards the swamp. The soil undergoes a transition from the sandy loam into the tenacious clays of the middle or 'back land.' The latter is often overflowed during the wet season, and it supports a growth of sweet gum, over-cup oak, willows, and water-oak, hackberry, pecan, and cane.

"The clays of the 'back land' doubtless belong, for the greater part, to the Port Hudson age as is indicated by the abundance of ferruginous and calcareous concretions found in them, unlike any found in the true river alluvium, as well as by the great thickness of continuous clay deposits.

"These clays are generally of a dark gray color, sometimes nearly black; again, light gray, traversed by cracks, and full of streaks and dots of ferruginous matter. They are very sticky and tenacious, and when exposed in large masses to the atmosphere become covered on the surface with a dull red coating of hydrated ferric oxide. When broken up by the plow or spade they crumble on drying into small angular blocks, of the size of a buckshot and under, giving rise to what is known throughout the bottom as 'buckshot soil.' Although these clays, as shown by analysis, are generally very rich in lime, yet calcareous concretions, so characteristic of the Port Hudson strata, are not always to be found in them. Thus I have not observed them further south than the latitude 32° 52′ of Yazoo City. North of that point, however, they are of constant occurrence.

"The uniformity of level in the bottom may very well account for the failure to observe these concretions, for anything like a fair profile is very rarely seen. The banks of the creeks and bayous are usually of such a gentle slope, and so covered with detritus in their lower parts, that little of interest can be observed without much digging. As we go from the 'back land' to the cypress swamp there is frequently very little change in the nature of the clay; and it is difficult, if not impossible, to distinguish between the 'buckshot' clay of the older formations and that of the recent swamp, except where the calcareous concretions above-mentioned come to our aid. The clays of both formations are usually dark gray, traversed with cracks, and full of ferruginous matter; both crumble into 'buckshot;' both support a similar vegetation, except where the presence of more or less standing water affects it. As the swamp is under water for a large part of each year, there is one alternation in its deposits between clay, leaves, and sand. One of the most characteristic sections of the Port Hudson strata observed, is on the bank of Tchula Lake, at the head of Honey Island. The three uppermost strata represent the alluvium, while those below are of the true Port Hudson character (see section). On the banks of the Yazoo River, not far from where the above section was taken, the succession of the strata was essentially the same; but the buckshot clays, corresponding with Nos. 4 and 6, *supra*, were entirely full of calcareous concretions, while the ferruginous concretions occurred at a lower level, nearly down to the water's edge, as is the case of Port Hudson.

"On Lake Beulah, latitude 33° 40′, in Bolivar County, the same strata appear; the clays, Nos. 4 and 6, being full of calcareous concretions. On Panther Creek, above Yazoo City, and on a small bayou which empties into the river at the city, the same facts may be observed.

"Of the stump stratum, No. 1 of Dr. Hilgard's profile, I have not seen any outcrop on the banks or bayous, &c., on account of the difficulties mentioned above. Logs, however, have frequently been struck in digging wells, though the introduction of tube or driven wells has very much impaired this source of information regarding the strata in the bottom.

"For instance, in General Wade Hampton's Walnut Grove plantation, near Lake Washington, in latitude 33° 05′, at a depth of about 30 feet in the blue clay, which underlies the dark-gray 'buckshot' clay, a fragment of wood was found. On the same plantation, while driving a tube for obtaining water, a stream of inflammable gas was observed to issue from the tube. At the time of my visit there, the gas had been burning uninterruptedly for three months. It escapes with considerable force, and might easily be utilized on the plantation.

"The composition of this gas is as follows:

CH_4	74.30
N	19.00
H	3.20
CO_2	3.50
	100.00

"The small percentage of carbonic acid found in this gas shows that it does not originate from vegetable matter in its first stages of decomposition, agreeing in this respect with the gas obtained from similar wells in New Orleans, and differing from the gas of recent marshes, which contains from 8 to 10 per cent. Below the stratum of blue clay, in which sticks, logs, &c., are found, there is a stratum of pebbles and sand, of the Orange Sand (Stratified Drift) formation. This pebble bed is very often reached in digging wells. The depth varies very greatly; thus, at the mouth of a small bayou which empties into Lake Washington, on the west side, there is a bed of pebbles, as is also the case at Proffit's Island, near Port Hudson, while in some wells it is not reached at a depth of 120 feet."

WATER.

Throughout the bottom, water is obtained either from shallow dug wells, 15 to 30 feet deep, or by means of iron tubes driven into the ground, as deep sometimes as 100 feet or more. The water always rises in the tubes to within 30 feet of the surface of the ground—in most cases to a level higher than that of the river and streams in the neighborhood, and in one instance, known to me, of a well on Indian Bayou, the water stood permanently in the tube 2 feet above the surface. Generally, the water is of a decidedly mineral character, especially in the very deep wells. When the tubes have been driven no deeper than 25 or 30 feet, the water is frequently as free from a mineral taste as river water, though always hard. I have made numerous analyses of the water from these driven wells, from various localities from Lower Deer Creek, in latitude 32° 40′, to the latitude 34° 23′ of Friar's Point, in Coahoma County, and the composition appears to be nearly the same in all.

The following is an analysis of the water from Governor Alcorn's place, near Jonestown, Coahoma County. The well is 119 feet deep. The water, when first drawn, is clear and sparkling, but soon becomes turbid, and deposits a ferruginous film upon all vessels in which it stands for any length of time.

$FeO\ CO_2$	Dissolved in free carbonic acid	4.877
$CaO\ CO_2$		19.575
$MgO\ CO_2$		17.672
SiO_2		17.482
$CaO\ SO_3$		0.610
$Na\ Cl$		1.746
$Na\ O$, $H\ O$	$2\ CO_2$	12.852
$K\ O$, $H\ O$	$2\ CO_2$	9.969
CaO	United with organic acid	14.665
MgO		.560
		100.008

SOILS.

The soils of the Yazoo bottom may be arranged in five classes, which differ materially from each other in fertility as well as in general physical properties. Their differences in the chemical composition are very striking, as may be seen by reference to the table.

First. A light-colored sandy clay, of close texture, with a few yellow spots. The growth upon this soil is swamp chestnut-oak chiefly, with sweet gum, ash, maple, willow oak, and an undergrowth of cane. This soil forms the white lands, which are considered very fertile. It occurs on Silver Creek, east of Sunflower River, and on Indian Bayou, west of the same, and is common in the vicinity of the Sunflower on both sides, and forms most of the cultivated lands on the banks of the bayous that have their courses at right angles to the Sunflower.

1.—*Indian Bayou, front-land soil, Sunflower County.*

Insoluble matter	87.898
Silica, soluble in $NaO\ CO_2$	4.036
Potash	.226
Soda	.116
Lime	.153
Magnesia	.256
Brown oxide of manganese	.048
Peroxide of iron	1.848
Alumina	2.565
Phosphoric acid	.162
Sulphuric acid	.042
Volatile matter	3.013
Total	100.363

Second. A dark-gray sandy loam, forming the front-lands of many of the creeks and bayous. It is fertile and easily cultivated. The growth is honey locust, hackberry, and sweet gum, and, where entirely above overflow, dogwood is a very common tree. I may add, however, that the dogwood ridges are inferior in fertility to others, where the soil is a similar dark-gray sandy loam

II.—*Dogwood ridge soil. J. L. Alcorn's plantation, Coahoma County.*

Insoluble matter	83.886
Silica, soluble in $NaO\ CO_2$	7.022
Potash	.392
Soda	.086
Lime	.259
Magnesia	.596
Manganese, brown oxide	.086
Iron, peroxide	2.691
Alumina	3.593
Phosphoric acid	.142
Sulphuric acid	.010
Volatile matter	2.007
Total	100.770

Third. A light-gray sandy loam, with yellowish and orange streaks. The loam is sometimes of a light-yellow color. This forms the immediate banks of the Sunflower River, Tchula Lake, and is a soil of frequent occurrence. It supports a growth of sweet gum, maple, willow-oak, elm, and hackberry.

III.—*Sunflower River, front-land soil, Issaquena County.*

Insoluble matter	71.164
Silica, soluble in $NaO\ CO_2$	13.506
Potash	.401
Soda	.191
Lime	.406
Magnesia	.696
Manganese, brown oxide	.011
Iron, peroxide	3.845
Alumina	6.889
Phosphoric acid	.165
Sulphuric acid	.016
Volatile matter	2.748
Total	100.038

Fourth. A light-gray clay, traversed by cracks, and crumbling, where exposed to the weather, into fragments—"buckshot." This clay differs in color and fertility from the dark-gray "buckshot" clay which has made Deer Creek so celebrated. The growth is the same as that of No. II; locality also the same.

IV.—*Light-gray buckshot clay. J. L. Alcorn's, Coahoma County.*

Insoluble matter	75.513
Silica, soluble in $NaO\ CO_2$	10.895
Potash	.606
Soda	.146
Lime	.386
Magnesia	.972
Manganese, brown oxide	.133
Iron, peroxide	2.804
Alumina	4.457
Phosphoric acid	.278
Sulphuric acid	.007
Volatile matter	4.401
Total	100.598

Fifth. A stiff dark-gray clay, sometimes nearly black, traversed in all directions by cracks, and full of streaks and dots of ferruginous matter. This is the "buckshot" clay par excellence, and forms the most fertile soil in the bottom. This and the preceding are Port Hudson clays, and form the "back-lands" and surface-soil of most of the swamps lying between the water-courses. They are for the most part subject to annual overflow, though there is usually a strip one-half to three-fourths of a mile wide on the banks of the streams under cultivation. The growth is sweet gum, overcup oak, willow oak, and water oak, hackberry, pecan; near the banks of the streams an undergrowth of cane, but in the low, swampy back-lands, no cane, but regular cypress glades.

V.—*Deer Creek buckshot soil. Virgin-Hardee Place, Issaquena County.*

Insoluble matter	51.063
Silica, soluble in NaO Co_2	20.707
Potash	1.104
Soda	.325
Lime	1.349
Magnesia	1.665
Manganese, brown oxide	.119
Iron, peroxide	5.818
Alumina	10.539
Phosphoric acid	.304
Sulphuric acid	.024
Volatile matter	7.369
Total	100.386

Prof. F. V. Hopkins sums up his deductions from observations made in Louisiana, as follows, Third Report, 1872, p. 189:

1. During a long period after the deposition of the drift, the land stood at about its present level, allowing the valleys to be cut in the drift that we now find covered by bluff deposits, and the earth they once contained to be restratified as the foundation for the delta. This foundation reaches above the surface of the water in Catahoula and at Port Hudson, as far south as the Five Islands, and was covered with a forest of cypress and other trees. After a time sufficient for the accumulation of four feet of shady leaf-bed about the roots of these trees, a depression began and continued until the water level stood at least sixty-eight feet above its present height at Port Hudson. This would carry the area of "dead water" 272 miles up the river valley, allowing three inches to the mile as the present slope of the water in the river. So small a depression left the Mississippi very much such a stream as it now is, to deposit sands and clays throughout the Port Hudson period, as at present. There occurred a further movement which left the headwaters of the river very much lower than now, while apparently not sinking Louisiana more than twenty-five feet further. The upper waters of the river then expanded into a lake-like estuary, almost without current as far as Fort Pierre, in Dakota, in latitude 44° 23′, and the northwest corner of Illinois. The plains of the Mississippi, far and near, became the swampy homes of innumerable snails, and the loess was deposited. Finally, a further depression of twenty-five feet in our latitude at least, and as far as Northern Mississippi, spread the area of dead water over all these swamps, and so diminished the already small current that only clayey silt could be carried by the flood. This forms our yellow loam; a reverse motion then began, which restored the height of the continent above the ocean. The rivers contracted to narrow channels, and began the work of cutting out their beds and forming anew their flood-plains and deltas—work by no means completed. The remnants of the old flood-plains remain—a fringe of bluffs on either side, as monuments of this "eventful history."

Again, in regard to the alluvium he says, p. 167:

The alluvial deposits of the Mississippi River are already classic ground for the geologist. Hastily as Sir Charles Lyell examined them in 1845, he gathered facts sufficient to form the basis of a calculation of the number of years that it must have taken the river to make its present delta.

He estimated the time at 67,000 years. (Second visit to the United States, Vol. 2, p. 188.) As the number was too high to suit the preconceived notions of many, there have been various efforts to reduce it. Foremost among these is that by General A. A. Humphreys in his report on the Mississippi River (p. 99), in which he states that the river flows, even in the delta region, "in a channel belonging to a geological epoch antecedent to the present." As this would greatly diminish the depth that he had assigned to the alluvium, Sir Charles Lyell appealed to the testimony of the specimens taken from the artesian well at New Orleans in 1856. These specimens were submitted to Prof. E. W. Hilgard, of Mississippi, for examination, and his report upon them appeared in the fall of 1870. The professor therein takes the view that the alluvium proper beneath New Orleans is but 31 feet thick, arguing that the marine deposits below, to a depth of 650 feet, are of the Port Hudson group. I followed him last year in this idea, and quoted his list of shells under the head of the Bluff formation. My observations this season oblige me to modify this conclusion somewhat. Wishing to ascertain as accurately as possible the actual depth of the alluvium, I instituted a series of experiments upon the waters of wells dug in the Port Hudson formation and in the bottom lands, respectively. I have found (as indeed Professor Hilgard had told me that he should expect) that the former contain a considerable proportion of sulphates and carbonates, while the latter show an excess of chlorides. This result is uniform, excepting where the wells happen to strike considerable beds of sand, when the waters are too pure to be distinguished. It is evident, therefore, that by testing the water of the deepest wells dug in the alluvium it is possible to tell whether they pass through it into the underlying Port Hudson groups or not. The patent wells that are made by simply driving a tube into the ground offer great facilities for this research, as the water that they furnish comes necessarily from the bottom of the well only. On a trip that I took from Baton Rouge to the Arkansas line, I analyzed the water of various wells of from seventy to one hundred feet in depth, and in not a single instance found any other than the alluvial characteristics. The alluvium, then, upon the upper part of the river being deeper, as a rule, than from seventy to one hundred feet, it is highly improbable that it is no deeper than thirty-one at the city of New Orleans. It is true that the artesian well passed at that depth from swamp deposits into marine; the question to be decided is, whether such a change is in this case a passage from one geological formation to another.

It is not necessarily so. The term alluvium is indeed so generally confined to river formations that we are apt to forget that these are but a small part of the strata that are forming in the present era. The fine blue clay of the Mediterranean, the chalk of the "Telegraphic Plateau" of the North Atlantic, and the deposits now settling in the Gulf of Mexico from the long brown line projected into it by the mighty Mississippi, are but marine equivalents of the alluvium proper. A vast bed of such marine equivalents now lies in front of our present delta, rendering the water shallow for a distance of 10 miles from the Passes. Here occurs a sudden slope that might be regarded as the proper continental slope of the present era, so greatly does it exceed that at the shore of the delta itself. The whole sea bottom including this shallow margin is covered with living beings, and the recent beds, alluvial equivalents though they be, are full of their exuviæ. Every advance that the delta makes in its progress towards the sea is necessarily based upon these recent beds. When, therefore, we dig through the river deposits and come to strata with marine shells, it does not follow that we have reached an antecedent geological formation, unless the fossils are those of extinct species. Now, the shells obtained beneath New Orleans are all of recent species, as far as known. There is no proof whatever, therefore, that the whole series of deposits may not be equivalents of the alluvium instead of belonging to the Port Hudson group. There are some reasons that lead to the supposition that they are very recent. The first of these has been already given, viz, that as I have proved the river alluvium to be over 100 feet in depth at various points between Baton Rouge and Arkansas, it ought to be even deeper at New Orleans, because that city is nearer the foot of the slope of the river valley. If we grant this, we are obliged to claim some of the upper marine beds as recent delta deposits, and Professor Hilgard has himself declared that no line can be drawn between these and the others. The depth of 650 feet offers no difficulty to this supposition, but rather aids the argument by completing the analogy between the Bluff period and the present. I have already alluded to the continental slope that occurs 10 miles south of the Passes. This slope follows the trend of the Gulf shore almost irrespective of the protrusion of the delta. It owes its formation, no doubt, to the opposition offered by the waves of the Gulf to the outflowing current of the river. The sediment is not allowed to spread far over the Gulf bottom, but is beaten back nearly to the shore. Now, this cause was in full operation during the Bluff period; only, as that was the time when the river was broader than now, owing to the depression of the land, its current was less than at present, and the continental slope of that period ought to follow the general curve of the Gulf shore even more accurately than does the modern one. The land has been raised since then, and the southern edge of the prairie region and the northern shores of Lakes Maurepas and Pontchartrain lie in about the anticipated direction. The chain of the Five Islands, however, protrudes beyond this line, so that the slope may lie nearer the city, but most probably *above* it. If so, and if the Gulf of that day was as deep near the slope as at present, New Orleans may rest upon recent deposits as thick as the Gulf is deep.

(The Port Hudson group. Hopkins, third report, p. 185:)

The area of the Port Hudson group in Louisiana embraces the Bayou Maçon hills, with strips along Bayou Bartholomew, and the Ouachita, Catahoula, Hollowell's, and Avoyelle's prairies, with occasional terraces upon Red River, and the prairie and short-leafed pine region of Saint Landry, Calcasieu, and Lafayette, upon the west of the Mississippi River. Upon the east it underlies the loess at Tunica Hills, and forms the bluffs upon the river below Bayou Sara Creek, extending southeast and east through the Felicianas, East Baton Rouge, Livingston, Tangipahoa, and Saint Tammany. It overlies the drift where the two are in contact, and is covered itself by loess, where that is present, and by the yellow loam. The delta formed by the Mississippi from the end of the Drift period to the era of the loess was composed of its strata, which are found also along the upper part of the river, at least as far as the Ohio, just as the modern alluvium forms both the newer delta, and extends besides to the headwaters of the river.

(The Drift; Hopkins, p. 191:)

The drift deposit seems once to have covered our whole State (Louisiana) to a depth of nearly 200 feet. It has been removed by denudation along the Mississippi and Red Rivers and lies buried beneath the delta accumulations of the Bluff period, probably extending far out under the Gulf. It remains upon the surface (except for the yellow loam) over the area of the Tertiary deposits extending widely east, west, and north beyond the limits of the State. It was formed evidently by running water, the direction of the current being from the northeast and north. The main constituents are coarse rolled sand, with fossiliferous pebbles and red and yellow sandy clays occurring in various alternations and with very irregular stratification.

In General Humphreys' report, p. 92, he states:

2. That the "blue clay" underlies the whole Yazoo bottom *below* the great sand stratum.

Dr. Smith says that the sand stratum is *below* it.

3. He says: "In the bluff at Vicksburg it underlies the stratum which contains marine shells, and which Sir Charles Lyell and Dr. Harper both pronounce Eocene Tertiary; that is, the oldest Tertiary stratum."

There is a gray or black lignitic clay in the position referred to, but it is undoubtedly Vicksburg Eocene.

4. He says: "It underlies New Orleans in strata alternating with sand and marine shells for at least 630 feet."

Dr. Hopkins says that the alluvium underlies New Orleans for at least 100 feet in depth, and in this I agree with him.

7. He quotes Lieutenant Warren as stating that this peculiar blue clay very closely resembles a formation which covers a great area in the immediate valley of the Missouri east of the Black Hills, which Dr. Hayden assigns to the middle of the Cretaceous, where the Missouri clay undoubtedly belongs, but has no relation whatever to the blue clay of the Port Hudson period.

On page 88, he says, "The bluff at Grand Gulf is similar in height and character (to that at Vicksburg). There is the same stratum of blue clay." This clay belongs to the later Grand Gulf period of the Tertiary. We find thus described as the same "blue clay" a clay belonging to the Cretaceous, one belonging to the Vicksburg Eocene Tertiary, one belonging to the Grand Gulf Tertiary, and an alluvial clay; and he also refers to one described by Captain Pope in the Llano Estacado, which is probably cretaceous, according to Prof. W. P. Blake.

SUMMARY.

The southern drift corresponds exactly in time and cause with the northern drift.

The Drift succeeded immediately the Tertiary, and overlies almost its entire area, as well as that of the Cretaceous, in the Atlantic and Gulf States.

Its heaviest gravel beds border the Metamorphic rocks, on the Atlantic slope, and as far south as Wetumpka, Ala., and from there to the mouth of the Ohio border the Carboniferous. On the west side of the Mississippi they border the Carboniferous in Arkansas and extend to the Colorado River in Texas. There are other large deposits near the present bed of the Mississippi River extending to the mouth of the Atchafalaya, which was probably the original course of the river. The Drift was covered at one time in the whole delta, at least as high as Memphis, by a stratum of clay of Port Hudson age, which is generally blue, and is also found in rivers and creeks tributary to the Mississippi, in Mississippi and Louisiana.

This has been to a large extent removed by the present Mississippi River, at and near its present course, and may have been removed over a large portion of the bottom and its place supplied by the alluvial deposits of the present river. The evidence furnished by General Humphreys of its forming the present bed of the river is not at all satisfactory or convincing, and does not agree with my observations. In his report he speaks of blue clay of no less than seven distinct geological periods, and classes them as one and the same.

The observations of Dr. Hopkins were continued for years over the whole of Louisiana, and his deductions seem to accord more nearly with the facts, certainly as to the thickness of the alluvium, which as far as I have seen, with a few exceptions, to be mentioned hereafter, is not less than 100 feet thick along the banks of the river from Memphis to New Orleans, as can be readily seen in a hundred places where the levees have been built, and in a few years have caved into the river frequently, as on the Atchafalaya, near Simmsport, acres of land having disappeared at once, leaving a vertical wall 100 feet deep, from the bottom of which trees and logs that had been buried or ages were uncovered.

There are a few points on the river where the Port Hudson clays have resisted all the efforts of the current to dislodge them.

At Wilton Landing—

At a point opposite Grand Lake, near the line of Arkansas and Louisiana—

At the mouth of Red River—

At L'Argent plantation—

At Bonnet Carré—

At New Texas Landing.

I have given above extracts from those who have made a study of these Quaternary formations, which I think contain substantially everything valuable that has been written upon them having any bearing on the question at issue. The sections which follow have been taken with care over the whole area involved, and from them you will see what value to attach to the various views expressed by the different distinguished scientists who have theorized upon this subject of such vital importance, not only to the residents of the overflowed lands, but to the whole nation. They all agree that the loess has occupied in a past age the whole valley now covered by alluvium.

They all attribute the erosion of the valley to a swiftly flowing current of the Drift period, which has left a continuous stratum of gravel and pebbles beneath the loess. All the later observers concur in the opinion first expressed by myself in 1867, that between the drift and the loess there has been a continuous deposit of clay, similar to that described by Sir Charles Lyell at Port Hudson, not only in the Mississippi Valley, but in the smaller tributaries. All agree that the present river deposits annually alluvium over the whole bottom, where it is not kept within its banks by levees, and that this alluvium is in a large part of the bottom as thick as the river is deep, say 100 feet.

My observations lead me to believe that neither the banks nor the bed of the river consist of the blue clay of the Port Hudson period, but of clays and sand of alluvial origin.

The admirable work of General Humphreys has been a credit to the nation, and the only lack in it is the want of such geological surveys as would have shown the true age and relations of the blue clay, which is the subject of this report. Later investigations by admirable observers would have been rendered more valuable if they had been allowed sufficient time to study the present course and the recent and continual changes in the current of the river. I have given you the most reliable data on record, and yet this is, I fear, not what you desired, an exhaustive report on the "blue clay." I have studied its relations at intervals for twenty years, and give you the results of all that I have been able to gather from scientific records, or my own personal observation.

Respectfully,

GEORGE LITTLE.

Hon. CARLILE P. PATTERSON,
Superintendent Coast and Geodetic Survey, Washington, D. C.

(1.) SECTION OF BLUFF AT MEMPHIS, TENN.

Feet.	Character of strata.	No.
10	Yellow loam	
40	Calcareous silt, loess, or bluff	3
10	Bluish white clay	2
40	Gravel and yellow sand	1

(2.) SECTION AT CROW CREEK, NEAR MADISON, SAINT FRANCIS COUNTY, ARK.

25	Yellow calcareous silt. (Bluff)	7
15	Yellow loam and clay. (Bluff)	6
10	Gravel. (Drift)	5
10	Sand. (Drift)	4
3	Blue clay. (Eocene)	3
10	Blue mud. (Eocene)	2
2	Blue clay. (Eocene)	1

(3.) SECTION AT HELENA, ARK.

6	Yellow silicious clay marl, with fossil shells	4
30	Yellow and orange sand and gravel and clay	3
20	Yellowish and whitish sand, with some gravel	2
12	Space concealed to bed of slough	1

(4.) SECTION NEAR SARDIS, PANOLA COUNTY, MISS. (MISSISSIPPI AND TENNESSEE RAILROAD).

10	Yellow loam	.....
12	Calcareous silt	.....
10	Gravel and sand	.....

(5.) SECTION AT YAZOO CITY, MISS.

....	Yellow loam	3
....	Calcareous silt	2
....	Bluish clay	1

(6.) SECTION OF THE BLUFF AT VICKSBURG, MISS. (HILGARD.)

10 to 20	Calcareous silt, with snails. (Bluff)	7
5 to 20	Bluish and yellowish hardpan, often pebbles (orange sand stratified). (Drift)	6
60 to 65	Alternating strata, 1 to 6 feet thick, of limestone and marl, containing the *Vicksburg fossils* and some bands of non-effervescent gray sand and clay	5
5	Black lignitic clay and gray sand, with *Ostrea gigantea*, *Corbula alta*, *Natica mississippiensis*, *Cytherea sobrina*, *Madrepora mississippiensis*	4
25	Gray or black lignitic clays or sands, with iron pyrites	3
3	Solid, lustrous lignite, with whitish cleavage planes	2
....	Unknown	1

(7.) SECTION AT GRAND GULF, CLAIBORNE COUNTY, MISS. (HILGARD.)

Feet.	Character of strata.	No.
60 to 70	Calcareous silt of the Bluff formation forming the hilltops	12
14	"Grand Gulf" sandstone, in ledges 10 inches to two feet in thickness	11
15	Gray sandy material, sometimes soft sandstone with an argillaceous cement, alternating with harder ledges, 6 to 10 inches thick, of friable whitish sandstone	12
2½	Solid whitish sandstone of good quality	9
2½	Greenish gray clay, with white veins of carbonate of lime	8
1	Soft white sandstone	7
½	Grayish yellow pipe clay	6
1	Dark gray brittle sandstone	5
3	Gray, semi-indurate clayey sand	4
17	Gray and yellowish sands and clays, semi-indurate, interstratified	3
3	Semi-indurate gray sand	2
2	Greenish gray clay, with veins of carbonate of lime	.....

(8.) SECTION AT RODNEY, CLAIBORNE COUNTY, MISS.

5	Yellow loam	4
100	Calcareous silt	3
5	Bluish clay	2
10	Gravel and sand	1

(9 *a.*) SECTION AT COLE'S CREEK, JEFFERSON COUNTY, MISS. (MRS. HUNT'S.)

20	Loess	2
5	Blue clay, with logs, and fruit, and leaves	1

(9 *b.*) SECTION ON BRANCH OF COLE'S CREEK, TWO MILES FROM MADDOX, ON FAYETTE, RED LICK AND UNION CHURCH, AND RODNEY ROADS.

2	Loam	.....
10	Mottled clay	.....
2	Drift	.....
2	Blue clay	.....

(9 *c.*) SECTION ON —— CREEK, SIX MILES FROM FAYETTE, ON NATCHEZ ROAD.

5	Loamy clay	.....
5	Blue sandy clay, with poplar log well preserved. (*Port Hudson*)	.....
5	Blue clay, with leaves, and beech and hickory nuts	.....
3	Pure blue clay, with whitish spots in bed of creek	.....

(9 *c*[1].) SECOND SECTION ON SAME CREEK, BELOW THE ROAD CROSSING.

3	Loamy clay. (Loess)	.....
5	Yellowish and white sand. (Drift?)	.....
3	Gravel. (Drift?)	.....
5	Clay. (Port Hudson?)	.....
2	Wood and leaves. (Port Hudson?)	.....
3	Blue clay. (Port Hudson?)	.....

(10.) SECTION AT DREW'S LANDING, ONE MILE ABOVE L'ARGENT LANDING, BELOW MOUTH OF FAIRCHILD'S CREEK DITCH EIGHT HUNDRED YARDS ACROSS BEND.

6	Sand	4
2	Sandy clay	3
5	Clay, with little sand	2
5	Blue clay	1

(11.) SECTION AT NATCHEZ, MISS.

Feet.	Character of strata.	No.
100	Gray calcareous silt of the Loess or Bluff formation, with helices and calcareous concretions	5
2	Brown loam, resembling surface soil, but calcareous	4
50 to 60	Orange and yellow sands, with some gravel. Orange sand or stratified drift	3
15	Ledges of ferruginous puddingstone and coarse sandstone. Orange sand or stratified drift	2
15 visible	Blue clayey sand and sandy clay of the Grand Gulf group	1

(12.) SECTION AT ELLIS CLIFFS, TWELVE MILES BELOW NATCHEZ.

30	Loess	2
76	Orange sand	1

(13.) SECTION AT BUFFALO CREEK.

20	Loam and silt	2
5	Blue clay, with mastodon skull and teeth	1

(15.) SECTION AT LOFTUS HEIGHTS, FORT ADAMS, MISS. (HILGARD.)

72	Yellowish gray calcareous silt, of Bluff formation	3
87	Orange sand, yellow, orange, and white sand	2
170	Argillaceous sandstone, yellowish gray in its mass, variegated with ferruginous spots and veins, and of different degrees of hardness, so as to weather into rough jagged surfaces. Traceable to water's edge	1

(16.) SECTION BELOW FORT ADAMS, AT WAREHOUSE LANDING.

150	Loess	3
40	Orange sand	2
40	Claystone	1

(17.) SECTION AT BARKER'S, SEVEN MILES EAST OF FORT ADAMS.

15	Loess	2
50 to 75	Orange sand	1

(18.) SECTION FIFTEEN MILES EAST OF FORT ADAMS.

1 to 5	Yellow loam	.....
....	Gravel	.....

(19.) SECTION TWENTY-ONE MILES EAST OF FORT ADAMS AND FOUR MILES FROM WOODVILLE, MISS.

5	Yellow loam	5
20	Orange sand	4
8	Reddish hardpan and pebbles	3
2	Blue clay	2
10	Red, yellow, and white hardpan	1

(20.) SECTION ON THOMPSON'S CREEK, AT McGEHEE'S.

10	Loess	2
5	Blue clay	1

(21.) SECTION AT RED RIVER LANDING.

5	Alluvial soil	4
3	"Buckshot" clay	3
40	Blue clay, with sand and "buckshot"	2
....	Quicksand and very little gravel	1

(22.) SECTION AT JUNCTION OF ATCHAFALAYA AND RED RIVERS.

Feet.	Character of strata.	No.
5	Gray sand	2
25	Red clay	1

(23.) SECTION AT TUNICA, LA. (HOPKINS), AND OPPOSITE TUNICA.

5	Alluvium	4
....	Loam	3
150	Loess	2
*5	Blue clay, with stumps	1

* Below surface.

(24.) SECTION ON TUNICA BAYOU, THREE MILES BACK OF TUNICA.

10	Loess	3
20	Sand and gravel	2
10	Clay	1

(25.) SECTION SIX MILES FROM TUNICA AND TWO MILES FROM PINCKNEYVILLE.

10	Loess	5
5	Red clay	4
20	White sand	3
20	Mottled clay	2
5	Blue clay	1

(26.) SECTION AT SAINT FRANCISVILLE.

10	Yellow loam	4
9	Sand	3
5	Sandy silt	2
2	Blue clay	1

(27.) SECTION AT PORT HUDSON (NEAR SAW-MILL). (HILGARD.)

4 to 6	Yellow surface loam	6
25	Yellow hardpan	5
7	Heavy greenish clay	4
6	Gravel, sand, and clay in irregular bands, like river alluvium, with pebbles, drift-wood, leaves, and mastodon bones	3
25 visible	Heavy greenish and bluish massy clay, similar to No. 4	2
....	....	1

(28.) SECTION AT PORT HUDSON, ALTON LANDING. (HOPKINS.)

5	Yellow loam	8
20	Hardpan, white and yellowish	7
21	Bluish joint clay	6
24	Sand	5
3	Ferruginous clay	4
13	Blue clay (massive)	3
4	Blue shale, stumps	2
3	White clay	1

(29.) SECTION MIDWAY BETWEEN PORT HUDSON AND FONTANIA. (HILGARD.)

8 to 10	Yellow loam, sandy below	6
18	White and yellow hardpan	5 (a)
8 to 15	Orange and yellow sand, sometimes ferruginous sandstone	5
7	Heavy greenish or bluish clay	4
18	White indurate silt and hardpan	3
30	Heavy green clay, with porous calcareous concretions above, ferruginous ones below; some sticks and impressions of leaves.	2
3 to 4	Brown muck, white or blue clay, with cypress stumps	1

(30.) SECTION AT ALLWORTH'S, FIVE MILES NORTH OF BATON ROUGE.

Feet.	Character of strata.	No.
17	Hardpan, white and yellowish	3
11	Sand	2
24	Blue clay	1

(31.) SECTION AT BATON ROUGE, UNITED STATES ARSENAL. (HOPKINS.)

23½	Yellow loam	3
15	Hardpan	2
16½	Blue clay	1

(32.) SECTION AN GARIG'S FERRY, AMITE RIVER, TWELVE MILES EAST OF BATON ROUGE.

5	Yellow hardpan. ¼ mile above, loam	4
3	White hardpan	3
10	Whitish hardpan. White and yellow sand, and 5 gravel	2
5	Blue clay	1

(33.) SECTION AT BONNET CARRÉ CREVASSE.

100	Alluvium	......
....	Blue clay, dredged from river bottom	......

(34.) SECTION AT BAYOU MANCHAC.

....	Close stiff clay in its bed	......

(35.) SECTION AT NEW ORLEANS.

2	Surface soil	11
15	Clay blue, tenacious, uniform	10
3.8	Clay coal black, containing rootlets, woody matter, &c	9
10.2	Sand and clay mixed, subtile, like the annual deposits of the Mississippi River	8
10	Clay	7
0.7	Sand	6
1.3	Shells	5
33	Sand	4
6.5	Shells	3
29	Clay and sand	2
34	Clay. (Port Hudson period?)	1

(36.) SECTION AT LAKE BORGNE.

25	Dark swamp clay, sea marsh	12
25	Bluish tough clay, fresh water	11
10	Blue clayey sand, fresh water	10
17	Drab-colored sand, fresh water	9
31	Blue clay, fluvio marine	8
....	Coarse gray sand, fresh water	7
....	Grayish clay, fluvio marine	6
....	Blue sandy clay, marine	5
16	Greenish micaceous sand, marine	4
....	Drab or blue tenacious clay, fluvio marine	3
....	Drab or bluish sand, fluvio marine	2
34?	Drab or bluish clay, marine. (Port Hudson?)	1

(37.) SECTION AT AVERA'S BLUFF, CHICKASAWHAY RIVER, GREENE COUNTY, MISS. (HILGARD.)

15	Yellow sand, with silicified wood. (Drift)	2
15	Compact bright blue clay. (Grand Gulf)	1

(38.) SECTION AT DWYER'S FERRY, PASCAGOULA RIVER, JACKSON COUNTY, MISS. (HILGARD.)

Feet.	Character of strata.	No.
2	Yellowish indurate clay—"Flatwood's clay"	5
4	Gray sand with yellow dots, containing particles of lignite and crystals of gypsum	4
7	Gray sandy clay, with lignitic layers, traces of leaves, and crystals of gypsum	3
4	Blue massy clay, with crystals of gypsum	2
12	Stratified gray clayey sands, cleaving into layers 1 to 6 inches thick	1

(39.) SECTION AT BAYOU BERNARD.

?	Sand?	.....
8	Dark bluish black clay, tenacious, fetid, and irregularly stratified with *Ostrea virginica*, *Balanus*, *Mytilus harmatus*	.....

(40.) SECTION AT SAUCIER'S WOLF RIVER, HARRISON COUNTY, MISS. (HILGARD.)

20	Gray and yellow sand, stratified more or less clayey, especially below	3
2 to 3	Yellowish gray massy clay	2
7 to 8	Matrix of dark gray or black clayey sand or muck, inclosing trunks, stumps, roots, and knees of cypress, with bark and wood preserved; also a few pine burrs	1

(41.) SECTION AT MRS. McRAE'S, WEST PASCAGOULA, MISS. (HILGARD.)

10 to 15	Sand	3
10	Sky-blue clay	2
?	Gray, calcareous, water-bearing sand, containing abundance of shells. (Hilgard)	1

(42.) SECTION AT SAM POWE'S, NEAR WINCHESTER, MISS.

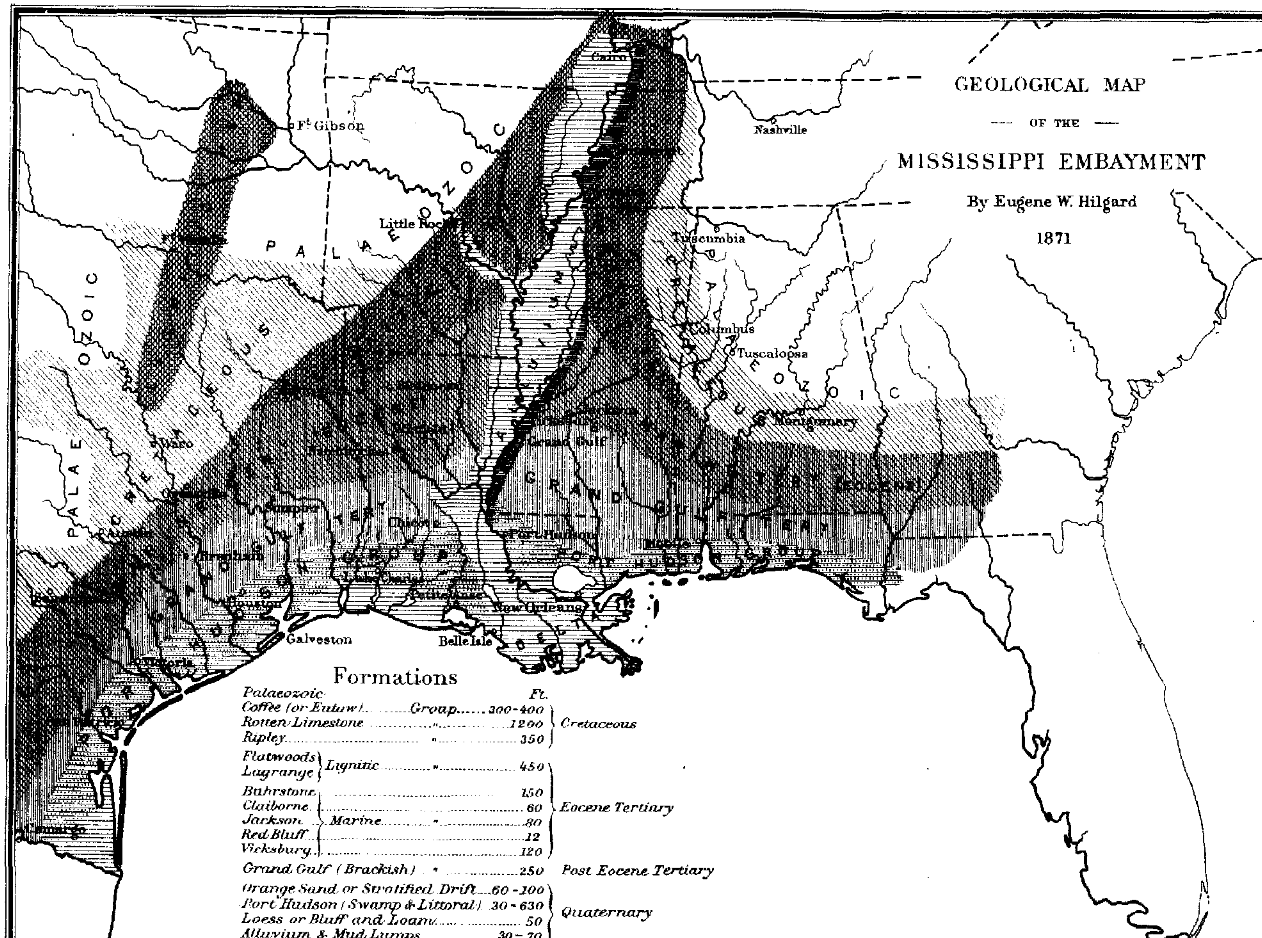
18	Yellow sand, with pebbles in its lowest portion (orange sand)	5
1½	White sand, with nodules of pipe clay	4
1 inch...	Black clay, with leaves	3
3	Grayish white sand, with vestiges of leaves or stratification lines	2
5	Bluish sandy clay, with roots and trunks of *Capuliferæ*, *Coniferæ*, *Palmæ*	1

(43.) SECTION AT SICILY ISLANDS, LA.

20	Yellow loam	4
24	Loess	3
26	Drift gravel	2
30	Grand Gulf	1

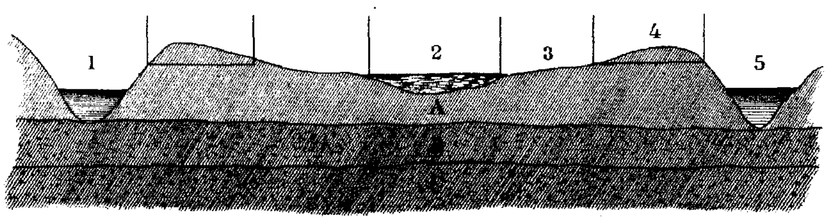
(44.) SECTIONS OF CARLEY'S WELL, NEAR HEAD OF CATAHOULA LAKE, LA.

11	Yellow loam	4
7	Fine yellow sand	3
¾ inch...	Salt in crystals	2
38	Blue clay, with cypress bark, limestone nodules, and fresh-water shells of recent species	1



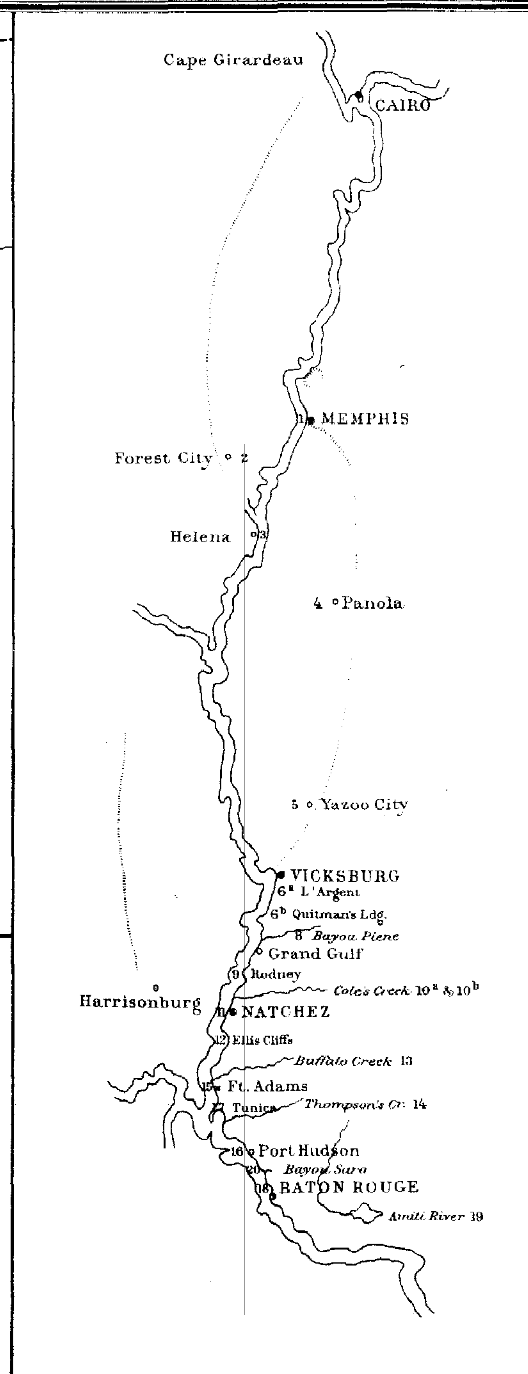
This Diagram of a Section through two Bayous, and the Land between them, will give a fair idea of the General Topography of the Bottom.

SECTION IN MISSISSIPPI BOTTOM, SHOWING THE ARRANGEMENT OF DEPOSITS.



1. Bayou.
2. Cypress Swamp.
3. Middle or Back-land.
4. High or Front-land.
5. Bayou.

A. Port Hudson Clays.
B. Blue Clay, with sticks and logs.
C. Gravel of Orange Sand age.
Between A. and 2. Buckshot.



Formations, and sections, and localities, tabulated.

Number.	Periods and formations.	1 Memphis.	2 Madison.	3 Helena.	4 Sardis.	5 Yazoo City.	6 Vicksburg.	7 Grand Gulf.	8 Rodney.	9 Cole's Creek.	10 Fayette? Creek.	11 Drew's Landing.	12 Natchez.	13 Ellis' Cliffs.	14 Buffalo Creek.	15 Fort Adams.	16 Below Fort Adams.	17 Barker's, 7 miles east of Fort Adams.	18 Fifteen miles east of Fort Adams.	19 Four miles from Woodville.	20 Thompson's Creek.	21 Red River Landing.	22 Atchafalaya and Red River Junction.
	QUATERNARY:																						
1	Alluvium											13										5	5
2	Loam	10			10				5	2	5				20				5	5			
3	Loess	40	40	6	12		20	70	100	20			100	30		72	150	15			10		
4a	Port Hudson hardpan																						
4b	Port Hudson blue clay	10							5	10	13	5			5								25
5	Drift	40	20	50	10		20		10	4?			75	76		87	40	75		40		(?)	
	TERTIARY:																						
6	Grand Gulf							61½					15			170	40		(?)				
7	Vicksburg						98																
8	Red Bluff																						
9	Jackson		15																				
10	Claiborne																						
11	Mansfield																						
12	CRETACEOUS																						
13	CARBONIFEROUS																						
14	DEVONIAN																						
15	SILURIAN																						

Number.	Periods and formations.	23 Tunica.	24 Tunica Bayou, 3 miles back.	25 Six miles from Tunica.	26 Saint Francisville.	27 Port Hudson, near saw-mill.	28 Port Hudson, Alton Landing.	29 Port Hudson to Fontania.	30 Allsworth's, 5 miles north of Baton Rouge.	31 Baton Rouge, United States Arsenal.	32 Garig's Ferry, Amite River.	33 Bonnet Carré.	34 Bayou Manchac.	35 New Orleans.	36 Lake Borgne.	37 Avera's Bluff, Greene County, Miss.	38 Dwyer's Ferry.	39 Bayou Bernard.	40 Saucier's Bluff.	41 West Pascagoula.	42 Winchester, Miss.	43 Sicily Islands, La.	44 Catahoula Lake, La.
	QUATERNARY:																						
1	Alluvium											100	20?	112	124								
2	Loam				10	6	5	10		23½												20	11
3	Loess	150	10	10																		24	
4a	Port Hudson hardpan		20	25	14	25	20	33	28	15	15						11						7
4b	Port Hudson blue clay		10	25	2	38	68	59	24	16½	5	(?)	(?)	34	34?		16						38
5	Drift															15			20	15	19½	26	
	TERTIARY:																						
6	Grand Gulf															15		8	11	10	5?	30	
7	Vicksburg																						
8	Red Bluff																						
9	Jackson																						
10	Claiborne																						
11	Mansfield																						
12	CRETACEOUS																						
13	CARBONIFEROUS																						
14	DEVONIAN																						
15	SILURIAN																						

APPENDIX No. 13.

A TREATISE ON THE PLANE-TABLE AND ITS USE IN TOPOGRAPHICAL SURVEYING.

By E. HERGESHEIMER, Assistant.

The representation of any portion of the surface of the earth in horizontal plan, as it would appear viewed from a vertical position over each point, is the modern form of a map, which may be considered as consisting of an infinite number of points, the establishment of the positions and relations of so many of which as may be necessary to define the features required constituting the instrumental work of the surveyor.

A point in space is the prime element of position, but is indefinite position; the addition of another point introduces the definite elements of direction and distance.

Direction, as applied to terrestrial surveying, is azimuth, or deflection from the true north and south line; or compass bearing, deflection from the magnetic north and south line; or the amount of deflection from any given line.

The amount of deflection of one line from another is measured by the angle formed at their intersection as a center.

Distance is measured by any unit conventionally established; the most definite of which, in present use, are the yard and the meter.

The addition of a third point introduces trigonometric functions, by which any given three elements of a triangle, except the three angles, serve to determine all the others; this with the plane-table, in topographical surveying, is graphically performed.

In a topographical map each point, besides being projected upon a horizontal plane, has its height, either within, above, or below a level surface, in some way indicated. The representation of details between the determined points completes the survey, and draws upon the artistic skill, perception, and judgment of the surveyor.

In surveys of such limited area as are generally made with the plane-table, questions of geodesy may be disregarded, except the convexity of the earth's surface and refraction as affecting heights.

Our inquiries will, therefore, be directed to the instrumental and personal processes necessary for a precise and intelligible representation of nature, and especially to those processes peculiar to the plane-table, and which constitute its special power, as well as to indicate, step by step, the proceedings and manipulations in the use of this instrument, which have generally heretofore been acquired through personal instruction.

For convenience of description the plane-table may be divided into three parts: 1. Tripod head and legs. 2. Movements. 3. Table-top or board.

The legs are made of wood as light as is consistent with requisite strength, shod with brass, and at their junction with the tripod head of sufficient width to reduce the chances of lateral motion to the minimum. The tripod head is sometimes made of wood, but in the latest instruments is made of brass.

The movements of the tables in use by the Coast and Geodetic Survey are of different construction, but all are of brass, and look to the same essentials, viz, sufficient strength for solidity, and horizontal revolving faces of large enough diameter and accurate fit to prevent vertical motion when clamped together, as well as sufficient room for lateral play of the axis of revolution of the upper plate, necessary in the different relations between the planes of the tripod head and the revolving faces of the movements, which latter are always required to be in a horizontal plane, and means for clamping the axis of revolution to the tripod head when the revolving faces have been made horizontal with the leveling screws; there being attached to the clamp of the revolving plate the usual tangent screw for fine motion.

The table-top or board should be made of well seasoned wood, panelled with the grain at right angles, to counteract as much as possible the tendency to warp; its upper surface finished as nearly

Fig. 1.

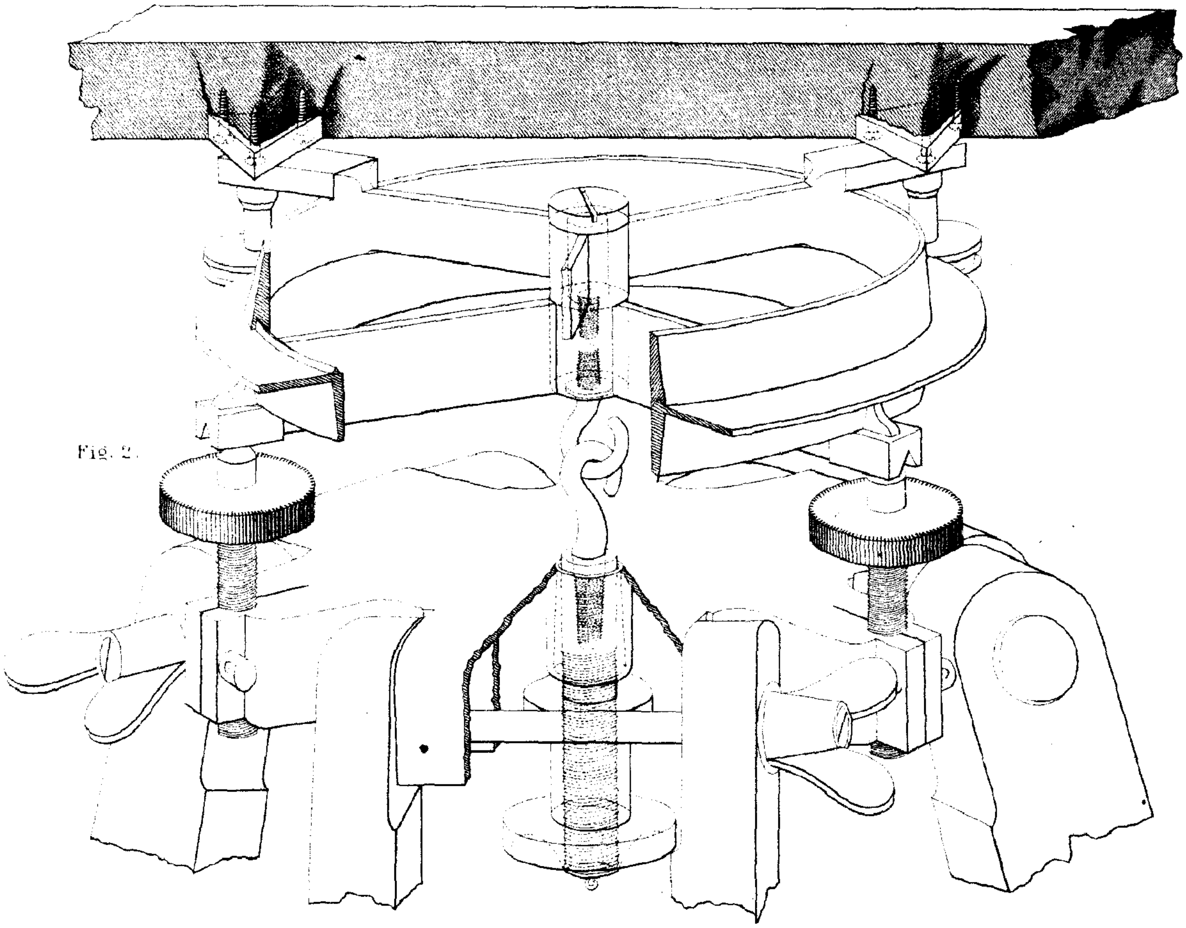


Fig. 2.

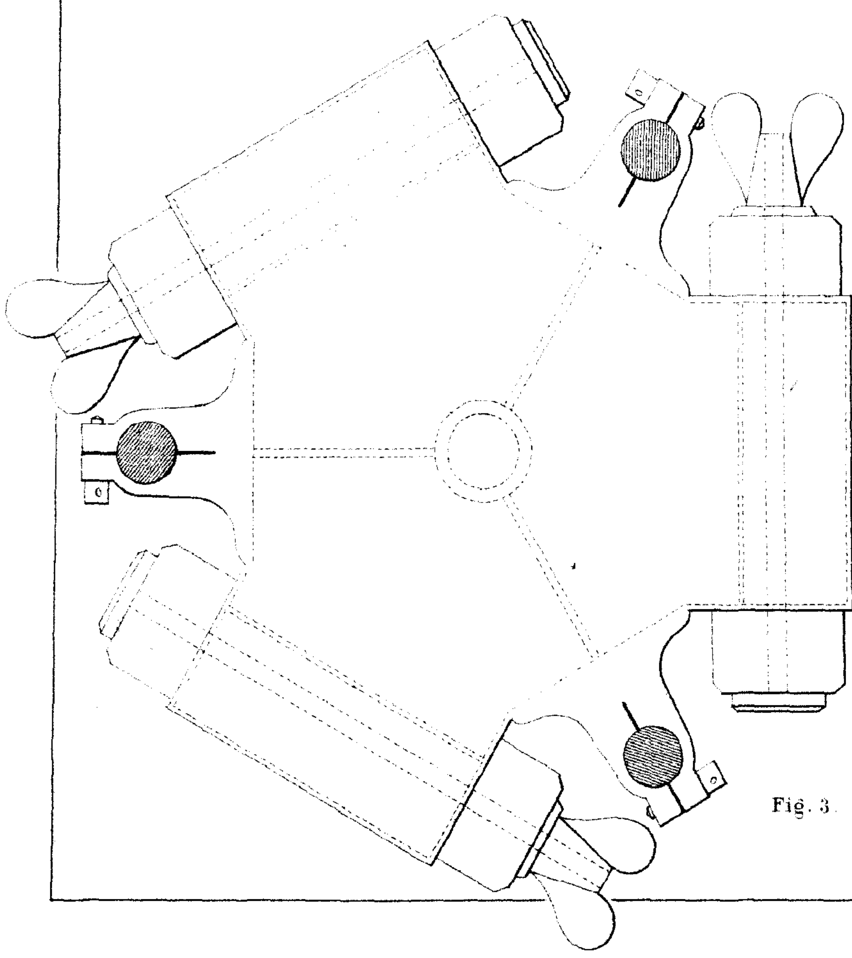
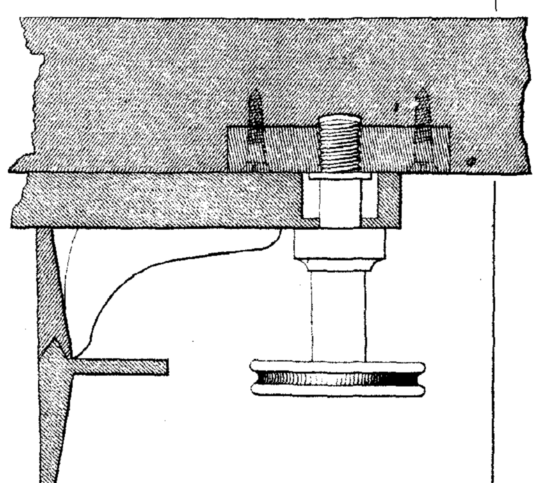


Fig. 3.



as possible in a plane and attached to the projecting arms of the movements with firmness; great care being taken that its upper surface shall be parallel to the plane of revolution of the movements so that the two planes shall remain parallel in all positions of the board.

As much lightness as is consistent with requisite strength should be sought in the construction of all the parts.

The accompanying illustrations (Nos. 49 and 50, Figs. 1, 2, and 3) of what is considered the most approved instrument will be sufficient, it is hoped, to show its construction without any minute description of details.

The most approved alidade (see illustration) consists of a brass or steel rule (12 inches long by 2½ inches wide), nickel-plated underneath, from and perpendicular to which rises a brass column (3 inches high), surmounted by Ys, receiving the transverse axis of the telescope, to one end of which axis is firmly attached a graduated arc of 30°, each side of a central 0, an accompanying vernier being attached to the lower part of the Y support.

The telescope is fitted accurately near its center of gravity within a closely fitting cylinder, to which is solidly attached the transverse axis. The telescope revolves within this cylinder 180°, stops being fitted for that range. This affords an easy mode of adjusting the cross-webs to the axis of revolution, and for correction, with a striding level, of the errors of level and collimation and of revolution of the telescope.

Upon the tube of the telescope are turned two shoulders, on which rests a striding spirit-level, which can readily be reversed or removed at pleasure. The usual eye-piece and diaphragm are used, but it is usual to attach to the diaphragm a thin glass plate having two finely engraved horizontal lines, the distance between which remains a constant chord for the measurement upon a divided staff, of distance; or, to attach to the eye-piece a micrometer with one of the horizontal wires movable, for measuring the angular distance of a fixed length, on a rod, which remains a constant chord.

To the rule of the alidade are attached two spirit levels, one in the longitudinal direction of the rule and the other at right angles to it.

A declinatoire accompanies the alidade and is carried in its box. It was formerly attached to the rule of the alidade with the north and south line of the arcs parallel to the edge of the rule. It is found most convenient, however, to have the declinatoire separate and made with the sides of the box parallel to the north and south line of the arcs, which have usually 10° on each side of the 0. This is necessary when the rule of the alidade is of steel. It can be used, however, for direction of magnetic north by placing the table in position at any point and removing the alidade a sufficient distance from the table not to influence the needle. When the declinatoire is in position, its needle pointing to the 0's of the north and south arcs, with its edge on the point occupied, it should be held firmly in place while the edge of the alidade rule is applied to the edge of the box so as to extend the direction the full length of the rule.

OLD STYLE ALIDADE AND ITS ADJUSTMENTS.

The old style alidade still in use consists of a brass rule about 22 inches long, having a circular level on its upper face. Near the middle of the rule is a perpendicular cylindrical column of brass called the "standard," surmounted by two square brass plates joined by screws, and supporting horizontally a conical journal, through which extends a closely fitting cone of brass, coming from and attached to the side of the telescope. This cone forms the axis of the vertical movement of the telescope, and is secured at the extremity by a screw which holds it in its place. The telescope itself has the usual cross-hairs and means of focal adjustment.

A transverse level is fastened to the edge of the upper of the two plates at the top of the standard by means of adjusting screws.

The telescope is so placed that its line of collimation is above and in the same vertical plane with the fiducial edge of the rule.

A vertical arc with a tangent screw and clamp is attached to the telescopic side of the lower brass plate, and, with a vernier which moves in arc as the telescope is raised or depressed, is used in the measurement of vertical angles for heights.

ADJUSTMENTS.—From the nature of the service in some sections of the country the plane-table is often necessarily subjected to rough usage, and there is a constant liability to a disturbance of the adjustments; still, in careful hands, a well-made instrument may be used under very unfavorable conditions for a long time without being perceptibly affected. One should not fail, however, to make occasional examinations, and while at work, if any difficulty be encountered which cannot otherwise be accounted for, it should lead directly to a scrutiny of the adjustments.

1. *The fiducial edge of the rule.*—This should be a true, straight edge. Place the rule upon a smooth surface and draw a line along the edge, marking also the lines at the ends of the rule. Reverse the rule, and place the opposite ends upon the marked points, and again draw the line. If the two lines coincide, no adjustment is necessary; if not, the edge must be made true.

There is one deviation from a straight line, which, by a very rare possibility, the edge of the ruler might assume, and yet not be shown by the above test; it is when a part is convex, and a part similarly situated at the other end concave, in exactly the same degree and proportion. In this case, on reversal, a line drawn along the edge of the rule would be coincident with the other, though not a true right line; this can be tested by an exact straight edge.

2. *The level attached to the rule.*—Place the instrument in the middle of the table and bring the bubble to the center by means of the leveling screws of the table; draw lines along the edge and ends of the rule upon the board to show its exact position, then reverse 180°. If the bubble remain central, it is in adjustment; if not, correct it one-half by means of the leveling screws of the table, and the other half by the adjusting screws attached to the level. This should be repeated until the bubble keeps its central position, whichever way the rule may be placed upon the table. This presupposes the plane of the board to be true. If two levels are on the rule, they are examined and adjusted in a like manner.

Great care should be exercised in manipulation, lest the table be disturbed.

3. *Parallax.*—Move the eye-glass until the cross-hairs are perfectly distinct, and then direct the telescope to some distant well-defined object. If the contact remain perfect when the position of the eye is changed in any way, there is no parallax; but if it does not, then the focus of the object glass must be changed until there is no displacement of the contact. When this is the case, the cross-hairs are in the common focus of the object and eye glasses. It may occur that the true focus of the cross-hairs is not obtained at first, in which case a readjustment is necessary, in order to see both them and the object with equal distinctness and without parallax.

4. *To make the line of collimation perpendicular to the axis of revolution of the telescope, and the axis of revolution parallel to the plane of the rule.*—The instrument is set up and carefully leveled, and the cross-hairs directed to a plumb or other vertical line. If the cross-hairs cover the line when the telescope is elevated and depressed, the adjustments are perfect; should they deviate, however, from the vertical line, this error may be attributable to two causes: 1st, the line of collimation is not perpendicular to the horizontal axis; or, 2d, the axis is not horizontal, and consequently not parallel to the plane of the rule. In the first case the motion of the cross-hairs will be in a curve, and upon being made to cover the vertical line when the telescope is horizontal, will deviate from it to the *same* side both upon elevation and depression. In the second case the movement of the cross-hairs will be in a straight line oblique to the horizon, and when made to cover the vertical line when the telescope is horizontal, they will, upon being elevated and depressed, appear upon *different* sides of the vertical line. These two cases will be considered separately.

When the construction of the telescope admits of it, the perpendicularity of the line of collimation to the transverse axis may be examined as follows: Direct the cross-hairs to a well-defined, distant object, as nearly upon a level with the telescope as may be, draw a line along the fiducial edge; then reverse the rule 180°, again placing the edge along this line, revolve the telescope upon its axis and again observe the object; if the cross-hairs cover it, the adjustment is perfect; if not, one-half the error must be corrected by moving the cross-hairs by means of the adjusting screws of the diaphragm, and the other half with the tangent screw of the table, and the operation should be repeated until the adjustment is complete.

In using the method just given, it may be taken for granted that the line of collimation revolves in the vertical plane of the fiducial edge, as any error arising from this not being the case would be inappreciable.

After this adjustment the horizontality of the axis should be examined. Direct the cross-hairs to a distant, well-defined, elevated or depressed object, having the table carefully leveled; draw a line along the fiducial edge, reverse the rule, and again direct toward the object; if the cross-hairs cover it, the axis is horizontal; if they do not, one-half of the deviation should be corrected by means of the screws attaching the upper plate to the top of the standard, or by means of the screws attaching the standard to the rule. The level attached to the axis should then be made central. In the alidades, as recently improved, the bearings of the axis being unchangeable, save by such violence as would destroy the instrument for all practical purposes, the foregoing adjustment and the succeeding one are, of course, unnecessary, as the instrument is to be considered as in constant adjustment in these respects.

5. *To make the line of collimation parallel to the vertical plane of the fiducial edge.*—The exact parallelism of these is not necessary, but it is essential that the deviation should remain constant. This adjustment may be examined by means of two needles stuck in the table. The table is turned so that the needles sight exactly to some distant object; the fiducial edge is then placed against them and the telescope directed to the object. If the cross-hairs bisect it, the adjustment is correct; but if they do not, it can be corrected by means of the screws attaching the standard to the rule.

6. *Zero of the vertical arc.*—When the line of sight is horizontal, the vernier of the vertical arc should read 0°, or the index error should be known. This may be examined by means of the distant sea horizon, or by setting up the alidade so that the center of the telescope is in the line of sight of an accurately adjusted leveling instrument, and then directing both instruments, while level, to a distant object; if any error be discovered, it may be corrected by setting the vernier at 0°, and adjusting the horizontal wire to the sea horizon or object.

When the above means are not available, the following method may be used: Set up the instrument at a point, measure the angle of elevation or depression of a distant object, remove the instrument to that object, and measure the angle of depression or elevation of the first point. These angles should be equal if the adjustment be correct; and if not equal, the index error will be one-half the difference of the two readings.

The following method of making this adjustment, where you have neither a separate level, a sea horizon, or an elevation, may be employed: Set up the table and level it carefully on any level piece of ground between two equidistant points A and B, say 600 or 800 meters apart. Determine with the table the difference of level of these two points, and remove the table to A. Measure carefully the distance from the ground to the center of the axis of the telescope, and add or subtract this from the difference of level of the point B, according as it is lower or higher than A. Set up a target or distinct point at this height at B, direct the cross-hairs upon it, and correct the vernier accordingly.

FIELD WORK.

As in all plane-table surveys it is important that sufficient points shall be determined from a measured base, at such distances from each other that, when plotted on the scale of the survey, they may be reached by the rule of the alidade from the intervening spaces, it will be presumed that this has been done, as is usually the case in the Coast and Geodetic Survey, and that the sheet to be used on the table has these points accurately plotted, so that they bear the same relation to one another as the corresponding points of nature.

The first proceeding is to secure the sheet to the table, so that it will be held firmly and evenly and not be disturbed in its position by the friction of the alidade, nor by ordinary winds. As the longest side of the board is usually made equal to the width of the sheet, and the sheet is usually longer than this width, the excess of length is rolled up inward, turned underneath the sides of the table and fastened with a metal spring-clamp, biting from the top of the sheet on the table to the inside of the roll beneath. One clamp at each end of the roll serves to hold the roll-ends securely. The sides of the sheet are sometimes held to the table by similar but shorter clamps, but it is preferable for the free movement of the alidade, and more secure against strong winds, that a metal strip, the length of the side between the end clamps, with spring clamps fastened to the outer edge, and biting the under side of the table, be used for holding down the edges of the paper. These strips have another important value—that scales of equal parts of the proportion of the survey can be marked upon them, and thus dispense with the scale usually carried separately. It is best to have all metal that comes in contact with the paper nickel-plated, as this does not corrode, and consequently does not soil the paper.

Sheets should never be rolled to a diameter less than three inches, as the compression and rupture of the surface fiber increases as the diameter decreases; and probably more to this than to any other cause is due the soft and spongy nature of the surface of many sheets after use in the field.

A signal having been erected at each triangulation point, and the table and alidade adjusted, the next proceeding will be to occupy one of the points. The table having been set accurately over the point and carefully leveled and set in approximate position, set the rule edge of the alidade on the line connecting the point occupied with any other determined point, unclamp and revolve the table until the latter point is within the field of the telescope, when the table should be clamped and the point bisected by the vertical web with the tangent screw; then take hold of the edge of the board and apply a gentle force in the direction of the revolution to determine if all is well clamped. Observe again the contact of the vertical web with the object, and correct with the tangent screw any error of contact. The table will then be in position, or, as it is sometimes called, "oriented." Then set the edge of the alidade rule upon the lines joining each plotted point and the point occupied, successively. Each corresponding signal or object should be bisected by the vertical web of the telescope. The failure to do so indicating error of plotting or change of dimensions of the paper, which must be examined and corrected. If, however, the extension of the line to each point of the sheet cuts the corresponding point of nature, the points of the sheet are correctly plotted in the directions observed, and the table is in position.

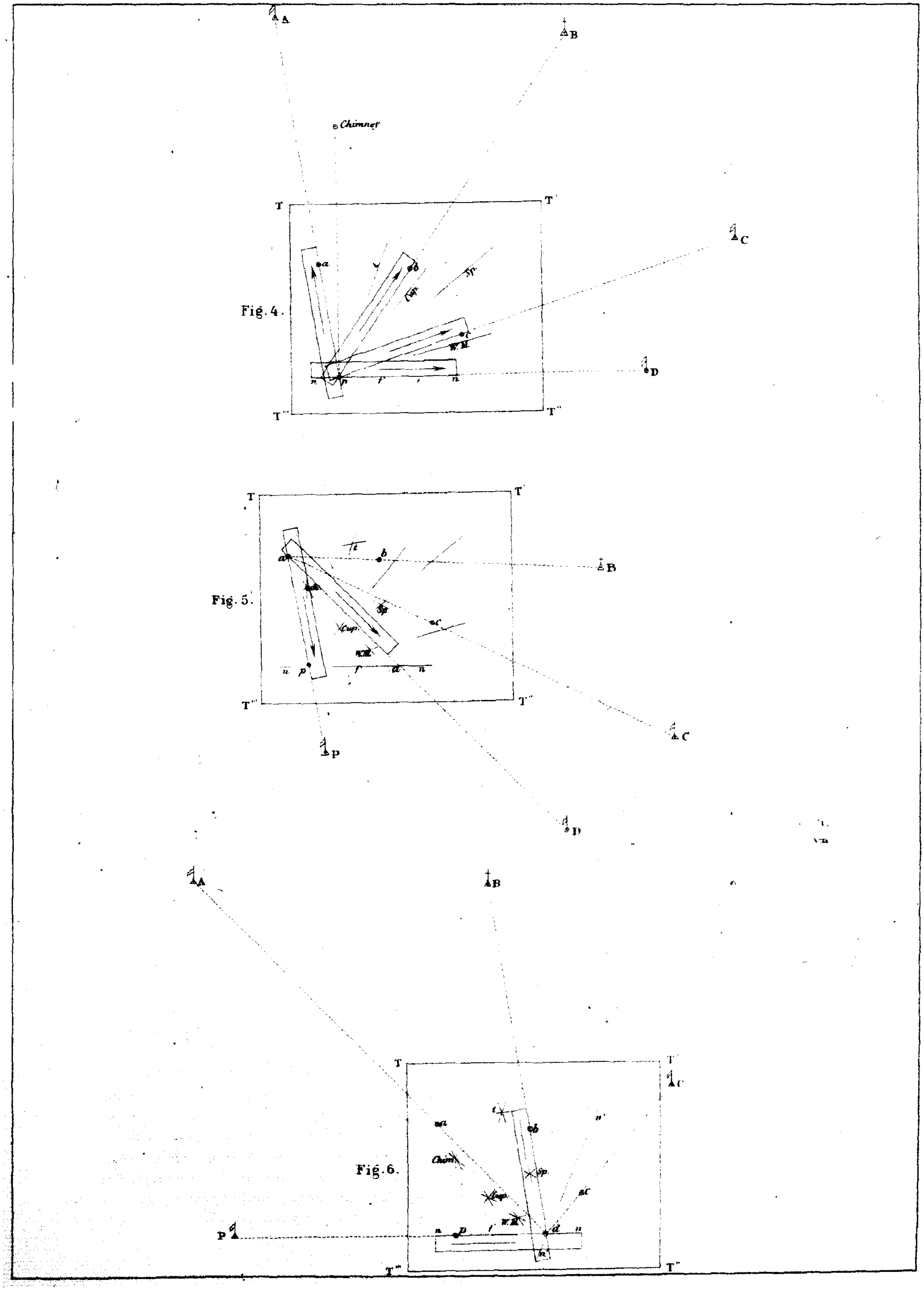
The chief and controlling condition in work with the plane-table, and without which no accurate work can be done, is that the table shall be *in position;* that is, that all lines joining points on the sheet shall be parallel to the corresponding lines of nature.

Let T, T′, T″, T‴ (Illustration 51, Fig. 4), represent the board of the plane-table, upon which is spread the sheet; the plotted triangulation point *a* upon the sheet representing the signal A upon the ground; *b*, the spire B; *c*, the signal C; and *p*, the station P; the small letters on the sheet representing the centers of the signals on the ground, which are referred to by corresponding capital letters.

The table is placed approximately level over the occupied station P, and put in position, also approximately, by the eye, so that the plotted points on the sheet are in approximate range with the station P and the signals or objects they represent in the field. Then plumb the point *p* over the station P, fixing the legs of the table firmly in the ground; place the alidade upon the table so that the rule shall extend across and parallel with the line joining two of the leveling screws; loosen the large clamp screw under the tripod head, and with the leveling screws bring the bubbles of the two levels on the rule to the center; clamp the screw under the tripod head, and the table is level. Now, unclamp the revolving plate, place the edge of the rule upon the plotted points *p* and *b*, the telescope being directed toward the spire B, as shown by the arrow-head of the figure, and revolve the table until B is seen in the field of the telescope; clamp the revolving plate, and with the tangent screw of the movements bisect the top or center of the spire B with the vertical web of the telescope. The table is now *in position*, if the points have been correctly plotted and the proper objects sighted. To verify this, place the rule upon the point *p* again, and upon the points *a* and *c*, consecutively, and if the two signals A and C are bisected by the vertical web of the telescope, the position is assured, and the lines connecting points of the sheet are parallel with the corresponding lines on the ground.

The next proceeding is to draw the line to the next point which it is desirable to occupy or determine, either some natural object which can be occupied, or a temporary signal placed for that purpose, as the signal D.

The edge of the rule is placed upon the point *p*, and moved about that point as a center until the signal D is bisected by the vertical web, and then a line, *f*, is drawn along the edge of the rule from *p* far enough to reach the estimated position on the sheet of the point *d*, and at each end of the rule the short check-lines *n n* are drawn. These check-lines may be marked on the sheet with names of objects, as in Fig. 4—*ch.*, chimney; *t.*, tree; *cup.*, cupola; *sp.*, spire; *w. m.*, windmill; or numbered, and a record kept of their objects sighted, where details are complex; and they


A
B
Chimney
T
T'
C
Fig. 4.
a
b
c
W.M.
D
n
p
f
n
T'''
T''
T
T'
Fig. 5.
B
a
b
c
Sp
Cup.
W.M.
n
p
f
d
n
T'''
T''
P
C
D
A
B
T
T'
C
Fig. 6.
a
b
Chim.
Sp.
Cup.
W.M.
c
P
n
p
f
d
n
T'''
T''

always serve to reverse the alidade upon, with the accuracy that is obtained by the greatest length of a range line.

In the same manner, lines to be afterward intersected should be drawn to such objects as it is desired to determine. Tangent lines to prominent objects, natural and artificial, and lines to objects comparatively near, the distances to which are to be measured, such as fence-corners, houses, road-angles, and turns in creeks, &c., should be drawn. If the height of the station be important, this should be determined, both as a guide for the lines of equal elevation in the immediate vicinity, and as a point of reference for determination of heights from other stations. The drawing of details is now to be completed, it being always desirable that the work at a station be completed when it is first occupied, so that, if possible, no return to it shall be necessary. Work being completed at a station, the alidade is placed in its box, the table clamped and removed, the signal re-erected, and the next station occupied.

While at a station the table is shaded by a large umbrella to soften the glare of the sun on the white surface, and to neutralize, as far as possible, its effect in contracting the dimensions of the paper.

The table having been moved to the point observed upon to put it in its first position, and having been accurately set up and leveled, set the alidade on the line connecting this point with the first point occupied, and revolve the table until the signal at the first point occupied is within the field of the telescope, when clamp the movements and with the tangent screw bisect the signal with the vertical web. The table is then in position, and the observation of each plotted point from this point in the same manner as at the first station will determine if each point is plotted correctly in direction from this point. If the two observed directions of each signal from the two points occupied intersect in the corresponding plotted point, the point is correctly plotted on the sheet. It is best, however, to occupy a third point, repeating the same proceeding; when the intersection of the three directions in any plotted point proves its position and relation to the other points correct beyond doubt.

When the table is in position at any determined point, any object in view may be observed through the telescope, and the edge of the rule being kept sharply on the point occupied, a line drawn along its edge will be the direction of the object observed; and as this determines only the one element of direction, it will be necessary to determine its distance from the point occupied either by measure or by intersection of this direction by a direction from some other fixed point, which intersects the first direction at an angle not less than 30° nor more than 150°; all acute intersections should be verified by a direction from a third point.

(Fig. 5.) The table is removed to the station A and placed over the point, put in approximate position, leveled, and the axis of revolution clamped as at station P. The rule is then set upon the line *a p*, the telescope directed toward the signal P, and the table put in position in the manner described. Then, keeping the edge of the rule upon *a*, direct the telescope to the signal D and draw the line *a d*, intersecting *f*, and determining the position of the point *d* upon the sheet, corresponding to D, and bearing the same relation in directions and distances from the points *p*, *a*, *b*, and *c* as the signal D does from P, A, B, and C. All lines to other objects which were drawn from *p*, and which objects can be seen from A, are intersected and determined in the same manner.

When a direction has been drawn from a station to any undetermined point that may be occupied, the position of the point may be determined by occupying it with the table, and putting the table in position by the line drawn to it, and *resecting* upon a signal whose corresponding point is plotted upon the sheet.

(Fig. 6.) The table is placed over the point D, put in approximate position, leveled, &c., as at the previous stations. The edge of the rule is then placed upon the line *d p*, passing through the point *p*, so that the checks *n n* are just visible along the edge, and the telescope directed toward the signal P, and the table put in position. The rule is then placed with its edge bisecting one of the plotted points, such as *b*, which will give a good intersection (the nearer 90° the better) with the line *f*, and is moved about that point as a center until the spire B is bisected by the vertical web. A line is now drawn along the edge of the rule accurately through *b*, crossing the line *f*. If this line intersects the line *f* at the point *d*, the position of the latter is assured, and a delicate hole with the dividers should be pricked at the point, surrounded by a small circle in pencil. Resection upon any other determined point will verify its position.

From this point *d* directions are observed and drawn to verify the previous intersections upon *cihmney, tree, cupola, windmill*, &c.

Signals should be observed as near the base as possible.

Signal poles should be straight and perpendicular, the flags upon them adapted in color to the background against which they will be seen oftenest, and be secured either by braces or by stones piled or earth thrown up around their bases. Points should also be well marked with pegs, or by measurements to neighboring permanent objects, so that in case their signals are disturbed their positions may be found.

On maps of a large scale it is important to plumb the plotted point exactly over the station, but on the usual field scales an approximation with the eye is all that is requisite.

All lines should be drawn lightly and carefully close to the edge of the rule with a finely-sharpened hard pencil. If the table and alidade be in proper condition, the contact of the edge of the rule with the paper will be perfect throughout its length, and in drawing a line along the edge care must be taken to preserve the same inclination of the pencil and to keep it sharp. If the rule should be raised from the paper at any part, great care is to be observed that the pencil does not run under the edge and thus deviate from a straight line.

The instruments should be kept scrupulously clean and free from sand or grit, and any foreign substance found between the surfaces which play upon one another should be immediately removed.

Where it is necessary to make a topographical survey in advance of the determination of points by triangulation, a reconnaissance is first made for the location of a base-line and selection of points to be determined with the plane-table.

The base is measured with sufficient accuracy, and conveniently, with a steel tape which has been compared with standard, to one handle of which is fixed an adjustment for temperature, so that the distance between the abutting faces of the handles represents its length at the standard temperature, usually 60° Fahr. Ordinary chain pins serve to mark the successive lengths in measuring.

The base is then properly located on the sheet in reference to the area to be embraced, and its length carefully set off. It is well, at the same time, to mark in three or four different parts of the sheet lengths of 1,000 meters, for the purpose of determining at any time the true scale of the sheet variable by the different hygrometric conditions of the atmosphere.

Signals having been erected at the selected points, the extremes of the base are occupied with the table, and the points, as far as may be reached with good intersections, determined from them, and lines of direction drawn to all the points visible, to serve as checks upon their determination from other points furnishing directions for good intersections. The survey then proceeds as usual.

It is well at the beginning of work to set off with the declinatoire at some determined point near the middle of the sheet, the magnetic meridian, for the purpose of putting the table in approximate position at any station with the declinatoire. The manner of doing this is elsewhere described.

Before finishing the field work, it is important, when the sheet has no projection, to provide data for drawing a true north and south line. This is done by drawing from a point upon the sheet, when the table is in position, a line in the vertical plane through Polaris and the point occupied and recording the time of observation. The azimuth of the star at that time being known, a true north and south line can accordingly be set off.

If a small transit instrument is at hand and carefully adjusted for movement in vertical plane, an assistant with a lantern can be located where the vertical plane through Polaris and the point occupied intersects the ground, at as great a distance from the point as the ground will admit of, within the limit of communication by light signals. When the assistant is in position, a stake is there driven, the direction to which, from the point occupied, may be determined by daylight.

If, in the absence of a transit, the alidade has not vertical range sufficient to reach Polaris, an illuminated plumb-line may be used for the alignment.

In a wooded country where it is impossible to find open spaces with range sufficient to see enough points for determination of position by resection, it is necessary to make use of the roads and trails for running traverses, with offsets to such lateral features as it may be practicable to reach without the expenditure of excessive labor and time in opening lines of sight.

For this purpose a small auxiliary plane-table, the working with which will not require more than two hands in addition to the aid in charge, affords the best facility. For, with compass, the deflections of the traverse will be only approximate, and with a transit instrument the necessity arises for plotting with protractor on a sketch with less accuracy and facility than the table affords. Besides, with the table, points may be transferred from the main sheet to the traverse sheet that may be occasionally seen through openings for lateral check on position.

In running traverses, great care should be taken to sight as low as possible upon the fore and back signals so as to avoid any error of deflection that might arise from inclination of the signal poles. Upon the distance rod there should be a mark corresponding to the average height of the optical axis of the telescope for observation of difference of height by vertical angle.

For rugged mountain work the table and alidade of ordinary size and weight are too heavy, although the heaviest may be used by a mounted party with proper appliances for transportation. Canvas cases for the movements and table top with broad suspending shoulder straps will enable them to be carried by mounted men, but sometimes under circumstances where the bad behavior of a horse would make serious trouble. Besides, it is only occasionally that a large table is absolutely necessary for reaching distant points, the work for a day in the majority of cases being confined to an area within the size of a small mountain table-top. Where it may be necessary to establish additional points with the small table, these may be subsequently determined in the general scheme, with the large table, as the necessity therefor arises. With a small table with top measuring 14 by 17 inches, and weighing 29 pounds, and alidade weighing with box 11½ pounds, work of the Coast and Geodetic Survey has been carried on in a bold, rough, rocky region without need of more than two hands and one rodman.

A short linen coat with large pockets, in the style of a hunting coat, is probably the best means for carrying the necessary accessories for plane-table work, viz, clinometer, metal scale, dividers, pencils, rubber, distance scales, tables of heights, tables for trigonometric computation, note book, and sketch book. For by this means the weight of these articles is distributed in separate pockets, where they are always ready when needed.

A metal chart case should always accompany the table to secure the sheet from sudden rain and other injury liable to occur in the transportation of the sheet to and from the field of work, and for its safe keeping when not in use. Its diameter should be not less than 3 inches, for no sheet can be rolled to a less diameter without serious rupture of the fiber of the paper.

For topographical reconnaissance a micrometer eye-piece in the telescope for distance measure is probably better than fixed lines in the diaphragm, because in the use of the former the chord on the staff or other object remains constant and can be made longer or shorter for greater or less distances, the variable angle being read with the micrometer. On a conspicuous tree, or on the face of a prominent rock, especially when on the shore of a body of water, a vertical distance the length of the chord of the experimentally made micrometer distance scale may be marked with whitewash, so that it may be used for the observation of distance from any point from which it may be visible. A lone tree on a divide may for this purpose be valuable for a large arc of visibility.

For reconnaissance of a harbor, the height of the mast of a vessel at anchor may be used in this way to advantage, a record of the time of observation being kept to know the vessel's position at the time under tide or current influence, which variation can be readily determined and plotted.

The sketching of topographical details in complex localities should only be entrusted to an aid who has resource enough to connect with advantage his work with the determined positions furnished him, and as no two topographical subjects will be found exactly alike, probably the only suggestion that need be given to govern proceedings is to make the work as complete as possible as it proceeds, so as to reduce the chances of omission of details likely to occur by leaving one part for another before the details of the first are exhausted.

All the signal-flags needed in a topographical survey can be made with white and red cotton cloth. A yard square is a suitable size, and conveniently the usual width of the cloth.

The table-bearer should be taught at the beginning of work the mode of setting the table over a point and taking it up from the same. In the first instance to grasp firmly the nearest two legs of the tripod, and with the knee to extend the third one until its foot reaches the ground at the proper distance from the point, when the other two feet are set in position. These distances from the point will vary as the ground may be level or sloping, the tripod head being kept vertically over the point and approximately horizontal being the essential conditions. In taking up the table the two near legs should be grasped firmly and the table raised, resting upon the other leg, upon which the first two are closed, when the table is raised in place upon the shoulder.

DETERMINATION OF THE POSITION OF AN UNKNOWN POINT BY RESECTION UPON THREE FIXED POINTS.

The greatest facility for the prosecution of a plane-table survey being afforded by the practicability of setting up the table at any undetermined point, from which three fixed points can be seen, and determining its position by *resection*, a knowledge of the capability and relative value of points under various conditions, for this purpose, is necessary for a ready use of them, and to apply the full graphic power of the table, with its special advantages.

For a better understanding of the principles involved in the graphic constructions with the table, the solutions of the "three-point problem" by construction and trigonometry will be given.

THREE-POINT PROBLEM.

By construction.

Let A, B, and C (illustration 52, Figs. 7, 8, 9, and 10) be three points the distances between which are known. A fourth undetermined point, D, is occupied, and the angles ADB and BDC measured. Then, to find the point D by construction—

From 180° subtract 2ADB, and from AB lay off, at A and B, the angles ABO′ and BAO′, each equal to half the remainder. From the point O′ thus determined, as a center, and with the radius AO′, describe the circumference BAD of a circle. The angle ADB will then be contained in the segment ADB, and the point D must be somewhere in the circumference BAD. In like manner, by means of the angle BDC, find another circumference, BCD, in which the point D must be found. The point, being on the two circumferences BAD and BCD, will be found at their intersection at D.

The angle at circumference being half that at center, the angle AO′B subtended by the same chord as ADB, will be 2ADB, and angles BAO′ and ABO′ being equal, and together the supplement of AO′B, each angle will be $= \frac{180° - 2ADB}{2} = 90° - ADB$.

THREE POINT PROBLEM.

By trigonometry.

To find the distances, from a given point, of three objects whose distances from each other are known:

(Figs. 11, 12, 13, and 14.) Let D be the given point, and A B C three points whose distances from each other are known; it is required to find the distances from D to the several points.

The angles ADB and BDC must be measured. Then describe a circumference through the three points A D C; draw AB, BC, AC, AD, BD, CD; from A and C draw lines to E, the point where BD cuts the circumference.

In the triangle A E C, the side AC is given, and all the angles are known; for ECA=EDA and CAE = CDE; therefore, AE can be found.

In the triangle A B C, the three sides being given, the three angles can be found. Then in the triangle A B E we know the sides AB, AE, and the included angle BAE=BAC ± EAC and the angle ABE can be found. Then in the triangle ABD all the angles become known and the side AB is given; therefore, AD and BD can be found; then CD can also be found.

If the angle B is the supplement of ADC, the point B will fall on E, and BCA=BDA and CAB=CDB. In this case D may be anywhere in the arc ADC, and the distances AD, BD, CD cannot be determined from the two measured angles ADB and BDC.

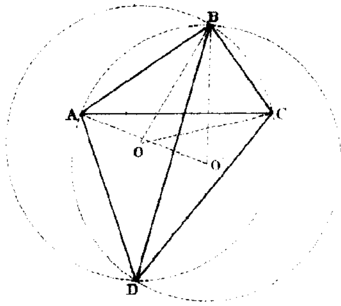
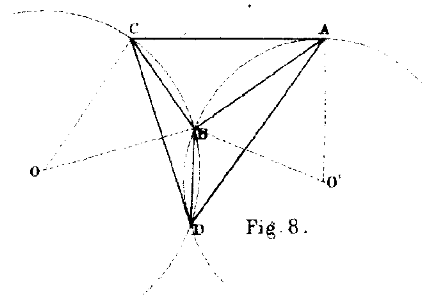


Fig. 7.



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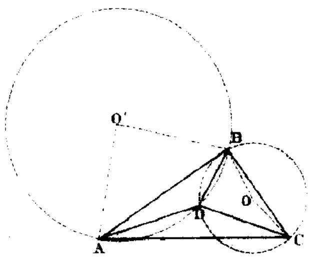

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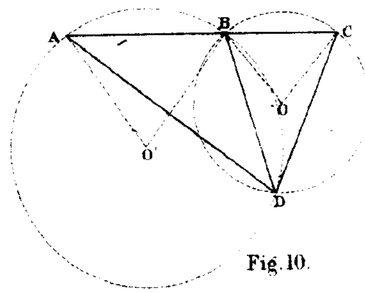

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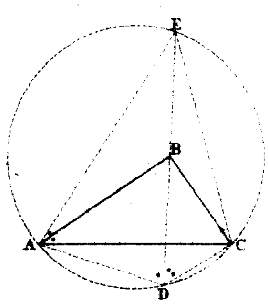


Fig. 11.

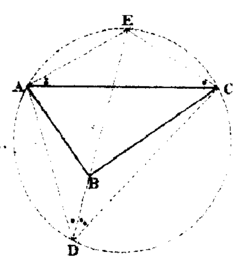


Fig. 12.

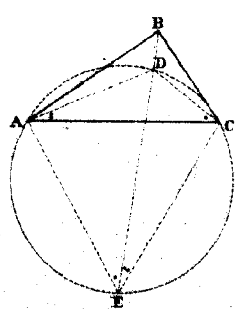
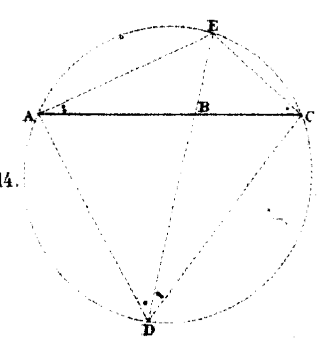


Fig. 13.



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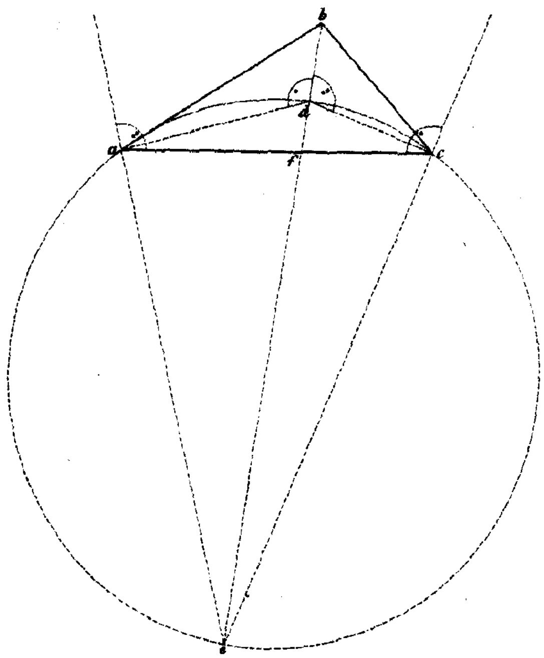


Fig. 15.

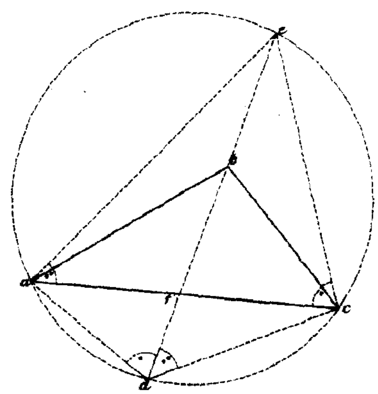


Fig. 16.

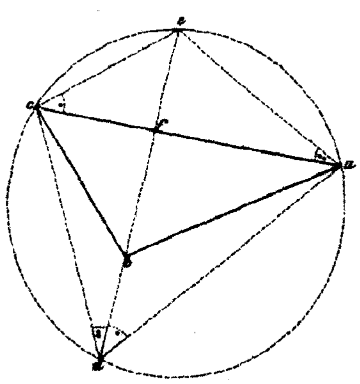


Fig. 17.

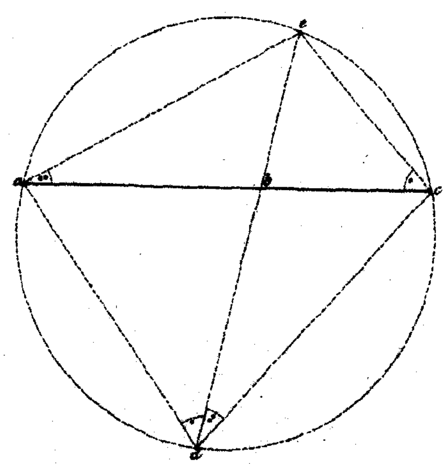


Fig. 18.

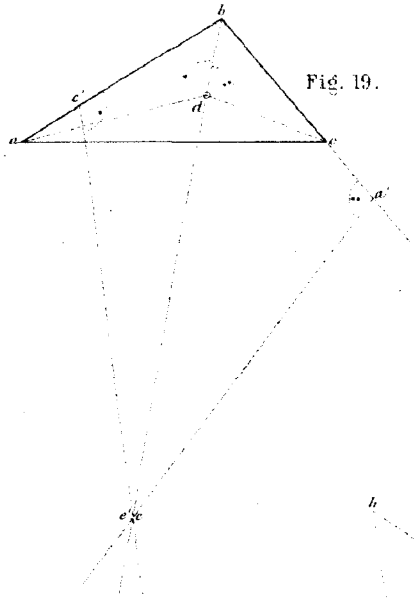


Fig. 19.

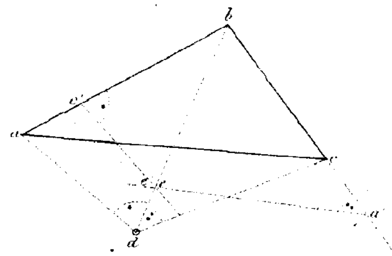


Fig. 20.

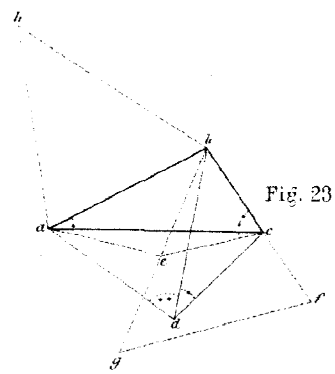


Fig. 23.

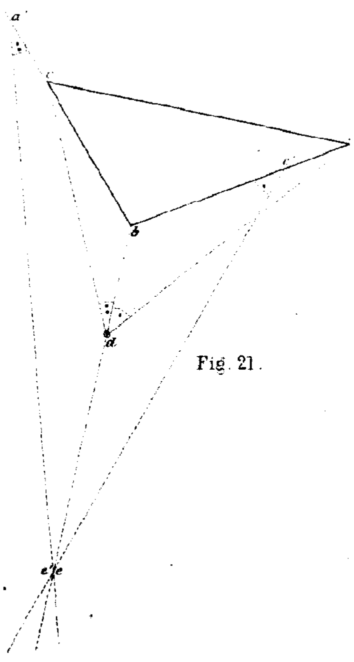


Fig. 21.

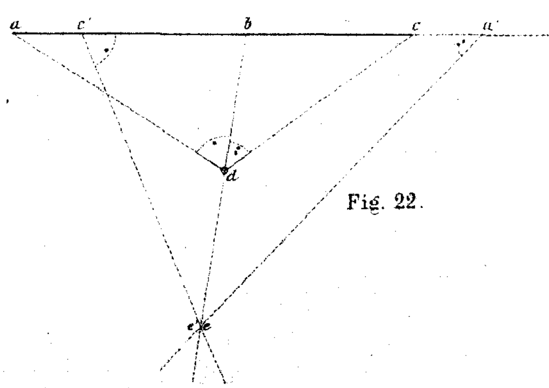


Fig. 22.

DETERMINATION OF POSITION BY RESECTION.

Bessel's method by inscribed quadrilateral.

The table is put at once in position at any unknown point from which three fixed points are visible, except in the circumference of a circle passing through the three fixed points, by two methods known as "Bessel's methods."

By one method a quadrilateral is constructed with all the angles in the circumference of a circle, one diagonal of which passes through the middle one of the three fixed points and the point sought. On this line the alidade is set, the telescope directed to the middle point, and the table is *in position*. Resection upon the extreme points intersects in this line and determines the position of the point sought.

Illustration 53 (Figs. 15, 16, 17, and 18.) Let *a b c* be the points on the sheet representing the signals A B C in the ground. The table is set up at the point to be determined (*d*) and leveled. The alidade is set upon the line *ca*, and *a* directed, by revolving the table, to its corresponding signal A, and the table clamped; then, with the alidade centering on *c*, the middle signal B is sighted with the telescope and the line *ce* drawn along the edge of the rule. The alidade is then set upon the line *ac* and the telescope directed to the signal C, by revolving the table, and the table clamped. Then, with the alidade centering on *a*, the telescope is directed to the middle signal B, and the line *ae* is drawn along the edge of the rule. The point *e* (the intersection of these two lines) will be in the line passing through the middle point and the point sought. Set the alidade upon the line *be*, direct *b* to the signal B by revolving the table, and the table will be *in position*. Clamp the table, center the alidade upon *a*, direct the telescope to the signal A, and draw along the rule the line *ad*. This will intersect the line *be* at the point sought. Resection upon C, centering the alidade on *c* in the same manner as upon A, will verify its position.

The opposite angles of the quadrilateral *adce* being supplementary,

$\angle ace$ and $\angle ade$ are subtended by the same chord *ae*, and $\angle cae$ and $\angle cde$ are subtended by the same chord *ce*; consequently, the intersection of *ae* and *ce* at *e* must fall on the line *db*; or, the segments of two intersecting chords in a circle being reciprocally proportional, the triangles *adf* and *cef* are similar, and the triangles *cdf* and *aef* are similar, and *d*, *f*, and *e* must be in a right line passing through *b*.

DETERMINATION OF POSITION BY RESECTION.

Bessel's method by construction of similar triangles.

By the other method two pairs of similar triangles are constructed having common factors.

In the triangle formed by the three fixed points, extend the shorter of the two sides from the middle point to the extreme points, and on its extension lay off the longer side from the middle point. On the longer side, lay off the shorter side from the middle point.

At the point on the extended side lay off the angle from the point sought between the signals of the shorter side, and at the point on the longer side lay off the angle from the point sought between the signals of the longer side. The lines so found will intersect in the line passing through the middle point and the point sought. Set the alidade on this line, direct it to the middle signal and the table will be *in position*. Resection upon the extreme points intersects in this line and determines the position of the point sought.

Illustration 54 (Figs. 19, 20, 21, and 22.) Let *a b c* be the points on the sheet representing the signals A B C on the ground. The table is set up at the point to be determined (*d*) and leveled. On *ab* lay off $bc'=bc$, extend *bc*, and on the extension lay off $ba'=ba$. Set the alidade on *cb*, and direct *b* to the signal C and clamp the table. With the alidade centering on *a'*, direct it to the middle signal B, and draw along the edge of the rule the line *a'e*. Then set the alidade on the line *ab*, direct *b* to the signal A, and clamp the table, and, with the alidade centering on *c'*, direct it to the middle signal B, and draw along the edge of the rule the line *c'e*. The intersection of *a'e* and *c'e* will be in the line passing through the middle point and the point sought. Set the alidade upon the line *be*, direct *b* to the signal B by revolving the table, and the table will be in position. Clamp the table, center the alidade upon a, direct the telescope to the signal A, and draw along the edge of the rule the line ad. This will intersect the line be at the point sought. Resection upon C centering the alidade on c in the same manner as upon A will verify its position.

For the purpose of demonstration call the point of intersection of the lines $a'e$ and $c'e$, c' on one side of bc, and e on the other side.

Since $\angle ba'e = \angle bdc$, and $\angle bc'e = adb$, triangles bdc and $ba'e$ are similar, and triangles bda and $bc'e$ are similar

then $$bc' : be' :: bd : ba$$

and $$be' : bc :: ba' : bd$$

$$be' = \frac{ba \times bc'}{bd}$$

$$be = \frac{ba' \times bc}{bd}$$

but $$ba = ba' \text{ and } bc = bc'$$

therefore $be = be'$ and $a'e$ and $c'e$ must intersect in the line bd, or—

(Figure 23): Lay off at a the angle $bae = \angle bdc$, and at c $\angle bce = \angle bda$, drawing the line bc, $\angle ebc = \angle abd$ and $\angle eba = \angle cbd$. Produce bc to f, so that $bf = ba$, and draw fg parallel to ce. Lay bfg on ba, so that f falls on a and g on h.

Then we have in the quadrilateral $ahbe$ and $abcd$

$$\angle bae = \angle bdc,\ \angle hbe = \angle abc$$
$$hb : be :: bg : bc :: bf : bc :: ba : bc.$$

The two quadrilaterals are therefore similar, and hence

$$\angle ebc = \angle hba = \angle abd$$
$$\text{and } \angle eba = \angle cbd.$$

In the use of the Bessel methods for the determination of position, the triangle formed by the three fixed points can be contracted or extended as may be desirable, by drawing a line parallel to the one joining the two extreme points, terminated by those joining the extremes with the middle point. The lines laid off at these representative extreme points, in the manner described for the extremes, with the alidade, will intersect in the line passing through the middle point and the point sought.

This affords the means of using a point on the sheet in view, which would not be within the size of the table when the other two points are shown, by contracting the triangle formed by the three points until both extremes are brought within the table size, and within the reach of the alidade. A resecting line for the point off the table can be drawn from its signal, near the estimated position of the point sought, and a line drawn through the corresponding point of the sheet off the table, parallel to this, will determine the precise position of the point sought, to be verified by resection on the other extreme point.

When the table is not in position, resection upon any three points, except from a point on the circumference of a circle passing through these points, will form a triangle called the triangle of error, or two of them will be parallel, intersected by the third.

The position of the true point can then be determined geometrically from these several intersections, and is always at the point of intersection of arcs of circles drawn through each two points and the point of intersection of the lines drawn from them; but the construction of these arcs is inconvenient in the field. More practicable modes of locating the points sought will be given in their order.

In the classification given below, based upon the location of the true point in relation to the triangle of error, the triangle formed by the three fixed points is called the *great* triangle, and the circle passing through the same points the *great* circle.

Illustration 55 (Fig. 24), CLASS 1.—When the point sought falls within the great triangle, the true point is within the triangle of error. (Case 1.)

CLASS 2.—When the point sought falls within either of the three segments of the great circle formed by the sides of the great triangle as chords (Case 2), or without the great circle and within the sector of the opposite angle of either angle of the great triangle (Case 5), the true point is on

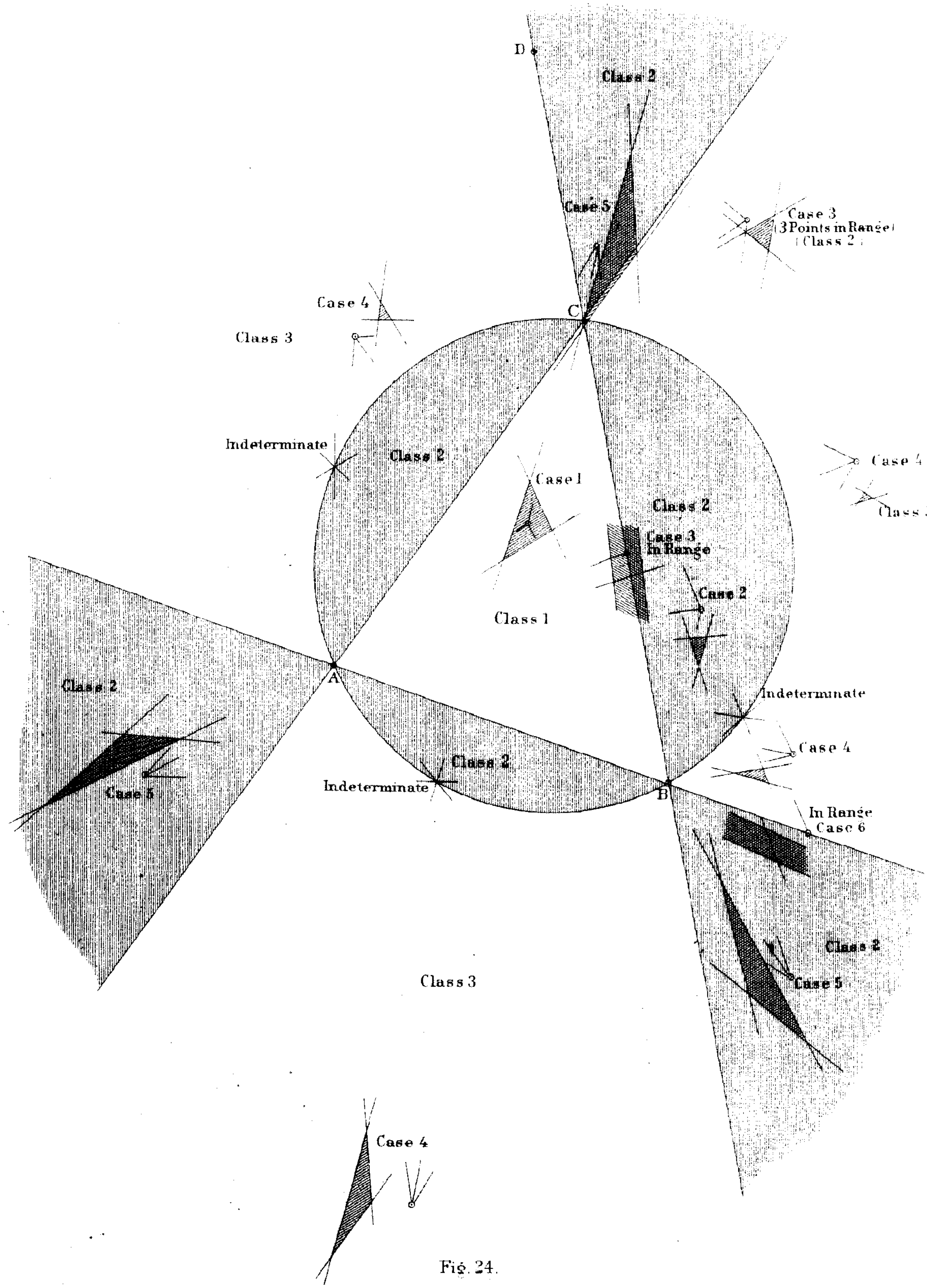

D
Class 2
Case 5
Case 3
(3 Points in Range)
(Class 2)
C
Case 4
Class 3
Indeterminate
Class 2
Case 1
Case 4
Class 3
Class 2
Case 3
In Range
Case 2
Class 1
A
Class 2
Case 5
Indeterminate
Case 4
Class 2
Indeterminate
B
In Range
Case 6
Class 2
Case 5
Class 3
Case 4

Fig. 24.

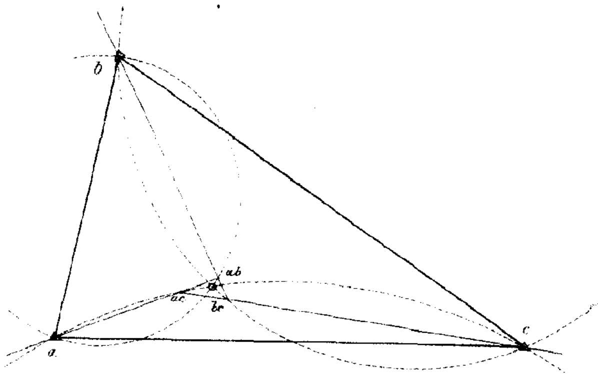
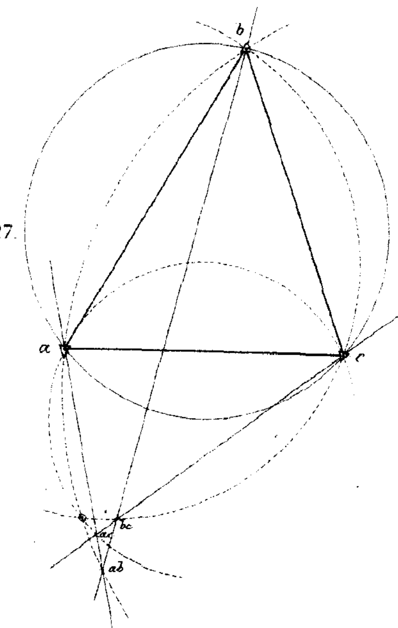


Fig. 25.

Fig. 27.



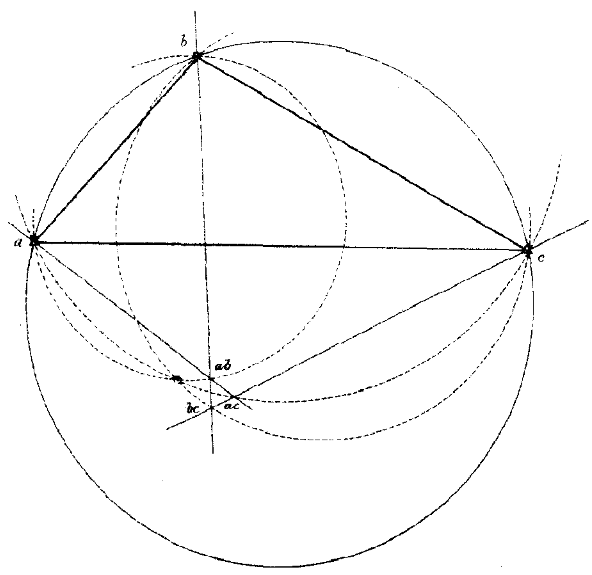


Fig. 26.

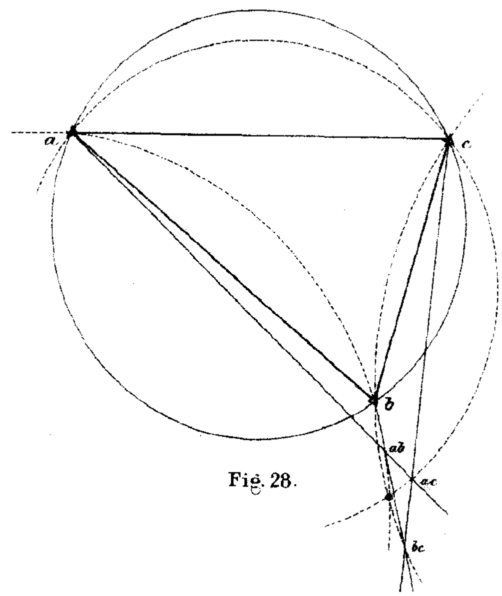


Fig. 28.

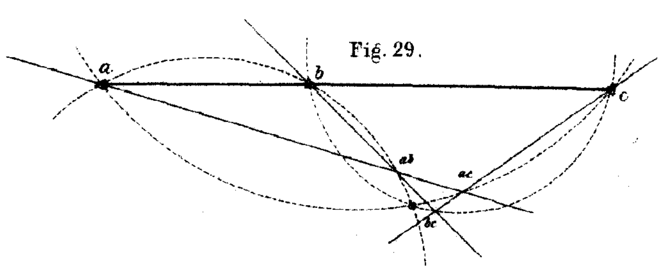


Fig. 29.

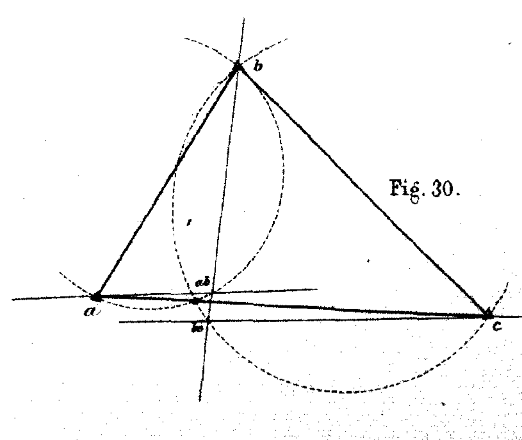


Fig. 30.

the side of the line from the middle point opposite to the intersection of the lines from the other two points. This also includes Case 3, where the three fixed points are in a straight line, in which case the points are considered as being in the circumference of a circle of infinite diameter, and the true point always lying in one of the segments of the great circle.

CLASS 3.—When the point sought falls without the great circle and within the sector of either angle of the great triangle, the true point is on the same side of the line from the middle point as the intersection of the lines from the other two points. (Case 4.)

In case the point sought falls on the range of any two of the points, and the table is deflected from true position, the lines from the two points will be parallel, intersected by the line from the third point. But this range can always be determined by alignment, the table set in position on the range, and the point occupied determined by resection on the third point. (Case 6.)

In case the point sought falls *near* the range of any two of the three points, the lines from the two points are so nearly parallel that their intersection falls off the table, but the relation of the true point to the triangle of error is in no way changed.

The accompanying diagram (Fig. 24) shows the fields embraced by the classes given above, also the location of each of the cases included in those classes.

A point on the circumference of the great circle being indeterminate, it is apparent that a determination should not be attempted in close proximity thereto, if better conditioned points are available.

The following cases are believed to include all possible conditions of the relation of the position of an undetermined point to three fixed points. The surveyor is supposed to face his signals and the directions right and left given accordingly:

CASE 1. Illustration 56 (Fig. 25.)—When the point sought is within the great triangle, the true point is within the triangle of error.

a b c are the projected points, and *ab ac bc* the false intersections from them, forming the triangle of error.

Rule.—If the line from any one of the points falls to the right of the intersection of the other two, turn the table to the left, and if to the left, turn it to the right.

When the point sought is without the great triangle the true point is also without the triangle of error, and is situated to the *right* or *left* of it, according as the table is out of position to the *left* or *right.*

CASE 2. (Fig. 26.)—When the point sought is without the great triangle and within the great circle, the true point is without the triangle of error, and the line drawn from the middle point lies between the true point and the intersection of the other two lines. This also includes Case 3 (Fig. 29), which rarely occurs in practice, where the three points are in a straight line, in which case the diameter of the circle may be considered infinite.

Rule.—If the line from the middle point is to the right of the intersection of the other two, turn the table to the right, and if to the left, turn it to the left.

CASE 4. (Fig. 27.)—When the point sought is without the great circle, and the middle point is on the far side of the line joining the other two points, the true point is without the triangle of error, and upon the same side of the line from the middle point as the intersection of the other two lines.

Rule.—If the line from the middle point is to the right of the intersection of the other two, turn the table to the left, and if to the left, turn it to the right.

CASE 5. (Fig. 28.)—When the point sought is without the great circle, and the middle point is on the near side of the line joining the other two points, the true point is without the triangle of error, and the line drawn from the middle point lies between the true point and the intersection of the other two lines.

CASE 6. (Fig. 30.)—When the point sought is on the range of either two points, and the table deflected from true position, the lines drawn from these points will not intersect, but will be parallel, intersected by the line drawn from the third point; the true point is then between the two parallel lines.

Rule.—When the line from the right-hand station is uppermost, turn the table to the right, and when that from the left hand is uppermost, turn it to the left.

Practicable modes of determining, from the triangle of error, the position of a fourth point by resection upon three fixed points.

1st. *Lehmann's method.* Illustration 57 (Fig. 31.)—This method is based upon the fact that the point sought is always distant from the three lines drawn from the three fixed points in proportion to the distances of the latter from the point occupied.

A, B, C are the projections of the three signals from which it is desired to determine by resection the position of a fourth point, D. The table being out of position to the right, the triangle of error formed by the three lines from A, B, and C is *ab ac bc*. The true point occupied lies at D, being at the intersection of the circles AB *ab*, AC *ac*, BC *bc*. Now, if perpendiculars be drawn from D to the lines drawn from A, B, and C, we shall have

$$Da : Db :: DA : DB \text{ or } Db : Dc :: DB : DC.$$

The relative distances of the point occupied from the three signals must be estimated, and the point located in reference to the three lines from A, B, and C accordingly.

An important fact, which serves as a simple guide in locating the point sought by this method, is that it is always on the same side of the line from the most distant point as the point of intersection of the other two lines. This follows from the fact that in turning the table into position, the end of the longest line will move faster than those of the shorter ones; consequently, to come together in one point of intersection, the longest line must move in the direction of the intersection of the two shorter ones.

Netto's method. (Figs. 32, 33, and 34.)—This method of determining the true position from the false intersections is ingenious but complicated.

The table not being properly oriented, and having resected upon a, b, and c, we have the triangle of error $e\ e'\ e''$. Now, by the Lehmann method, judge of the position of d (the point sought). Set the alidade on db and revolve the table so that the line of sight passes the signal B. Resect again on a, b, and c, and we have the triangle of error $g\ g'\ g''$. Join e and g, and through both points draw parallel lines $i\ i$ and $k\ k$. Lay off $ei=ef$ and $gk=gh$. Join i and k and the intersection l lies in the line of sight from the true point to the middle point b. Set on this line, resect upon a and c, and d is the point sought.

If the two triangles of error are situated on the same side of the true line of sight to the middle point, the parallel lines are set off on one side of eg only.

The triangles of error $e\ e'\ e''$ and $g\ g'\ g''$ are always similar $\llcorner g'' = \llcorner e'$, $\llcorner g' = \llcorner e''$, $\llcorner g = \llcorner e$, and as the two points e and g are always in the circumference of the same circle, if the table is deflected equally on the opposite sides of the true line of sight to the middle point, the triangle of error will be equal, and $ef=gh$. On the true line of sight gh and $ef=o$.

In the triangles gkl and eil, ii and kk being parallel, $\angle g = \angle e$, $\angle l$ is common, therefore $\angle k = \angle i$, and the triangles are similar, and $el : gl :: ei = ef : gk = gh$.

The point sought (d) must lie in the circle passing through aec, and also through agc. Draw the circle $a\ g\ d\ e\ c\ s$, join s with e and g, then we have

$$\angle dse = \angle dce \text{ and } \angle dsg = \angle dag$$
$$\angle dce = \angle dbe'' \text{ and } \angle dag = \angle dbg''$$
$$\text{Therefore } \angle dse = \angle dbe'' \text{ and } \angle dsg = \angle dbg''$$
$$\text{also } se \text{ parallel to } be'' \text{ and } sg \text{ parallel } bg''$$
$$\text{and the triangles } sle \text{ and } blf \text{ are similar,}$$
$$\text{and the triangles } slg \text{ and } blh \text{ are similar;}$$
$$\text{from which we get } le : lf :: ls : lb$$
$$\text{and } lg : lh :: ls : lb,$$
$$\text{also } le : lf :: lg : lh \text{ and } le : le - ef :: lg : lg - lh$$
$$\text{that is, } el : ef :: gl : gh \text{ or } el : gl :: ef : gh.$$

The amount of the angle at l is always an indication of the value of the determination of the point sought. The nearer the angle is to 90°, the better the determination.

TWO-POINT PROBLEM.

The occasion may arise where it is desirable to place the table in position at a given point, from which point only two determined points are visible. This may be done by the following methods:

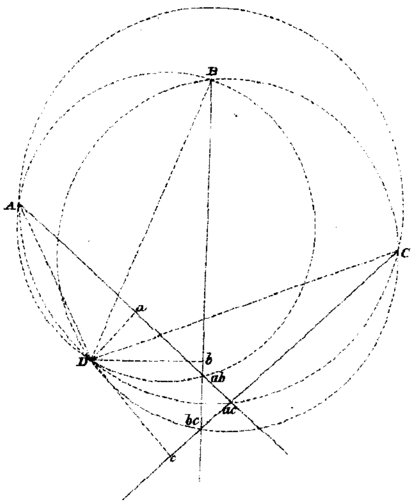


Fig. 31.

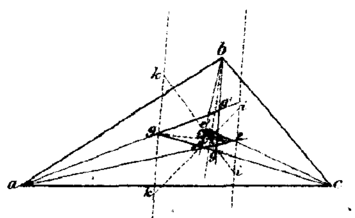


Fig. 32.

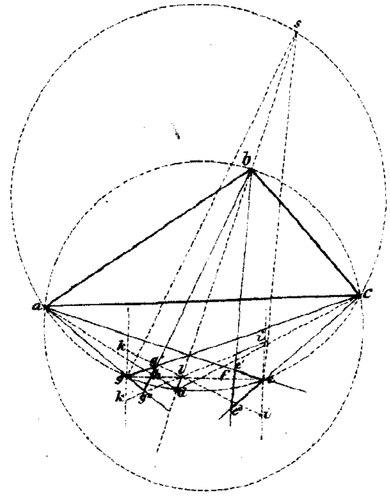


Fig. 33.

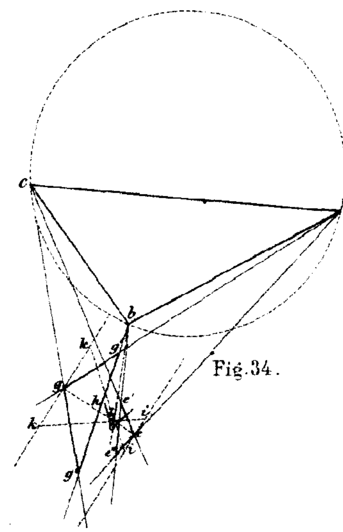


Fig. 34.

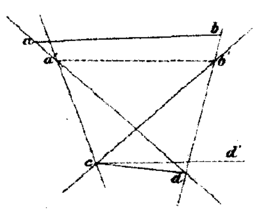


Fig. 35.

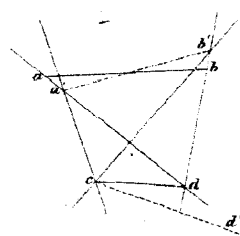


Fig. 36.

Fig. 39.

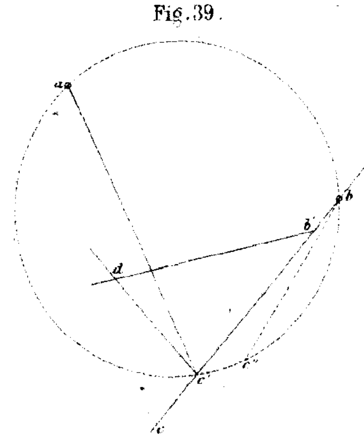


Fig. 37.

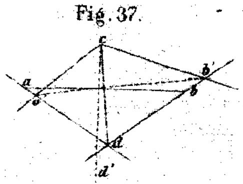
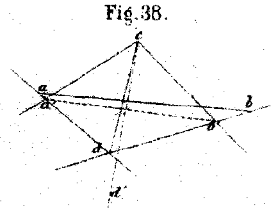


Fig. 38.



The first mode possesses the virtue of making no linear measurement, and demonstrates in a very satisfactory manner the power of the table in determining position by resection.

(Figs. 35, 36, 37, and 38.)—Two points, A and B, not conveniently accessible, being given, by their projections *a* and *b*, to put the plane-table in position at a third point, C. (The capital letters refer to points on the ground, and the small ones to their corresponding projections.)

Select a fourth point, D, such that the intersections from C and D upon A and B make sufficiently large angles for good determinations. Put the table approximately in position at D, by estimation or by compass, and draw the lines A*a* B*b*, intersecting in *d;* through *d* draw a line directed to C. Then set up at C, and assuming the point *c* on the line *d*C, at an estimated distance from *d*, and putting the table in a position parallel to that which is occupied at D, by means of the line *cd*, draw the lines from *c* to A and from *c* to B. These will intersect the lines *d*A *d*B at points *a′* and *b′*, which form with *c* and *d* a quadrilateral *similar* to the true one, but erroneous in size and position.

The angles which the lines *ab* and *a′b′* make with each other is the error in position. By constructing now through *c* a line *cd′*, making the same angle with *cd* as that which *ab* makes with *a′b′*, and directing this line *cd′* to D, the table will be brought into position, and the true point *c* can be found by the intersections of *a*A and *b*B.

Instead of transferring the angle of error by construction, we may conveniently proceed as follows, observing that the angle which the line *a′b′* makes with *ab* is the error in the position of the table. As the table now stands, *a′b′* is parallel with AB, but we want to turn it so that *ab* shall be parallel to the same. If we, therefore, place the alidade on *a′b′* and set up a mark in that direction, then place the alidade on *ab* and turn the table until it again points to the mark, then *ab* will be parallel to AB, and the table is in position.

Another method is as follows (Fig. 39):

Two points, A and B, not conveniently accessible, being given by their projections *a* and *b*, to put the plane-table in position at a third (undetermined) point, C.

Set up the table at the point sought as nearly in position as can be done with the eye, and resect upon A and B, intersecting the line *bc* at *c′*. The angle *ac′b* is the true angle at the point occupied, subtended by AB, being the angle of nature actually drawn; therefore, the true point must be on the circumference of the circle passing through *abc′*. Construct this circle. Measure off a base, CD, at least half the length of CB, at right angles, or nearly so, to *bc*, in either direction most convenient. Set up a signal at D, and with the alidade draw the line *c′d*. Remove the table to D, and, by means of a signal at C (the point sought), and the line *dc′*, bring the table into a position parallel to that which is occupied at C. With the alidade centering on *d*, observe the signal B, and draw the line *db′* intersecting *cb* at *b′*. *c′b′* is the distance of the point C from B, and this distance laid off on the circle *ac′b* as a chord from *b* will give *c″*, the true position of the point C. A fourth point may then be occupied, and by resection upon A, B, and C the accuracy of the determination of C verified.

Where it is possible to get the two signals A and B in range, it is easy to determine the position of a third point by a mode long practiced by topographers.

Set up the table anywhere on the range line, and, having set up a signal at the point sought, resect upon it, intersecting the range line anywhere, and by means of the range signal and the line to it the table may be set in parallel position to that occupied in the range, which is the true position, and the point sought may be determined by resection upon the two fixed points and their projections.

REPRESENTATION OF THE TERRENE.

Since no topographical map can be complete without some systematic representation of the undulations and changes of slope of the surface of the ground—"terrene," as the French term it—caused by the oscillations of the earth's crust, erosion, abrasion, or artificial works, various modes have been devised for such representation.

The earliest maps gave rude views of hills, mountains, &c., in elevation, with their bases in position on plan, in the same manner as trees were represented.

Near the end of the eighteenth century Major von Müller, of the Prussian army, represented with approximate normal hachures with distinct shadings, slopes, which he called "gentle, less inclined, inclined, steep, precipitous, and perpendicular."

About 1815, the admirable system by Major von Lehman, of the Saxon army, was published; by which hills were shaded by normals based upon the amount of reflected vertical light from planes inclined to the horizon, by successive steps of 5° of slope, and which, with some modifications in the higher and lower slopes, remains the most approved system of to-day.

A most important step, whose origin does not seem to be well established, but which probably resulted as a necessary consequence from attempts to represent hills in plan, had regard to the drawing of the lines formed by the prominent changes of slope, termed "contours," which Colonel Olsen, of the Danish Generalquarteermesterstab, in 1833, defines as indicating "the general form of the locality, the most striking changes in declivities, tops, slopes, and bases of hills, &c.," and which are always the lines controlling a topographical sketch. They may be described as the lines bounding areas of approximately equal slope, or as lines through points where the surface changes in any marked degree its inclination to the horizon.

Since the introduction in 1744, by the French geographer, Philip Buache, of the method of representing hills by successive lines of equal elevation, the true contour system has been often lost sight of, and sometimes to the exclusion of the most characteristic elements of the terrene. Often these lines are the outcrop of rock, or the top or base of a precipitous ledge, which, in the directions of strike and dip, incline to the horizon, and which are but feebly represented by lines of equal elevation instead of contours; more attention being given to the continuity of the level element than to the striking changes of form and character of surface. It is, in fact, at this point where the perception of form and facility of drawing the same become important factors in the power of the topographer for accurate and characteristic representation of the peculiar type of form which constitutes his subject.

As to the modes of determining and drawing lines of equal elevation, each case will present some peculiarities which must be met, as they are presented, by the topographer's own resources; and as on the ordinary scales of topographical surveys a limit of minuteness of detail must be fixed, a sound management of work, established by experience, will find its strength resting upon a discrimination between important and trifling features, and a ready decision of what to omit as well as what to include. Labor may be spent in the development of small individual features which are comparatively lost on the scale of the work, while the features characteristic of the forms by oscillation, erosion, or abrasion, indicative of the forces producing the same, and which give distinctive character to the terrene, may be lost sight of in the too careful attention to minute details.

The characteristic features of a terrene are, perhaps, best observed from a point nearly on the same level, but as between drawing features from above or below for a reasonable range, drawing from below is probably the better, as features viewed from any considerable height above are apt to appear flattened and much detail of undulation lost sight of.

It is for this reason that the views of a mountainous region, from points between base and summit, are usually grander than those from the extreme summit.

But, since a precise representation of the terrene requires stations for positions at intervals not too far apart, the necessity will not arise for observing form of surface much above or below the point of observation.

In the location and drawing of curves of equal elevation, the alidade is used both as a level for the observation of objects the same height as the instrument and for measuring angles of elevation and depression to points whose distances from the instrument are known, for the determination of their heights. Except for the questions of refraction and curvature of the earth, we have then the base and three angles of a right-angled triangle to find the perpendicular.

The true level continuity of a curve of equal elevation should always be maintained and not deflected either above or below to include any special feature or accident of ground that may be found in any zone between two curves, but touched by neither. In this case intermediate curves should be used in ground of regular form, and in ledges of rock and artificial works the actual contours should be drawn and heights determined.

The vertical intervals at which curves should be drawn must be determined by the object and necessities of each case, and, in a measure, by the gentleness or abruptness of the slope. As a rule, with such features as prevail on the eastern coast of the United States, intervals of 20 feet are found to develop the form with sufficient detail on $\frac{1}{10000}$ scale, but, for purposes of construction, intervals of 5 feet or even less are often found desirable on larger scales.

When the slopes are gentle, and little difference in height makes marked change in horizontal position, the use of the spirit leveling instrument is important and almost indispensable in locating curves accurately.

In abruptly mountainous and comparatively inaccessible regions, where sketching must be relied upon, prevailing contours and 100-foot curves may suffice to develop all necessary features.

A level surface, having each point the same distance from the center of attraction (the center of the earth), is a spherical surface parallel to the surface of the sea. As the radii of such a surface are all vertical, a horizontal surface at any point is tangent to the same, and while every level line is a curve in the spherical surface, every horizontal line is a right line in the tangent horizontal plane.

Since a ray of light from any object to an observer does not come to the eye in a right line, but is refracted by the atmosphere into a curved line, with its concavity towards the earth, the object appears above its true position, and requires for the true height a correction of the apparent height. This we term refraction, which varies in amount under different conditions of the atmosphere; but for topographical purposes it is sufficiently exact to consider it $\frac{8}{100}$ of the angle formed by the two verticals of the point observed and the point occupied.

Two verticals forming an angle of 1 second at the center of the earth include a distance of about 30 meters on the earth's surface.

The deviations of the earth's curvature and refraction from the horizontal being in opposite directions, for short distances may be regarded as compensating one another, but for accurate determination of difference of height between two points by leveling, the instrument should be placed equidistant between them, so that the amount of deviation from the level is equal on each side, and therefore compensated.

For convenience, a table of heights for different distances and angles is used in the work of the Coast and Geodetic Survey, in which correction is made for curvature and refraction.

Table showing the height in feet corresponding to a given angle of elevation and a given distance in meters.

Meters..	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000
Angle.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1′	0.3	0.4	0.6	0.6	0.8	0.9	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.8
2	0.6	0.8	1.0	1.2	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2	4.5	4.7
3	0.9	1.2	1.5	1.8	2.2	2.5	2.8	3.1	3.4	3.8	4.2	4.4	4.8	5.3	5.6	5.9	6.3	6.6
4	1.2	1.5	2.0	2.4	2.8	3.2	3.6	4.1	4.5	4.9	5.4	5.8	6.3	6.8	7.2	7.6	8.1	8.6
5	1.5	1.9	2.4	2.9	3.5	4.0	4.5	5.0	5.5	6.1	6.6	7.1	7.7	8.3	8.8	9.4	9.9	10.5
6	1.8	2.3	2.9	3.5	4.2	4.8	5.3	5.9	6.6	7.2	7.9	8.5	9.1	9.8	10.4	11.1	11.7	12.4
7	2.1	2.7	3.4	4.1	4.8	5.5	6.2	6.9	7.6	8.4	9.1	9.8	10.6	11.4	12.1	12.8	13.5	14.3
8	2.4	3.1	3.9	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.1	12.0	12.9	13.7	14.5	15.3	16.2
9	2.7	3.5	4.4	5.2	6.2	7.0	7.9	8.8	9.7	10.7	11.6	12.5	13.4	14.4	15.3	16.2	17.2	18.1
10	2.9	3.8	4.9	5.8	6.8	7.8	8.8	9.8	10.8	11.8	12.8	13.8	14.9	15.9	16.9	17.9	19.0	20.0
11	3.2	4.2	5.3	6.4	7.5	8.6	9.6	10.7	11.8	13.0	14.1	15.1	16.3	17.5	18.6	19.7	20.8	21.9
12	3.5	4.6	5.8	6.9	8.2	9.3	10.5	11.7	12.9	14.1	15.3	16.5	17.7	19.0	20.2	21.4	22.6	23.8
13	3.8	5.0	6.3	7.5	8.8	10.1	11.4	12.6	13.9	15.2	16.6	17.8	19.2	20.5	21.8	23.1	24.4	25.7
14	4.1	5.4	6.8	8.1	9.5	10.9	12.2	13.6	15.0	16.4	17.8	19.1	20.6	22.0	23.4	24.8	26.2	27.6
15	4.4	5.7	7.2	8.6	10.2	11.6	13.1	14.5	16.0	17.5	19.0	20.5	22.0	23.6	25.0	26.5	28.0	29.5
16	4.7	6.1	7.7	9.2	10.8	12.4	13.9	15.5	17.1	18.7	20.3	21.8	23.5	25.1	26.7	28.2	29.9	31.4
17	4.9	6.5	8.2	9.8	11.5	13.1	14.8	16.5	18.1	19.8	21.5	23.1	24.9	26.6	28.3	30.0	31.7	33.4
18	5.2	6.9	8.7	10.4	12.2	13.9	15.7	17.4	19.2	21.0	22.8	24.5	26.3	28.2	29.9	31.7	33.5	35.3
19	5.5	7.3	9.1	10.9	12.8	14.7	16.5	18.4	20.2	22.1	24.0	25.8	27.7	29.7	31.5	33.4	35.3	37.2
20	5.8	7.7	9.6	11.5	13.5	15.4	17.4	19.3	21.3	23.3	25.2	27.2	29.2	31.2	33.2	35.1	37.1	39.1

Table showing the height in feet corresponding to a given angle of elevation, &c.—Continued.

Meters..	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000
Angle.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
21′	6.1	8.0	10.1	12.1	14.2	16.2	18.2	20.3	22.3	24.4	26.5	28.5	30.6	32.7	34.8	36.8	38.9	41.0
22	6.4	8.4	10.6	12.6	14.9	17.0	19.1	21.2	23.4	25.5	27.7	29.8	32.0	34.3	36.4	38.5	40.7	42.9
23	6.7	8.8	11.1	13.2	15.5	17.7	20.0	22.2	24.4	26.7	29.0	31.2	33.5	35.8	38.0	40.3	42.5	44.8
24	6.9	9.2	11.5	13.8	16.2	18.5	20.8	23.1	25.5	27.8	30.2	32.5	34.9	37.3	39.6	42.0	44.3	46.7
25	7.2	9.6	12.0	14.4	16.9	19.3	21.7	24.1	26.5	29.0	31.4	33.8	36.3	38.8	41.3	43.7	46.2	48.6
26	7.5	9.9	12.5	14.9	17.5	20.0	22.5	25.0	27.6	30.1	32.7	35.2	37.8	40.4	42.9	45.4	48.0	50.5
27	7.8	10.3	13.0	15.5	18.2	20.8	23.4	26.0	28.6	31.3	33.9	36.5	39.2	41.9	44.5	47.1	49.8	52.4
28	8.1	10.7	13.4	16.1	18.9	21.5	24.2	26.9	29.7	32.4	35.2	37.8	40.6	43.4	46.1	48.8	51.6	54.3
29	8.4	11.1	13.9	16.7	19.5	22.3	25.1	27.9	30.7	33.6	36.4	39.2	42.1	45.0	47.8	50.6	53.4	56.2
30	8.7	11.5	14.4	17.2	20.2	23.1	26.0	28.9	31.8	34.7	37.6	40.5	43.5	46.5	49.4	52.3	55.2	58.2
40	11.5	15.3	19.2	22.9	26.9	30.7	34.6	38.4	42.3	46.1	50.0	53.9	57.8	61.7	65.6	69.4	73.3	77.3
50	14.4	19.1	23.9	28.7	33.5	38.3	43.2	47.9	52.7	57.6	62.4	67.2	72.1	77.0	81.8	86.6	91.5	96.3
1° 00	17.2	22.9	28.7	34.4	40.2	46.0	51.7	57.5	63.3	69.0	74.8	80.6	86.4	92.3	98.0	104	110	115
1 10	20.1	26.7	33.5	40.1	46.9	53.6	60.3	67.0	73.8	80.5	87.2	93.9	100.7	107.5	114.3	121	128	134
1 20	23.0	30.5	38.3	45.8	53.6	61.2	69.0	76.6	84.2	91.9	99.6	107.3	115.1	123	131	138	146	154
1 30	25.8	34.4	43.0	51.6	60.3	69.0	77.7	86.1	94.7	103.4	112.0	120.7	130	138	147	155	164	173
1 40	28.7	38.2	47.8	57.3	66.9	76.6	86.3	95.6	105.2	115	124	134	144	153	163	173	182	192
1 50	31.6	42.0	52.6	63.0	73.6	84.2	94.9	105.2	115.7	126	137	147	158	169	179	190	200	211
2 00	34.4	45.8	57.4	68.9	80	92	103	115	126	138	149	161	172	184	195	207	218	230
2 30	43.0	57.3	71.7	86.0	100	115	129	144	158	172	186	201	215	230	244	259	273	287
3 00	51.6	68.8	86.2	103.2	120	138	155	172	190	207	224	241	259	276	293	310	328	345
3 30	60.2	80.4	100.5	120.5	141	161	181	201	221	241	261	281	302	322	342	362	382	402
4 00	68.9	91.8	114.8	137.7	161	184	207	230	253	276	299	322	345	368	391	414	437	460

Example of use of table of heights.

Angle of elevation from point A to point B, distant from each other 1,756 meters = 1° 56′.

	Meters.		Feet.
1° 50′......	1,700	......	179.00
1° 50′......	50	......	5.26
1° 50′......	6	......	.63
0° 06′......	1,700	......	10.40
0° 06′......	50	......	.29
0° 06′......	6	......	.04
			195.62

Point B is 195.62 feet above point A.

Formula for determining heights by a vertical angle and distance.—The difference of level consists of two parts, that which arises from the angle of elevation above the horizontal plane of the station, and that which is due to the curvature of the earth. The former depends upon the angle and distance, the latter upon the distance and the earth's radius. If a' be the angle of elevation in minutes of arc, d the distance, h the height, then, as the tangent of 1′ is $\frac{1}{3437}$, we have for the first part $h = \frac{1}{3437} a'd$, if h and d are both expressed in the same units of length; but if d is expressed in meters and h in feet, one meter being 3.28 feet, we get $h = \frac{1}{1048} a'd$. For the fraction $\frac{1}{1048}$ we may conveniently and with sufficient accuracy put $\frac{1}{1000}$ less $\frac{1}{20}$ of $\frac{1}{1000}$, and thus find the rule: *Multiply the distance in meters with the number of minutes of arc, point off the thousandth part, and subtract the twentieth part of the number thus obtained.* This will give the first portion of difference of height, whether elevation or depression.

The second term, depending on the curvature, varies as the square of the distance, and amounts to 0.22 foot in 1,000 meters, including the effect of ordinary refraction. As with the instruments under consideration extreme accuracy is not attainable, it is plain that for distances under 1,000 meters this term may be neglected. When the distance is greater we have the following rule: *Take the thousandth part of the distance in meters, square the same, having regard to the first decimal figure, and multiply by* 0.22. This term is always positive; if the first term be an elevation, it is increased; if a depression, it is diminished by the second term.

Example.—Distance = 5,500 meters; angle of elevation, 36′.

$\frac{1}{1000}d \times a'$ =	198. 000	$\frac{1}{1000}d$ =	5. 5
subtract $\frac{1}{20}$	9. 9	square =	30. 2
		multiply by	0. 22
first term	188. 1		
second term	6. 6	second term	6. 64
sum	194. 7 = difference of elevation in feet.		

Comparison of feet and meters.

[1 meter = 3.280869 feet.]

Meters.	Feet.	Feet.	Meters.
1........	3. 2809	1........	0. 3048
2........	6. 5617	2........	0. 6096
3........	9. 8426	3........	0. 9144
4........	13. 1235	4........	1. 2192
5........	16. 4043	5........	1. 5240
6........	19. 6852	6........	1. 8288
7........	22. 9661	7........	2. 1336
8........	26. 2470	8........	2. 4384
9........	29. 5278	9........	2. 7432

Probably the best reference for heights of points on the earth's surface is to the mean level of the sea, since the mean of any rise and fall of the tides is approximately this level. In practice, however, mean high water is usually taken, as this includes all land not covered by the tide range, and is the line dividing land from water.

It is well, in commencing the survey of a region bordering on tide-water, to erect a signal at the assumed high water line, carefully noting the height of the top of the flag above the same, to be used for observing angles of depression for heights from points occupied during the progress of the survey. As the heights of other points are determined in the course of the survey, and verified by observations from or to two or three points, these in turn may be used for the same purpose.

It must not be forgotten, however, that the beds of rivers slope toward the sea, and that there is a gentle fall of the surface even of apparent tide-levels towards the ocean. It is best, therefore, to make the 0 for heights at a point nearest the ocean.

As the progress of topographical work is usually from the shore-line inward, this affords the most favorable direction for drawing the curves of equal elevation, and as it is desirable that all work at a station shall be completed when it is first occupied, so as to avoid the necessity of returning to it, the curves should be drawn by the eye from the shore-line to the points sighted and determined for position and height, to be checked by reverse drawing from those points when in turn occupied; and so from station to station, drawing to and from in reverse will check and verify, between stations not too far apart, such comparatively small errors of position as an accurate eye will soon learn to estimate. The heights of sufficiently close points must be determined to guard against any wide range of estimate of height by the eye.

In abrupt slopes of considerable extent the use of a pocket clinometer is of much value to determine the degree of slope, and to draw accordingly the curves by the widths of their zones (the cosines of angles of slope) from a paper scale prepared for the purpose. (See Fig. 46.) Illustration 61.

The use of the alidade as a level for observing determined objects of the same height as the instrument is a valuable aid in locating curves, as is also the use of a rod showing marks the same distance apart as the vertical distance between the curves, for the purpose of locating with the alidade, as a level, the curve or curves immediately below the station occupied.

The two methods of surveying curves of equal elevation are known as the *Regular* and the *Irregular* methods.

The *Regular methods* include—

1. Surveying and leveling the skeleton and its traverses.
2. Surveying and leveling the profile lines.
3. Surveying and leveling the base of each level section.
4. Surveying and leveling the parts of several level sections from one station.
5. The division of the terrene into squares, triangles, or parallelograms.

The profile is a traverse line on which are determined the heights of the points at which the surface changes slope. The points where this line is intersected by the successive level equidistances are with the level and rod easily determinable.

To determine the base of each level section the table is set up in position where this level intersects the profile, and using the alidade as a leveling instrument, with the target fixed on the staff at the height of the optical axis of the telescope, the line is traced by locating the aid by successive steps at characteristic points of the terrene, when the target comes in the horizontal plane of the optical axis, direction and distance of the rod being determined and drawn in each case. A line drawn through these points, recognizing features between the stations, locates the curve. In this operation allowance should be made for curvature and refraction, when the distance becomes sufficiently great to make it a factor.

When parts of several level sections are run from one station, set up the table at a point in an equidistance curve, and observe on the staff the height of the optical axis of the alidade. Set the target on the staff above this height as many equidistances as its length will include. The aid carries the staff below the instrument and is signaled to stop when the target comes in the horizontal plane of the optical axis, and at successive steps traverses the lower curve. The target is then lowered on the staff one equidistance and the next curve above is in the same manner traced, continuing the proceeding until the level of the instrument is reached, when the table is moved to an upper station and the proceeding continued until the summit is reached.

By the mode of regular division of the surface into squares, triangles, or parallelograms, pegs are driven at regular intervals, and their heights determined by level in the way that may be most convenient, a spirit-leveling instrument being the most accurate.

The *Irregular method* consists in determining the positions and heights of a number of characteristic points of the terrene, and in determining from these the traces of the curves.

This is the method generally used in surveys embracing such areas as the sheets of the Coast and Geodetic Survey on scales of $\frac{1}{10000}$ and $\frac{1}{20000}$.

It has the merit that the development of the terrene proceeds with the survey of the skeleton, and does not necessitate a return to a station when once occupied. In connection with the determination of position by resection it works harmoniously and economically, since points that would be selected for position as having the best outlook are likely to be the characteristic ones of the terrene.

ADJUSTMENT OF THE NEW ALIDADE FOR THE OBSERVATION OF ALTITUDES.

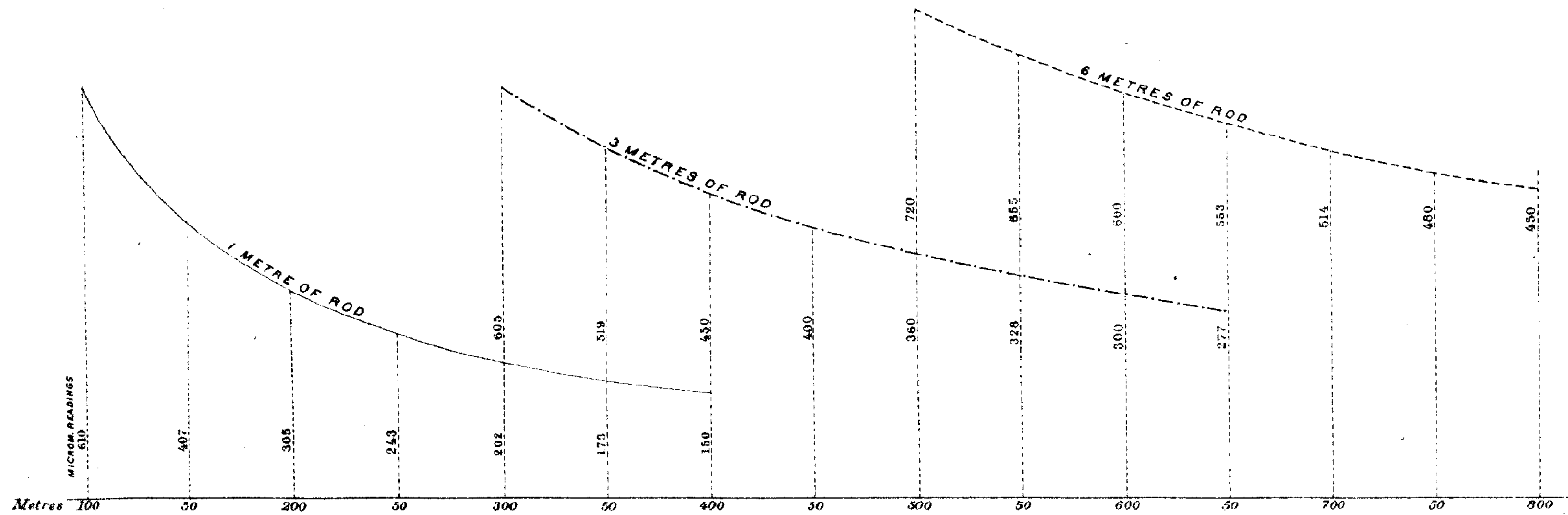
The telescope can be turned about itself within the short tube on the transit-axis through which it passes. Two stops define the positions in which the wire is horizontal. In order to adjust the horizontal wire to the level (*i. e.*, to have it point horizontally when the striding-level indicates that the collars on which it rests are level), proceed thus:

1. Adjust the striding-level by reversing it end for end and correcting its error—half the difference by its own adjustment, half by the tangent-screw of the telescope.

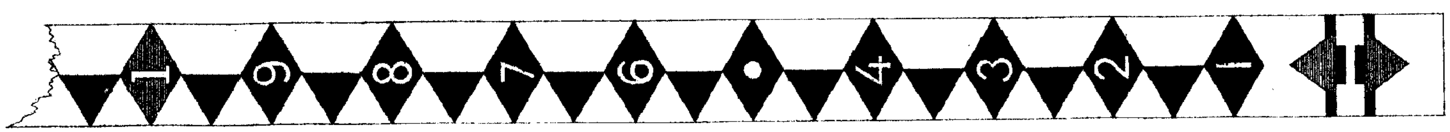
2. Point the telescope to a target and note the reading, or make a mark where the wire points when the bubble is in the middle.

3. Revolve the telescope about itself, put the level on again, and note the reading, or mark the place where the telescope now points when the bubble is in the middle.

4. The mean of the two pointings is the true level line, upon which the wire is to be adjusted, which may be done in this way: point the wire to the mean of the two observations by the tangent-screw; then, by means of the adjusting-screws, bring it to point on the *lower* reading, if the second



Micrometer readings of U.S.C. and G.S. Alidade No. 80
on One, Three and Six Metres.
100 div. to 1 turn of Screw. 1 div. = 2".31 of arc.



Division of the Telemeter Rod

 Red

reading has been *high*, and *vice versa*. If now brought back to the mean by the tangent-screw, the bubble should be in its place; and, when the telescope is turned back into its first position, the adjustment should verify.

5. If it is now desired to make the vernier read *zero* on the vertical arc, the table must be carefully leveled; and in order to do this more perfectly than can be done with the circular level, it may be done by observing the striding-level; the telescope remaining clamped, the striding-level should read the same in every position of the alidade when the table is perfectly level. (In general, this will be found too delicate a test, as the table is not sufficiently *even* for so sensitive a level to be employed.) The table being leveled, move the telescope with the tangent-screw until the bubble is in the middle, and then set the vernier to read zero; the screw-holes in it are oblong, so that it admits of being pushed either way.

6. It is easy to have the adjustments near enough to serve for running curves of equal elevation, but in determining the heights of stations, it is best to make the observations complete, with reversals, both of level and of telescope, taking the mean of the observations, by which the errors of adjustment are eliminated. This, in fact, is always done with the theodolite, and should be equally done with the alidade when precision is required.

The following may serve as an example:

TELESCOPE DIRECT.

Level direct, reading	+ 0° 1′	
Level reversed, reading	0′	
Mean	+ 0° 0′.5	
Station, reading	+ 2° 17′	
Elevation (difference)		2° 16′.5

TELESCOPE INVERTED.

Level direct, reading	− 0° 2′	
Level reversed, reading	− 1′	
Mean	− 0° 1′.5	
Station	+ 2° 12′	
Elevation (difference)		2° 13′.5
Mean		2° 15′

It will be seen, from analyzing this observation, that the level was one-half minute out of adjustment, the horizontal wire one and one-half minutes, and that revolving the telescope about itself changed its relation to the index on the vernier by 1′. The mean is free from all errors of adjustment.

DISTANCE.

Distance is measured either directly by successive contiguous units of any conventional standard, or by some instrumental process of triangulation upon a divided or marked staff, or from the two ends of a measured base, known as parallax.

In the first case the essentials are that the measurement shall be made horizontally, or the inclination observed and reduced to the horizon; that a right line of direction shall be followed, or the deflections carefully observed and reduced to a right line between the extreme points, and that the contact of the extremities of the successive units shall be as exact as possible. For precise measurement, temperature should be observed, and all lengths reduced to one temperature, usually 60° Fahr.

The instrumental methods in plane-table surveys are either with two horizontal fixed lines on glass or webs in the diaphragm of the alidade telescope, which subtend variable lengths on a divided staff, in proportion to distance; the staff having been experimentally divided on measured distances: or a micrometer eye-piece to the telescope, with two horizontal webs in the diaphragm, one of which is movable by a finely-cut screw, subtending a given length distinctly marked by two targets on a rod. The angle, as indicated by the rack and the divisions of the screw-head, giving the distance from a table experimentally made, on measured distances. In practice it has been found that an extension-rod, with targets 6 meters apart, may be used for details, to 800 meters, without important graphic error, on the usual scales of topographical surveys, with a micrometer, whose unit of division = 2″.31 of arc (see illustration 58).

By these methods 400 meters may be measured within 1 meter, which on the usual scales of plane-table work is inappreciable, and within the probable changes of the dimensions of the paper by hygrometric influences.

By the method of fixed lines in the diaphragm the angle remains constant and the chord variable, and by the micrometer method the chord remains constant and the angle variable.

STADIA.*

"It is composed of—

1. A graduated staff from 2 to 3 meters in height, with two movable targets. Sometimes one of these targets is fixed at the top of the staff.

We will first consider the use of a staff with two movable targets, and afterwards indicate the modifications necessary in using a staff with one fixed target.

The face of the target is ordinarily divided into four equal rectangles. Two of these, on the same diagonal, are white; the others are red. The line F F′ (fiducial line), resulting from the opposition of colors, is visible with great distinctness. The distance between the fiducial lines of the targets is read on the back of the staff.

2. A telescope to which is attached a vertical arc, for measuring the angle of the optical axis with the horizon, and which is supported on a tripod.

(Illustration 59, Fig. 40.) The telescope is composed of two double convex lenses, inserted in a cylindrical tube blackened inside. The lens directed to the object is called the "object-glass"; it receives the rays of light coming from the object. These rays, refracted within the tube, form an inverted image "*a b*" of the object AB at the focus, where the diaphragm carrying the cross-hairs is inserted.

The diaphragm, which is perpendicular to the optical axis, is fixed in a cylinder sliding in the principal tube with a gentle friction. It has two very fine threads crossing at right angles, the point of intersection being in the optical axis.

For measuring distance a third line (horizontal) is inserted, and sometimes a fourth one (horizontal). It is only in this particular that ordinary telescopes differ.

The eye-glass serves to magnify the image of the object. It is a magnifying glass placed between the eye and the image on the diaphragm, and is adjustable according to the eye of the observer. The cylinder carrying the eye-glass has a small opening for the eye of the observer.

To sight an object it is first necessary to set the eye-piece—to bring the eye-glass nearer to or removed from the diaphragm—until the cross-hairs are distinctly visible. Unless this is done the object sighted will be an illusive one. To verify the adjustment, let the image be viewed as obliquely as possible. It must always appear to coincide with the webs, whatever the position of the eye may be. The extent of the eye-piece being thus regulated, the telescope is in adjustment and the diaphragm in the focus.

The distance d from the image of an object to the object-glass is called the focal distance. It depends upon the remoteness, D, of this object. If D is infinite, it is a minimum, and is then named "the principal focal distance."

There exists between dD and the principal focal distance f the relation

$$\frac{1}{D}+\frac{1}{d}=\frac{1}{f}$$

*From "Traite de Topographie," par C. Maes, Capitaine au 7ᵉ regiment de ligne, Professeur a l'ecole Militaire de Bruxelles.

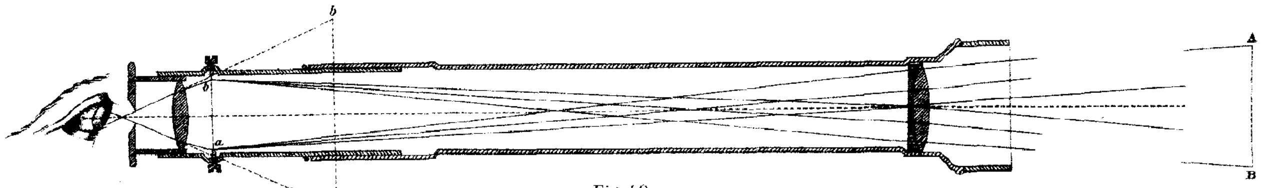


Fig. 40.

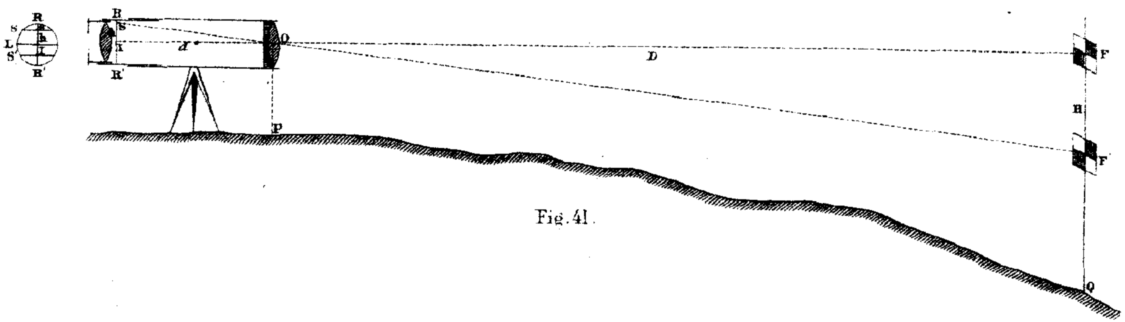


Fig. 41.

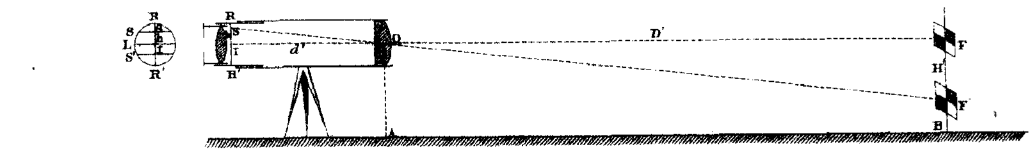


Fig. 42.

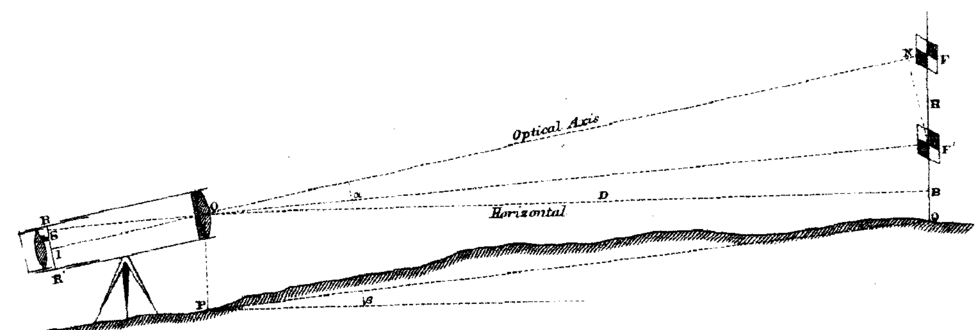


Fig. 43.

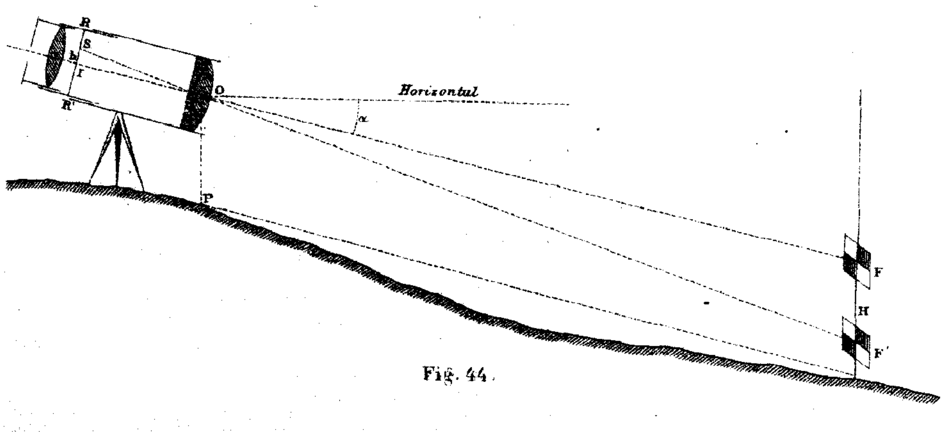


Fig. 44.

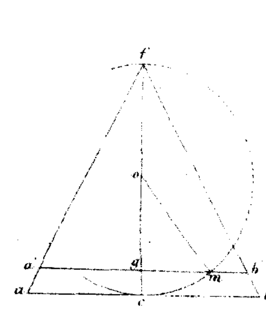


Fig. 45.

The distance f can be determined experimentally for each object-glass. In topographical telescopes it never exceeds 30 to 40 centimeters. The reach of these telescopes is about 700 to 800 meters.

Adopting for f the value $0^m.35$, we compute "d" by the above formula, and substituting for D different values, we find that within the usual limits of observation, from 20 to 800 meters, the focal variation does not attain one centimeter, and that it is more sensible in short than in long distances.

The relations between D and d are found to be as follows:

$D=20^m$	$d=0^m.35623$
$D=100^m$	$d=0^m.35123$
$D=102^m$	$d=0^m.35120$
$D=200^m$	$d=0^m.35061$
$D=300^m$	$d=0^m.35041$
$D=400^m$	$d=0^m.35031$
$D=410^m$	$d=0^m.35030$
$D=700^m$	$d=0^m.35017$
$D=715^m$	$d=0^m.35017$

These results prove besides, that beginning with 100 meters, the focal variation for distances above 100 meters amounts only to few tenths of a millimeter, a quantity inappreciable in the telescope, however delicate the mechanical contrivance for setting the eye-piece. It is only by a mere accident that the diaphragm is at the exact focus, because its position is the result of approximations by which we judge whether it is in the focus, but it will still seem to be so if it is moved slightly either way the fraction of a millimeter. We are setting the same not to measure the focal distance, but simply to view the staff distinctly, so as to set with facility and certainty the targets to the intended height.

We insist on this observation, because it does justice to the idea of measuring the focal distance d, corresponding to the remoteness D, on the tube of the telescope, and of computing D by the formula

$$\frac{1}{D}+\frac{1}{d}=\frac{1}{f}$$

the quantity "f" having previously been determined with great precision.

It is proposed to measure the distance D of the object-glass from the staff by the height "H" intercepted on this staff between two fixed threads of the diaphragm. Or, supposing the staff parallel to the plane of the diaphragm, if we represent by h the interval between the two threads S and L.

(Fig. 41.) It follows from the similarity of the triangles FOF′ and SOI

$$D : d :: H : h, \text{ or}$$

$$D=H\times\frac{d}{h}$$

the fundamental relation of the theory of the telemeter.

H is read on the staff, but the ratio $\frac{d}{h}$ cannot, as previously shown, be obtained with precision. So the problem is not susceptible of an exact mathematical solution.

The interval h being known, if we take from a table of distances, computed for a certain telescope, the value of d corresponding to an estimated distance, D, we obtain a very approximate solution, even if the estimate of D should contain an error of 100 meters.

But this manner of proceeding, a very tedious one, because it would necessitate for each distance to be measured a computation of the ratio $\frac{d}{h}$, would not give an idea of the obtained approximation, and would, besides, present the inconvenience of requiring the previous determination of h.

The practical way to avoid the direct measurement of "h", and the necessity of determining an approximate value of $\frac{d}{h}$ for each of the distances D to be observed, is as follows:

1st. We proceed the same as if the focal distance was invariable and equal d'—a focal distance corresponding to a known distance, D′. We arrive at the same supposition by substituting in the formula $D=H\times\frac{d}{h}$ for the quantity multiplying H, a constant $\frac{d'}{h}=C$.

Assuming this hypothesis, we conclude that the values obtained for the distances to be measured are the products of a constant coefficient, C, and the heights of the rod intercepted between the threads of the diaphragm called "read distances"; we designate them by $\triangle$ to distinguish them from the true distances, D.

Before commencing operations with the telemeter we determine the constant coefficient, C, by an experimental standard reference. For this purpose we measure with a chain or rod on level ground a distance AB=D′.

(Fig. 42.) Place the telescope on station A, its object-glass in the vertical plane of this point, its optical axis directed horizontally to the staff held vertically by an aid in B. Having set the same with the utmost care, let the fiducial lines F and F′ of both targets come successively under the threads L and S of the diaphragm. Note the interval FF′=H′, separating both targets, viz, the height of the rod, and from the proportion $D' : d' :: H' : h$ follows

$$\frac{d'}{h}=C=\frac{D'}{H'}.$$

Supposing D′=140 meters and H′=0^{m}.80, the constant coefficient will be

$$C=\frac{140}{0.80}=175.$$

Repeat this operation several times, and if the values found for C differ only very little, adopt the arithmetical mean for the value of the coefficient.

The coefficient of the telemeter being thus known, we get the reduction to the horizon of any desired distance as follows: Establish the telescope on station P (Fig. 43), the object-glass in the vertical of this point, its optical axis directed to the staff kept vertically in Q; bring it carefully in the focus, and bring successively the fiducial lines F and F′ under the threads L and S of the diaphragm, and record the interval H=FF′. We find that the distance Δ for the distance D of the object-glass from the staff

$$\triangle=H\times C$$

If H=2^{m}.415 and C=175, we have $\triangle=2^{m}.415\times175=422^{m}.625$.

2d. Compute the correction $\Sigma=D-\triangle$, to be applied to Δ, to obtain D as exact as possible.

$$C \text{ being } =\frac{d'}{h}$$

we have

$$\triangle=H\times\frac{d'}{h}$$

But d is the focal distance corresponding to D, therefore

$$D=H\times\frac{d}{h}$$

or

$$\frac{D}{\triangle}=\frac{d}{d'}$$

and

$$D=\triangle\times\frac{d}{d'}$$

This result shows that $\triangle$ differs only very little from D.

In reality we have

$$\Sigma=D-\triangle=\triangle\times\frac{d}{d'}-\triangle=\triangle\left(\frac{d-d'}{d'}\right)\;.\;.\;.\;.\;.\;.\;1$$

Or, for a telescope whose principal focal distance is 0^{m}.35, the maximum of $\frac{d-d'}{d'}$ is, according to the previous table, $\frac{0.0062}{0.35}$, or about $\frac{1}{50}$, so that for distances of 100, 200, 300–700 meters the difference $D-\triangle$ is respectively equal to no more than 2, 4, 6, 14 meters.

This being established, it is easy to be satisfied, from an examination of the table of focal variations, that in computing the focal distance, δ corresponding to Δ, by the formula

$$\frac{1}{\triangle}+\frac{1}{\delta}=\frac{1}{f}$$

and substituting this value for d in formula (1), the result

$$\Sigma=\triangle\frac{\delta-d'}{d'}$$

will only differ from the real Σ by a quantity insignificant for practical purposes.

We are then at liberty to take

$$\Sigma=\triangle\frac{\delta-d'}{d'}$$

an equation whose second term is entirely known.

The relations

$$\frac{1}{D'}+\frac{1}{d'}=\frac{1}{f}$$

and

$$\frac{1}{\triangle}+\frac{1}{\delta}=\frac{1}{f}$$

giving

$$\frac{\delta-d'}{d'}=\delta\frac{D'-\triangle}{\triangle D'}$$

from which we get

$$\Sigma=\delta\frac{D'-\triangle}{D'} \quad \ldots\ldots (2)$$

and under this form is ordinarily the correction due to the focal variation presented.

Let us have for an example $D'=100^{m}$, and $\triangle=500^{m}$. From the equation

$$\frac{1}{500}+\frac{1}{\delta}=\frac{1}{0.35}$$

we have

$$\delta=0^{m}.35024$$

therefore,

$$\Sigma=0^{m}.35024\frac{100-500}{100}=-1^{m}.40096;$$

hence, we have in this case the real distance, D, equal the read distance minus $1^{m}.401$, or

$$500^{m}-1^{m}.401=498^{m}.599.$$

Making the experimental standard reference for a distance, D′, equal to or in excess of the mean between the greatest and least distances to be measured, we may neglect in topographical surveys, without an appreciable graphical error, the correction Σ and take the read distance $\triangle$ for the true distance D.

In reality, the relation (2) shows that D′ having been chosen in such a manner, the numerical value of Σ will in all cases be smaller than δ, because δ never exceeds from 35 to 40 centimeters, and because the scales $\frac{1}{M}$ adopted for the projection are generally much smaller than $\frac{1}{2000}$ the quantity $\frac{\Sigma}{M}$ will be one-eighth of a millimeter at most.

It is well understood that in case of subsequent computations the smallest correction of Σ should be considered. But in this case, to avoid the computation of the focal distance δ corresponding to each observation, we replace in equation (2) the variable δ by the constant representing the focal distance of the standard reference by trial. The error resulting from this substitution is entirely insensible in practice, especially if the distance D′ is taken between the indicated limits.

If the line of sight is not horizontal, which happens in measuring distances on a slope, the station is made at one end of the slope and the manner of proceeding should be slightly modified. This does not necessitate a change in the standard reference, because the topographer can select the ground for this trial.

The constant coefficient C of the telemeter being thus known, let the reduction to the horizon of the distance PQ be determined from the point P. (Fig. 43.) Station the telescope in P, the object-glass in the vertical of this point and the optical axis directed to the fiducial line of the upper target, fixed at a convenient height. Then bring the fiducial line F′ under the upper thread and note, first, the angle a which the telescope makes with the horizon, and, second, the height of the rod FF′=H.

This makes, as in the general case, the read distance $=\triangle H\times C$.

It remains to determine OB=D, the reduced distance. The staff held perpendicularly is not parallel to the diaphragm, which, as before mentioned, is perpendicular to the optical axis; so that the fundamental proportion cannot be furnished by the triangles FOF′ and SOI. From F′ draw the perpendicular F′N on the optical axis; the two triangles F′ON and SOI being similar, we are brought back to the general case, and we obtain

$$ON=NF'\times C+\Sigma,$$

designating by Σ the focal correction.

But,

$$NF'=H\cos NF'F=H\cos a,$$

therefore, because

$$\triangle=H\times C,\ ON=\triangle\cos a+\Sigma,$$

rom which

$$OF=ON+NF=\triangle\cos a+\Sigma+H\sin a,$$

and

$$OB=OF\cos a=\triangle\cos^2 a+\Sigma\cos a+H\sin a\cos a.$$

This is the formula for the reduction to the horizon of distances observed with the telemeter.

If we work on a small scale and have chosen the distance for standard reference, as before mentioned, we may neglect the last terms $\Sigma\cos a$ and $H\sin a\cos a$.

This is done in the war department of Belgium, where, in work projected on a scale $\frac{1}{20000}$ is adopted for the read distance $\triangle=H\times C$, and for the reduced distance $D=\triangle\cos^2 a$.

It must not be forgotten that a is the angle which the optical axis makes with the horizon, and not the inclination β of the straight line passing through the extreme ends of the distance PQ.

To determine $\triangle\cos^2 a$, $\triangle$ and a being known, a simple computation with logarithms is sufficient, but this determination is facilitated by a table giving from degree to degree the reduced distance for $\triangle=10$, 20, 30–90 meters.

Inclination in degrees.	Horizontal projection of—								
	10 m.	20 m.	30 m.	40 m.	50 m.	60 m.	70 m.	80 m.	90 m.
°									
1	9.997	19.995	29.993	39.991	49.988	59.986	69.984	79.981	89.979
2	9.99	19.98	29.97	39.96	49.95	59.94	69.94	79.92	89.91
3	9.98	19.96	29.93	39.91	49.88	59.86	69.84	79.82	89.80
4	9.96	19.92	29.88	39.84	49.80	59.76	69.72	79.68	89.64
5	9.94	19.88	29.81	39.75	49.69	59.63	69.57	79.50	89.44
6	9.91	19.82	29.73	39.64	49.56	59.46	69.37	79.27	89.20
7	9.88	19.76	29.64	39.52	49.40	59.28	69.16	79.04	88.91
8	9.84	19.68	29.53	39.37	49.21	59.06	68.90	78.74	88.58
9	9.80	19.60	29.40	39.21	49.01	58.80	68.61	78.41	88.21
10	9.75	19.51	29.27	39.02	48.78	58.54	68.29	78.05	87.79
11	9.70	19.41	29.11	38.82	48.52	58.22	67.93	77.64	87.34
12	9.65	19.30	28.95	38.60	48.24	57.90	67.55	77.20	86.84

Use of the table.

1st $\triangle=160.20$ and $a=7°\ 00'$.

160.2 { 100 .... 98.80
60 .... 59.28
0.2 .... 0.1976 }

D=158.2776

2d $\triangle=98.70$ and $a=4°\ 00$.

98.7 { 90 .... 89.64
8 .... 7.968
0.7 .... 0.6972 }

D= 98.3052

The explanations given in reference to the case where $\triangle = D$ is greater than $\frac{M}{8000}$ can be repeated here. Meanwhile we have to add, other conditions being equal, that the quantity $\triangle - \triangle \cos^2 a$ can be less often neglected than the quantity $\triangle - \triangle \cos a$, the difference between the distance measured with a chain on the slope and the projection of this distance.

The first one of these quantities is nearly double the second, thus:

$$\triangle - \triangle \cos^2 a = \triangle \sin^2 a \text{ and } \triangle - \triangle \cos a = 2 \triangle \sin^2 \frac{1}{2} a$$

If we take for the sine the arc, which could be done without great error as long as a is small the two quantities will be $\triangle a^2$ and $\triangle \frac{a^2}{2}$.

In case that neither a table of logarithms nor a reduction table is at hand, the distance should be reduced graphically, thus:

(Fig. 45.) Supposing $ab = \triangle$ in the scale of the drawing; erect in the middle of ab a perpendicular, cf, and from a point, O, of this perpendicular describe a circle so that ab becomes a tangent Construct in O an angle $com = 2a$; through m draw a line parallel to ab, and join a and b with f, which is the extreme end of the diameter through c.

We have $a'b' = ab \cos^2 a$

for

$$\frac{a'b'}{ab} = \frac{fg}{fc} = \frac{fo + og}{2fo} = \frac{fo + om \cos 2a}{2fo} = \frac{fo + fo \cos 2a}{2fo} = \frac{1 + \cos 2a}{2} = \cos^2 a$$

All said in regard to the operation with two movable targets applies in the use of a staff whose upper target is fixed.

To measure, for instance, the reduced distance of PQ (Fig. 43), select the station either at the foot or at the top of the slope. Suppose we station in P; establish the object-glass vertically over this point, direct the optical axis to the fiducial line F of the fixed target of the staff, kept vertically in Q. Let the fiducial line F′ of the movable target come under the upper thread S of the diaphragm.

The vertical position of the staff could be assured by means of a plumb-line attached to the top of the staff, but this is accomplished in a more complete way through adaptation of a circular level, placed under the eye of the aid, who is thus enabled to correct instantly the lateral deviations and deviations within the plane of vision.

Note first the angle a which the optical axis makes with the horizon. Second, the height of the staff FF′ = H, and the computation OB is made in the same way as explained in the preceding.

A so-called telling staff is very often used, because its division turned towards the observer is visible with such distinctness that the observer is enabled to read directly the height of the fixed target above the vision line. It is apparent that this staff does not need a movable target.

The work with a staff with one fixed target is done more rapidly than with a staff whose both targets are movable. If we try the standard reference on level ground with the former one, we ought to consider in the computation for the constant coefficient C, the inclination a of the optical axis; but we avoid this complication by operating thus:

Station the instrument, the telescope horizontal, on ground slightly inclined; the aid descends the slope and is stopped at a point where the upper target is under the thread L of the diaphragm; the distance D′, separating this point from the station point, is then measured by the chain horizontally, and the height of the staff H, intercepted between the threads L and S, determined and we get

$$C = \frac{D'}{H'}$$

To determine with the telemeter the distance in a straight line between two points P and Q (Fig. 44.)

Make either one of the two points your station, for instance P, and sight in a direction parallel to the ground, viz, direct the optical axis to a point, F, on the staff whose height is equal to the height of the rotation axis of the telescope above the ground. Bring afterwards the lower target under the thread S, and H being the height of the staff FF′, we find through arguments analogous to those previously used.

$$PQ = OF = H \times \cos a + \Sigma - H \sin a$$

We have enjoined, as a general rule, that the thread L be directed to the upper target and not the thread S′, or, in other words, to use the threads L and S in preference to those of S and S′. One of the reasons by which we have been guided is as follows: If we intersect the upper target by the thread L which meets the optical axis in I, we obtain besides H and a the height at which the axis passes above the observed point, and we have thus all the necessary elements for the computation of the difference of the height of the extreme ends of the line to be measured.

If we do not require this difference of height, we employ the threads S and S′. Enlarging thus h we diminish C, which is an advantage, considering the precision, but an inconvenience considering the rapidity of operation, because the greater h is, the shorter must be the distances to be observed."

PROJECTIONS FOR FIELD SHEETS.

It is presumed that determination has been made, by triangulation, of points most suitable for the use of the topographer who follows with the plane-table work, and that a sketch of the same is at hand, giving an approximate skeleton map of the area to be surveyed. The location or orientation (as it is sometimes called) of the sheet is then based upon several important considerations.

It may be taken as a rule that the intervisibility of the points extends across valleys, from summit to summit, or across rivers, bays, and other bodies of water. So that generally the line of greatest depression of the valley (Thalweg) should follow as nearly as practicable the middle of the sheet, regard being had for any abrupt change of direction or importance of lateral features; or, in other words, the subjects to be surveyed should be divided as far as possible into water basins, extending from divide to divide, and not center upon a ridge forming portions of two basins. The reason for this being, that from either slope of the basin points are visible on the opposite summits which will be common to the sheets which include the adjoining valleys, while from the middle of the valley points will be visible on both summits.

From the written descriptions of the points determined, discrimination should be made in regard to their temporary or permanent character. A flag in a tree is likely to have disappeared soon after its determination, and the usual cut of a triangle in its bark may have disappeared before the lumberman's axe, while a church spire, a light-house, a house chimney, a copper bolt in a rock, or a bottle buried beneath the surface of the ground, is more likely to be recovered and to be of service to the topographer.

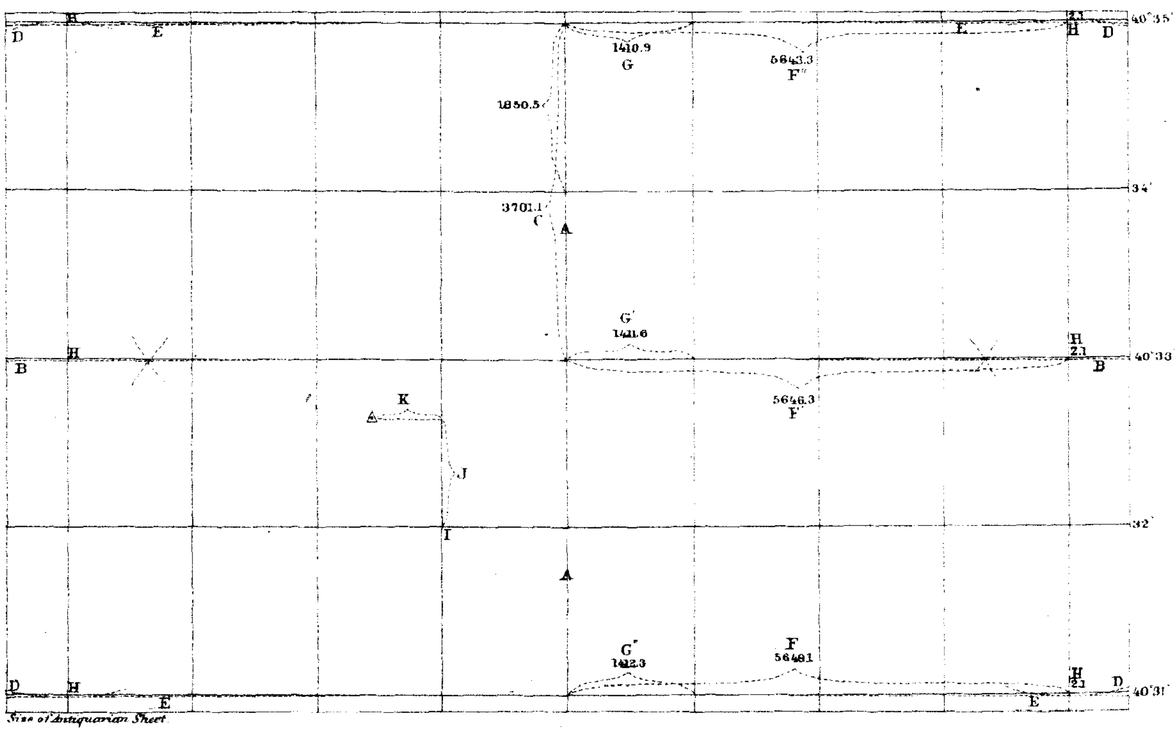
Two intervisible points, one of which may be occupied, or three inaccessible points, are all that are absolutely necessary upon a sheet for the commencement of work, for from, or upon these, all other points required may be determined, and it is oftener more important, from considerations of economy of time and facility for work, to have more regard for comprising the topographical subject in its entirety, where points may be determined at convenience, than to furnish a large number of determined points at the expense of the best orientation of the sheet in regard to topographical details.

In flat sections where the vertical question is scarcely a factor, the main question is generally a plan that will comprise the area with the fewest sheets compatible with a sufficient overlap of common points; and where the object is a survey of one side of a river or other body of water, points on the opposite shore should be included where possible.

Where it is possible, the sheet should be located by one familiar with the peculiar topography of the region to be surveyed, and with some knowledge from observation of the relative value of the points between which there may be any necessity for discrimination.

Where the surface is broken without any marked basins of large area, and when the sheet, on the scale determined upon, will comprise several successive basins and dividing ridges, the consideration of reach from higher to higher summits should control as in the reach over one valley; thereby affording the best means for determining position and any desirable auxiliary points in the lower intermediate summits and in the valleys.

Points at the junction of confluent streams have usually large arcs of visibility, and are conse-



Diagram, illustrating the mode of constructing the Conic Projection for Plane Table Work, Scale $\frac{1}{10,000}$

Scale of Diagram, $\frac{1}{30,000}$

quently of great value for purposes of orientation. If, therefore, such a point should be near but off the edge of a sheet of regular dimensions, and from the necessities at the opposite edge cannot be included by it, it is often well to extend the length of the sheet so as to include the point, even though there may be no intention to complete topographical details upon the additional piece.

Light-houses are often of this character, the reasons governing the selection of their positions for light purposes having equal weight in the selection of such positions for survey signals.

The question of the mode of seasoning paper for use on the plane-table is an important one.

It is well known that by the exposure on the table in the field of the usual linen paper (Whatman's) backed with muslin, the result in most cases is a permanent contraction of its dimensions. The sheet while in use in the field, although shaded when the table is set up at a station, is frequently exposed to the direct rays of the sun while the table is moved from station to station This, probably, has the effect of evaporating much of the moisture in the paper and producing permanent contraction.

It would, therefore, seem a reasonable proceeding to subject the paper for some time before the projection is made to the same conditions it is compelled to meet in the field, so as to reach as nearly as possible the minimum dimension now produced by field use. Seasoning by exposure to the sun in the open air would, therefore, seem to afford the conditions for the desired result.

A sketch giving the triangulation points and the approximate shore-line comprised in the area to be surveyed, being before the draughtsman, he proceeds as follows:

The limits of the sheet having been determined, the middle meridian A (see illustration 60) is located and drawn, and its intersection with the most central parallel determined, at which point the perpendicular B is erected.

The number of minutes of latitude on the central meridian, above and below the central parallel, being known, take the corresponding distance from Table VI, "Projection Tables," C. S. Report, 1853, Appendix No. 39, from under the head "Meridional Arcs," and lay it off (C) above and below the central parallel; and with the same distance as radius, strike arcs D D D D above and below from near the extremities of the perpendicular B. With a well-tested straight edge draw lines EE through the north and south minutes on the central meridian, and tangent to the two arcs DD, to the right and left. This gives three parallel lines perpendicular to the central meridian.

From the same Table VI, from under the heads "Lengths of Arcs of the Parallels," take out the value corresponding to the number of minutes of longitude, east and west of the central meridian, and lay off the whole distance FF′F″ on each perpendicular, taking each distance from its appropriate latitude. Subdivide these into minutes GG′G″.

For the areas usually covered by plane-table sheets the corrections X, for determining the abscissas from the arcs of parallels (Table VI, head "Co-ordinates of Curvature.") are inappreciable, and may be disregarded; the ordinates Y only being used. These give the distances to be set off from the lines B and E, perpendicularly toward the pole, for each minute of longitude counting from the central meridian. For ordinary field projections of scale $\frac{1}{10000}$ the ordinate of the extreme minute only need be used, and the parallel drawn a right line from the point so found to the central meridian. This ordinate H being set off on each of the parallels, the meridians are all drawn in with a fine ruling pen, then subdivided into minutes, and the parallels carefully ruled in through the points of subdivision.

The projection is verified by applying the measure of a number of minutes of latitude and longitude, and by a comparison of diagonal measurements on different parts of the sheet.

All measurements should be carefully taken from the scale with a keenly pointed beam-compass, and the marks pricked in the paper should be as light as possible to be seen, so as to insure the greatest possible accuracy.

The draughtsman is supplied with a list of triangulation points, which gives their relative distances, their latitudes and longitudes, and also the equivalents in meters of the *seconds* of latitude and longitude, according to which the points are now plotted on the sheet by measuring from the corresponding minutes. Thus in the diagram the distance J represents the seconds of latitude; K, the seconds of longitude of the trigonometrical point.

The accuracy of the plotting is tested by a measurement of the respective distances between the points with a beam-compass, these distances being also given. The latitude and longitude are then plainly marked, usually on the north and east sides of the sheet, at one extremity of each parallel and meridian, and the pencil marks erased.

It sometimes becomes necessary to base topographical work upon a detached scheme of triangulation, before the usual astronomical observations have been made. In this case the only elements given are the distances from the points to two projected arcs of rectangular co-ordinates (which are assumed) and the distances between the points. The projection for plotting these consists simply of axes of ordinates and abscissas so laid on the sheet that it will embrace all the points required by the surveyor, and in the manner most convenient for his work; and the points are plotted from these by the intersection of two arcs with the distances of the points from the axes as radii, either north or south, east or west of the axes, as the plus or minus signs given may indicate. The only test is by the distances between the points, and there should be at least two from each. If the work be correctly done, a regular projection can be constructed on the sheet after it is finished and the required astronomical work is completed.

In case it so happens that for some special purpose it becomes urgent to undertake a piece of topography, when neither the data for projections nor co-ordinates are at hand, plotting by distances is the only resource left, and, of course, great care is necessary.

When a sheet has no projection it is advisable to draw squares of 1,000 or any specified number of meters on it, by means of which the projection can ultimately be laid down correctly.

Hill Curves for every 20 feet difference of level. Scale $\frac{1}{10.000}$

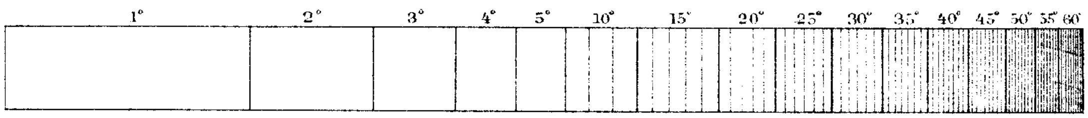


Fig. 46.

Slope.	Proportion of Height to Base	Length of Base to 1 foot of Height (in feet.)	Length of Base to 20 feet of Height (in feet.)	Length of Base to 20 feet of Height (in metres.)
1°	1 to 57	57 . 29	1145 . 8	349 . 1
2°	1 to 29	28 . 64	572 . 8	174 . 5
3°	1 to 19	19 . 08	381 . 6	116 . 3
4°	1 to 14	14 . 30	286 . 0	87 . 1
5°	1 to 11	11 . 43	228 . 6	69 . 7
10°	1 to 6	5 . 67	113 . 4	34 . 6
15°	1 to 4	3 . 73	74 . 6	22 . 7
20°	1 to 3	2 . 75	55 . 0	16 . 7
25°	1 to 2	2 . 14	42 . 8	13 . 1
30°	1 to 1.7	1 . 73	34 . 6	10 . 5
35°	1 to 1.4	1 . 43	28 . 6	8 . 7
40°	1 to 1.2	1 . 19	23 . 8	7 . 2
45°	1 to 1	1 . 00	20 . 0	6 . 1
50°	1 to 0.8	0 . 84	16 . 8	5 . 1
55°	1 to 0.7	0 . 70	14 . 0	4 . 3
60°	1 to 0.6	0 . 58	11 . 6	3 . 6

APPENDIX No. 14.

ON THE DETERMINATION OF TIME, LONGITUDE, LATITUDE AND AZIMUTH.

By CHARLES A. SCHOTT, Assistant.

INTRODUCTION.

In the annual reports of the Superintendent of the Coast Survey for 1866, 1868, and 1872, there appeared certain papers on the determination of time, latitude, and azimuth, originally intended to form part of a proposed Coast Survey manual of field operations. Their object was to facilitate the field and office work by presenting in a concise style, methods and formulæ, references to instruments, forms of record and arrangement of reductions. These papers are, therefore, of an entirely practical character, intended to assist the observer and computer and to secure as great uniformity as possible in the treatment of the astronomical work.

The titles of these papers were as follows:

Determination of time by means of the transit instrument. Appendix No. 9, Coast Survey Report of 1866.

Addenda to preceding paper. Appendix No. 10, Coast Survey Report of 1868.

Determination of weights to be given to observations, &c. Appendix No. 12, Coast Survey Report of 1872.

Determination of latitude by means of the zenith telescope. Appendix No. 10, Coast Survey Report of 1866.

Determination of the astronomical azimuth of a direction. Appendix No. 11, Coast Survey Report of 1866.

Addenda to preceding paper. Appendix No. 10, Coast Survey Report of 1868.

In the original compilation of the papers of 1866, the writer derived much assistance from the previous labors of Mr. James Main, connected with the computing division, by whom the formulæ had been put in a concise and systematic form.

The supply of these annual reports having become exhausted, the papers were collected and reprinted under one cover, under the title Professional Papers: "Determination of Time, Latitude, and Azimuth"; Washington, 1876. The demand for this edition by those officially connected with the Survey, as well as by others engaged on work of this character, made it desirable to issue a new edition, advantage of which was taken to introduce the telegraphic determination of longitude, and such additional matter and improvements as had suggested themselves from experience during the past years; also to replace in part older forms of instruments by illustrations exhibiting some of more modern construction. The separate papers on each subject are now consolidated and the whole is presented subdivided into four parts.

The subject-matter of the following pages will be strictly confined to the exposition and use of portable instruments, namely, the transit instrument for the determination of time and longitude, the zenith telescope for latitude, and the theodolite for azimuth, and will include the use of the combination or meridian telescope for the first two operations, also of the transit, in any of its forms, for the last-named or azimuthal determination.

CHARLES A. SCHOTT,
Assistant, United States Coast and Geodetic Survey.

DECEMBER, 1881.

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PART I.

DETERMINATION OF TIME

BY MEANS OF THE TRANSIT INSTRUMENT.

WITH FOUR PLATES.

ILLUSTRATING:

1. FORTY-SIX INCH (117^{cm}) TRANSIT.
2. SMALL FOLDING TRANSIT.
3. TRANSIT AND EQUAL ALTITUDE INSTRUMENT.
4. PRISMATIC TRANSIT AND ZENITH TELESCOPE.

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PART I.

DETERMINATION OF TIME BY MEANS OF THE TRANSIT INSTRUMENT.

(With four plates.)

(1) *General remarks on the use of the transit instrument.*—This paper exclusively refers to the portable transit instrument, in any of its forms, as used in the Coast and Geodetic Survey and when mounted in the plane of the meridian for the purpose of obtaining local time from observations of transits of stars over its threads or lines, in connection with an astronomical clock or a chronometer regulated to sidereal time. The use of the instrument when mounted in the vertical plane of a close circumpolar star out of the meridian has not recommended itself on account of its greater complexity, both in field and office work, as compared with the usual method, especially when considering the ease with which a transit may be placed approximately in the meridian, the chronometer correction being generally roughly known, or may readily be known in advance of placing the instrument. Nor is the instrument used on the Survey with its telescope in the prime vertical for latitude purposes. The observations are either made by the method of "eye and ear," or by chronographic registration—the former for nearly all purposes, excepting for telegraphic longitude work, for which latter an automatic record is always preferred. In using the first method the observer will of course mark his own time; that is, he will pick up the beats of the chronometer and carry them forward mentally up to the time of transit of the star which he will estimate to the nearest tenth of a second. This method is always used for slow-moving stars.

(2) *Description of the transit instrument.*—Two sizes of portable transits are employed on the Survey—the larger and older ones made by Troughton and Simms of London, almost exclusively used for the telegraphic determination of astronomical longitudes and generally for moon culminations before 1846, in which year the telegraphic method came into use; the smaller ones, made by Würdemann and others, of Washington, to serve for the determination of the local time needed for astronomical azimuths, or latitudes, or other minor purposes. In the hands of skillful observers these two classes of instrument give almost equally good results, and they compare favorably with the much larger transits usually employed at astronomical observatories, where special difficulties are encountered in consequence of the greater difficulty of reversal of axis, and the more serious effect of flexure. In case of necessity, and when an approximate degree of accuracy suffices, any ordinary astronomical theodolite or altazimuth instrument may be converted temporarily into and used as a transit. The larger-sized transits have a telescope of about 117^{cm} or forty-six inches focal length, with a clear aperture of about 7^{cm} or $2\frac{3}{4}$ inches, and magnifying powers, as generally used in connection with prismatic eye-pieces, varying between 80 and 120 diameters. An instrument of this kind is shown on the first of the accompanying plates. (Illustration 62). Originally they had no reversing apparatus. All of them have since been provided with reversing apparatus, which raises, turns, and lowers the telescope by means of an eccentric cam, rendering the former clumsyand risky reversal by hand now an operation as expeditious as it is safe. Of late these instruments have also been supplied with a delicate ether level and a larger circle in the place of one of the old finders, for the purpose of latitude determination, and their eye-piece micrometer can now be turned 90 degrees, so as to answer equally for horizontal and vertical differential measures. They also have glass diaphragms. Thus equipped, these instruments can be made to do service for time, longitude, latitude, and azimuth observations, as will be shown further on. One of the smaller-sized transit instruments is shown on illustration No. 63. Its characteristic feature is the folding frame, which renders it exceedingly portable and handy for immediate use. These instruments have

telescopes of about 66^{cm} or 26 inches focal length, with apertures of about 5^{cm} or 2 inches, and are ordinarily used with a magnifying power of about 40 diameters. Instruments of this kind are reversed by hand. The combination instrument shown in illustration 64, known as Davidson's transit and equal altitude instrument, was devised by Assistant George Davidson in 1853* to answer both for determination of time and latitude (and if need be for longitude and azimuth). Its chief peculiarity is its reversing frame of broad basis, with scale and micrometer attached to facilitate setting the telescope quickly in the plane of the meridian, and an improved clamp not liable to disturb the horizontal axis of the telescope when the azimuth screw usually attached to one of the Y^{s} is slightly moved for purposes of adjustment.† It has all the needed attachments for use as a zenith telescope. This instrument will be further referred to under the article Latitude, or in Part II of this paper. In connection with this instrument Assistant Davidson prepared a table giving azimuth and apparent altitude of Polaris for field use in placing the meridian instrument in the plane of the meridian, which see in Coast Survey Report for 1870, Appendix No. 22. This instrument carries a telescope of about 79^{cm} (31¼ inches) focal length, of an aperture of about 6^{cm}.7 (2⅝ inches), which bears a magnifying power of 100 diameters, and will permit the observation of stars of the seventh magnitude. Illustration 65 shows a prismatic transit of the Steinheil pattern (as proposed by him in August, 1849, in the Astronomische Nachrichten, Vol. XXIX, p. 177, with plate). It is, moreover, completely fitted for latitude work on the principle of the zenith telescope. The details of the construction, as made by the firm Fauth and Co., of Washington, were designed by Mr. G. N. Saegmuller, mechanician to the Coast and Geodetic Survey. Instruments of this form possess great portability, and are, therefore, specially suited for use in mountainous countries. The horizontal axis of the instrument, for transits in the meridian and for latitude work on the principle of the zenith telescope, is adjusted to the plane of the prime vertical so that by rotating it to point to the proper zenith distance any star in the meridian may be made to transit over the threads or lines of the diaphragm. This axis is specially guarded against flexure, and is really a double tube; the pivots, of 5^{cm} diameter, are of phosphor-bronze. At one end it carries the prism with which the objective is almost in contact; the prism by complete internal reflection bends the rays of light coming from the star and directs them to the focus of the eye-lens fixed at the opposite end of the axis. It has three sets of double adjusting and holding screws for adjustment, and two other screws for fastening it in its cell. The aperture is 6^{cm} for the larger and 5^{cm} for the smaller size; focal length, about 64^{cm} (25 inches). A small hole in the back of the cell of the prism admits of the usual illumination of the field, which has seven vertical fixed lines, and one movable line at right angles connected with the micrometer for latitude work. The diameter of the vertical circle is 15^{cm}, and carries a delicate ether level as well as a small rough level to serve, when the circle is used, as finder. A striding-level is provided for the horizontal; axis also a reversing apparatus, as shown in the plate. The clamp is applied at the middle of the axis.

Usually the transit instruments are fitted in their focal plane with 5 or 7 threads or lines, single or double, ruled on glass and placed vertically for the observations of the transit of stars. Besides these the diaphragm generally has two close horizontal threads or lines, between which the star is made to traverse the field during transit. For telegraphic operations and in connection with a chronograph there were formerly used diaphragms of not less than 25 threads, arranged in 5 tallies of five threads each; these were soon supplanted by glass diaphragms, by which greater permanency of the lines and of the intervals was secured. Glass diaphragms, now made very thin, are little liable to breakage, and are unaffected by the humidity of the atmosphere. Of late years this excessive number of lines, as formerly used in telegraphic longitude work, was reduced by the writer to 11 or 13, disposed of in 5 tallies, the first and last containing only one line each, the second and third tally three, the middle one being composed of five close lines. The five central lines of the tallies are equidistant and may be used for the eye and ear method, and the middle tally will serve for observing the transit of a close circumpolar star. To avoid error from parallax, in case the eye should not be directly over the thread or line when transited by the star, the field of view

* Coast Survey Report of 1867, Appendix No. 8, and Description of the Davidson Meridian Instrument, Report of 1879, Appendix No. 7.

† Description of an improved open vertical clamp for the telescopes of theodolites and meridian instruments, devised by George Davidson, Assistant, United States Coast Survey. Report of 1877, Appendix No. 13. [Also Report of 1874, Appendix No. 15.]

is limited by a slide with a circular opening, which is moved by the observer successively over the lines as traversed by the star. The instruments are supplied with prismatic eye-pieces, except those of the Steinheil form, which do not require them.

The finders of these instruments are usually about 10^{cm} (4 inches) in diameter, and rarely less than about 9^{cm} ($3\frac{1}{2}$ inches). They can be read by means of verniers to single minutes, and if the telescope has two finders one may be graduated to read zenith distances, the other to read altitudes: otherwise the observer's convenience may be suited. The striding-level is filled with ether, hermetically closed, and supplied with a chamber to regulate the length of the bubble at all temperatures. The sensitiveness of the level may be such that a change of one second of arc is represented by a motion of the bubble of one millimeter. When the portable transit is used with the sole object of obtaining local time it is not customary to make any use of a mercurial or artificial horizon, nor is there any azimuth mark put up, though the latter may be convenient to quickly replace the instrument in the meridian in case of any disturbance. If a mercurial horizon is used, and the reflected images of stars are observed, one of the most simple and effective ways to shelter the mercury from the direct force of the wind is to place the mercury trough at the bottom of the junction of two tubes, one pointed a short distance upwards towards the instrument, the other passing through a hole in the side of the observatory, and protected with an outside covering of a piece of mosquito bar or lace. The mercurial film horizon,* in which vibrations are speedily extinguished, invented by Mr. J. H. Lane, of the Weights and Measures Office, was found to require delicate handling, the films being liable to fracture.

(3) *Adjustment of the instrument.*—The stone, brick or cement pier, block of wood, frame stand or other support for the transit may be set approximately in position with regard to the meridian by means of a compass-needle, the magnetic declination being known and allowed for. The top of the pier is leveled and the frame of the instrument placed in position, so that the transit axis coincides as near as may be with the plane of the prime vertical; the adjusting-screws of the Y's, both for horizontal and vertical motion, are placed nearly in the middle of their position; the striding-level is carefully adjusted, and the transit axis of the telescope leveled. The threads are then placed in the focus of the eye-piece and set vertical. The telescope is adjusted to sidereal focus with the diaphragm in the focus of the eye-piece. The adjustment for collimation may be effected by means of a distant object or by means of a collimating telescope, the axis being reversed in its Y's during the operation. This method suffices for the portable instrument, and gives a first approximation, to be afterward tested and perfected by means of transits of stars.

If not otherwise known the local time may readily be obtained by the use of a sextant, with an accuracy within a fraction of a minute, and the latitude may be found either by a map or by the same instrument, the nearest minute of arc being sufficient. For the purpose of placing the transit in position, a small altitude and azimuth instrument may also very advantageously be used for ascertaining with sufficient approximation the local time, latitude, and direction of the meridian. To point the telescope to a star when culminating, and supposing the finder to read zenith distances, we have for a star $\left\{ \begin{matrix} S \\ N \end{matrix} \right.$ of the zenith $\zeta = \pm \varphi \mp \delta - r$ where the upper sign refers to southern and the lower sign to northern stars with respect to the zenith; the refraction, r, may generally be neglected. The index error of the finder may readily be removed by pointing to a known star and keeping it between the horizontal threads when transiting, for which position the finder is to be made to show the correct setting. The chronometer time of the transit of a slow-moving (polar) star is next computed, the telescope pointed to it, and the star bisected with the middle thread at the computed time of culmination, making use of the slow azimuth motion of the Y, or, if need be, by shifting the frame of the instrument. The axis having been leveled, we next set for and observe two close zenith-stars, one north, the other south of it, and one with clamp east, the other with clamp west, from which we obtain a very close approximation of the chronometer correction to sidereal time. The process of bisecting a circumpolar star may then be repeated, or, if need be, a fast-moving star may be followed and bisected at the computed chronometer time of culmination, using the azimuth screw only for this adjustment, after which the telescope will generally be found nearly enough in the plane of the meridian to admit of commencing the regular series of observa-

* Description of a new form of mercurial horizon. Report of 1871, Appendix No. 16.

tions. When the frame of the instrument is in satisfactory adjustment its position on a stone or brick pier may be secured by embedding the foot-screws or bed-plate in plaster of Paris.

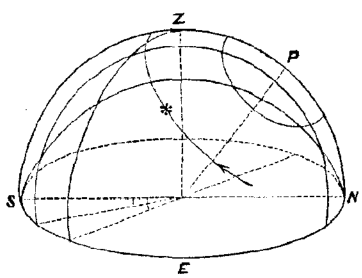
(4) *Method of observation.*—Generally, a series of observations commences with transits of stars selected to furnish instrumental corrections, then follow transits of so-called time-stars; and the night's work is concluded by again observing stars of the character first named.

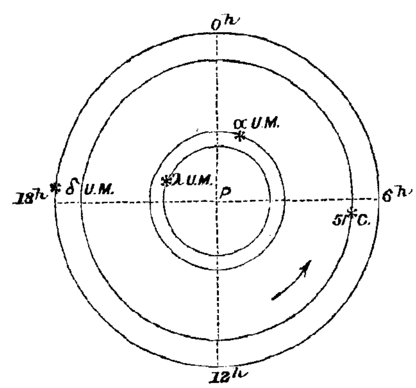
The deviation from horizontality of the transit axis is determined by level readings for each star, if possible, and the inequality of pivots is to be allowed for. The value of a division of the striding-level is ascertained by any of the methods explained in connection with the zenith telescope and the effect of temperature is to be allowed for, if sensible.

The collimation is ascertained by observing one-half of the number of stars with clamp east [or west]; then reversing the telescope and observing the remaining half, clamp west [or east]; or we may specially observe for collimation, noting the transits of a close circumpolar star over one-half of the threads, then reversing the telescope and noting the remaining transits over the same threads now presented in the reverse order; it is well to note the state of the level during each transit.

The deviation in azimuth is obtained from observations of stars differing considerably in declination (sometimes called high and low stars), but little in right ascension, or from observations of two close circumpolar stars, one culminating above the other below the pole, and having a difference of right ascension not differing much from 12 hours. It is not safe to rely on the stability of the instrument and the constancy of the rate of the chronometer by observing the *same* star at upper and lower culminations next following. Knowing the reading of the azimuth-screw for any two states of the instrument in which the azimuthal deviation has been determined, the value of one division of its micrometer-head becomes known. It is desirable that the sum of the azimuthal corrections for the circumzenith stars nearly balance, and that for any two zenith stars the mean of the tangents of their declinations equal the tangent of the latitude, or $\frac{1}{2}$ $(\tan \delta + \tan \delta') = \tan \varphi$, the deduced chronometer-correction will then be free from any error in azimuth.

In making up his observing programme, the observer, in the first place, may select his stars from the List of Standard Mean places of Circumpolar and Time Stars, prepared for the use of the United States Coast Survey by Dr. B. A. Gould (second edition, Washington, 1866), or, more conveniently, he will take them from the collections given in the American Ephemeris and Nautical Almanac (or from the English Nautical Almanac); should more stars be desirable, they may be selected from the five Greenwich catalogues, but, in preference to others, from the Field Catalogue of 983 Transit Stars (mean places for 1870) prepared by Assistant G. Davidson in 1874; of this





catalogue printed copies can be supplied to observers. Respecting the selection of circumpolar stars for instrumental deviation, it is desirable that they should not be too close to the pole; that is, their motion should not be inconveniently slow.

If more than one observer engages in the same series of observations, their relative personal equation must be ascertained by methods explained in the telegraphic determination of longitudes.

(5) *Method and formulæ of reduction.*—The usual formulæ* for reduction of transit-observations

* For a full discussion of the use of the transit instrument, the reader may be referred to W. Chauvenet's Manual on Spherical Astronomy, Philadelphia, 1863, vol. ii, pp. 131–209.

with portable instruments are here given in a concise form; and, in order to facilitate their application, tables of transit factors accompany this paper. The formulæ are arranged with reference to the mean of the threads, and not to the middle thread, which latter may be more convenient in fixed observatories in connection with collimators, and where the instrument is less frequently reversed.

Equatorial intervals of threads or lines.

To determine these, select complete transits of stars of great declination.

Let

$t_1, t_2, t_3, \ldots t_n$ be the observed times of transit over the successive threads;
t their mean and
$i_1, i_2, i_3, \ldots i_n$ their equatorial intervals from the mean thread and
δ the declination of the star:

$$t = \frac{1}{n}(t_1+t_2+t_3 \quad \ldots \quad +t_n)$$

$$i_1=(t_1-t)\cos\delta$$

$$i_2=(t_2-t)\cos\delta$$

etc.

$$i_n=(t_n-t)\cos\delta$$

also

$$0=i_1+i_2+i_3 \quad \ldots \quad +i_n$$

The intervals of the threads $\left\{\begin{matrix}\text{east}\\ \text{west}\end{matrix}\right\}$ of the mean thread will then be $\left\{\begin{matrix}-\\ +\end{matrix}\right\}$ at upper culmination.

For stars within 10° of the pole (as for δ Urs. Min., 51 Cephei, Polaris, and λ Urs. Min.), use the formulæ:

$$i_1=(t_1-t)\cos\delta\ \sqrt[3]{\cos\tau_1}$$

etc.

$$i_n=(t_n-t)\cos\delta\ \sqrt[3]{\cos\tau_n}$$

where $\tau_1, \tau_2, \tau_3, \ldots \tau_n$ the hour angles of the circumpolar star for the successive threads.

When the chronometer has a large rate, the intervals require to be corrected for it.

Incomplete transits.

When the star was not observed on some of the threads, the time of transit over the mean of all the threads may, by means of the known intervals of the threads, be found as follows:

$$t = \text{mean of observed times} + \frac{\text{sum of equatorial intervals of missed threads} \times \sec\delta}{\text{number of observed threads}}$$

If the transit over one or a few threads only is observed, we may use the formula

$$t = \text{mean of observed times} + \frac{\text{sum of equatorial intervals of observed threads} \times \sec\delta}{\text{number of observed threads}}$$

taking care, however, *first* to change the sign of the intervals.

In reducing broken transits of a circumpolar star, use $i_1 \sec\sqrt[3]{\tau_1}$, $i_2\sqrt[3]{\sec\tau_2}$, $\ldots$ $i_n\sqrt[3]{\sec\tau_n}$ in the place of the equatorial intervals $i_1, i_2, \ldots i_n$. (See accompanying table.)

Apply also a correction for rate, if necessary.

τ	$\log\sqrt[3]{\cos\tau}$	$\log\sqrt[3]{\sec\tau}$	τ	$\log\sqrt[3]{\cos\tau}$	$\log\sqrt[3]{\sec\tau}$	τ	$\log\sqrt[3]{\cos\tau}$	$\log\sqrt[3]{\sec\tau}$
1^m	9.99999	0.00000	16^m	9.99965	0.00035	31^m	9.99807	0.00133
2	99	01	17	960	040	32	858	142
3	99	01	18	955	045	33	849	151
4	98	02	19	950	050	34	840	160
5	97	03	20	945	055	35	831	169
6	95	05	21	939	061	36	821	179
7	93	07	22	933	067	37	811	189
8	91	09	23	927	073	38	800	200
9	89	11	24	921	079	39	789	211
10	86	14	25	914	086	40	778	222
11	83	17	26	907	093	41	767	233
12	80	20	27	899	101	42	756	244
13	77	23	28	892	108	43	744	256
14	73	27	29	884	116	44	732	268
15	9.99969	0.00031	30	9.99876	0.00124	45	9.99719	0.00281

Correction for rate of chronometer.

A correction for rate of chronometer must be applied to the mean of the threads; it is done as follows:

Let T be an assumed sidereal time (it is convenient to have it an exact hour) near the middle of the interval of observing the group of stars,

r_h the hourly rate of the chronometer, which is known approximately, and

α the right ascension of the star observed:

then

$$\text{Correction for rate} = (\alpha - \text{T})\, r_h$$

the quantity $\alpha - \text{T}$ being expressed in hours.

The rate is $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ when the chronometer is $\left\{\begin{matrix} \text{losing} \\ \text{gaining} \end{matrix}\right\}$.

Correction for inclination.

Let

w, e be the west and east readings of the level,

w', e' the west and east readings of the level when reversed,

d the value of one division of the level, expressed in seconds of arc,

b the level error representing the inclination of the axis of the instrument; it will be found $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ when $\left\{\begin{matrix} \text{west} \\ \text{east} \end{matrix}\right\}$ end of axis is too high:

$$b = \tfrac{1}{4}\left\{(w+w') - (e+e')\right\}\frac{d}{15} \text{ or } = \left\{(w+w') - (e+e')\right\}\frac{d}{60}$$

and correction for level-error, in seconds of time—

$$b \cos(\varphi - \delta) \sec \delta = b\,\text{B}$$

δ, when north, is to be taken $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ for $\left\{\begin{matrix} \text{upper} \\ \text{lower} \end{matrix}\right\}$ culmination; when south, it is negative.

For a star reflected in mercury, B changes sign. The factor B is tabulated for various values of δ and zenith distances $\zeta = (\varphi - \delta)$, which is $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ for a star $\left\{\begin{matrix} \text{south} \\ \text{north} \end{matrix}\right\}$ of the zenith.

B will thus be found positive except for stars at lower culmination.

Correction for inequality of pivots.

The correction for inequality of pivots, supposing them circular, applies directly to the level constant. If the same V gives level reading too great (is high) both before and after reversal of nstrument, half the difference of the level correction is the effect due to the difference of diameters of the pivots; but if the east V shows high $\left\{\begin{matrix} \text{before} \\ \text{after} \end{matrix}\right\}$ and the west V high $\left\{\begin{matrix} \text{after} \\ \text{before} \end{matrix}\right\}$ reversal, half the sum of the level corrections gives the effect. The half of the effect is the correction to the level constant for inequality of pivots (the transit axis passing through the centers of the pivots), $\left\{\begin{matrix} - \\ + \end{matrix}\right\}$ to $\left\{\begin{matrix} \text{large} \\ \text{small} \end{matrix}\right\}$ pivot. (See example of record and of computation for inequality of pivots further on.

Correction for collimation.

Let c = error of collimation in seconds of time.

At upper culmination, c will be $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ when mean of threads or lines is $\left\{\begin{matrix} \text{east} \\ \text{west} \end{matrix}\right\}$ of line of collimation for any assumed position, say for clamp west.

At lower culmination, c will be $\left\{\begin{matrix} - \\ + \end{matrix}\right\}$ when the mean of threads or lines is $\left\{\begin{matrix} \text{east} \\ \text{west} \end{matrix}\right\}$ of line of collimation.

Correction for error of collimation $= \pm\ c \sec$, $\left\{\begin{matrix} + \\ - \end{matrix}\right\}$ for $\left\{\begin{matrix} \text{upper} \\ \text{lower} \end{matrix}\right\}$ culmination.

$$= \pm\, c\,\text{C}$$

where C = collimation factor, which has been tabulated at the foot of the accompanying table.

C will thus be found positive except for stars at lower culmination.*

To find the error of collimation of the telescope by means of a circumpolar star: Note the transit of the star over the first series of threads, including or excluding the middle thread then reverse the axis and note the transit over the same threads, now in the reverse order. Find the time of transit over the mean of all the threads, both before and after reversal, by the method already explained, and correct for rate, inclination and inequality of pivots, if necessary. The state of the level should be noted for each thread.

Let t = time of transit before reversal and t' after reversal; then for—

upper culmination, $c = \frac{1}{2}(t' - t) \cos \delta$, for position of axis before reversal.

lower culmination, $c = \frac{1}{2}(t - t') \cos \delta$, for position of axis before reversal.

To this is to be added $p \cos (\varphi - \delta)$ if the pivots are unequal (see computation for pivot inequality further on).

Correction for deviation.

Let a = the azimuthal error in seconds of time.

a is $\left\{ \begin{matrix} + \\ - \end{matrix} \right\}$ when line of collimation of telescope is $\left\{ \begin{matrix} \text{east} \\ \text{west} \end{matrix} \right\}$ of south.

The correction for azimuthal deviation is $a \sin (\varphi - \delta) \sec \delta = a$ A.

δ, when north, is $\left\{ \begin{matrix} + \\ - \end{matrix} \right\}$ for $\left\{ \begin{matrix} \text{upper} \\ \text{lower} \end{matrix} \right\}$ culmination; when south, it is negative.

The factor A is tabulated for various values for δ and ζ.

A will thus be found positive, except for stars between the zenith and pole.

To find the azimuthal deviation from the transit of two stars, which differ considerably in declination: Let the observed times of transit be corrected for rate, inclination, inequality of pivots and collimation error; then—

$$a = \frac{(\alpha' - \alpha) - (t' - t)}{A' - A}$$

where α, t, A and α', t', A$'$ are the apparent right ascensions, times of transit and azimuth factors respectively for the preceding and following star. It will be seen that A is $\left\{ \begin{matrix} + \\ - \end{matrix} \right\}$ when the star culminates $\left\{ \begin{matrix} \text{south} \\ \text{north} \end{matrix} \right\}$ of the zenith and at the lower culmination it is also positive.

For lower culminations, the star's right ascension is to be increased by 12^h. It is desirable that the low star should differ over 50° in declination from the high star and if two close circumpolar stars are observed, their right ascensions should differ 12 hours nearly.

Correction for diurnal aberration.

When great precision is required, apply to the star's apparent right ascension the effect of the diurnal aberration = $\left\{ \begin{matrix} + \\ - \end{matrix} \right\} 0^s.021 \cos \varphi \sec \delta$ for $\left\{ \begin{matrix} \text{upper} \\ \text{lower} \end{matrix} \right\}$ culmination.

Ordinarily the correction for diurnal aberration may be included in that for collimation.

Personal equation.

Let the transits of a star over the first series of threads, including or excluding the middle thread, be noted by one observer and the remaining transits by the second observer; reduce the observations of each to the mean thread by aid of the known equatorial intervals, the difference in the results will be the personal equation. A number of stars may be observed in this manner, with the observers leading alternately and the mean of all results should finally be taken. It is desirable that not less than twenty stars be observed. The method as described above is one of the best known. Personal equation machines for either absolute or relative values may be employed, provided the reliability of their indications has previously been established.

Chronometer correction.

The corrections to the observed time, t, of the transit of a star for instrumental deviations

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* The signs of B and C are always the same except when a reflected image is observed.

using Mayer's formulæ as above, becomes a A + b B + c C and consequently the chronometer correction (on local sidereal time)

$$\Delta t=\alpha-(t+a\,A+b\,B+c\,C).$$

(6.) *Reduction of transit observations by application of the method of least squares.*

Let

$$\Delta T_0=\text{the chronometer correction} \left\{ \begin{matrix} + \\ - \end{matrix} \right\} \text{ when } \left\{ \begin{matrix} \text{slow} \\ \text{fast} \end{matrix} \right\} \text{ at an assumed middle time } T_0;$$

$t_1, t_2, t_3 \ldots$ = the observed times of transit of a number of stars forming a group, corrected for rate, inclination and inequality of pivots;
$\alpha_1, \alpha_2, \alpha_3 \ldots$ = their right ascensions;
$A_1, A_2, A_3 \ldots$ = their azimuthal factors and
$C_1, C_2, C_3 \ldots$ = their collimation factors;
also let

$$\alpha_1-t_1=\tau_1$$
$$\alpha_2-t_2=\tau_2$$
$$\alpha_3-t_3=\tau_3$$
etc.

and $\Delta T_0=\Delta T+\delta T$, where δT is an unknown correction to an assumed chronometer correction ΔT; also let

$$\tau_1-\Delta T=d_1$$
$$\tau_2-\Delta T=d_2$$
$$\tau_3-\Delta T=d_3$$
etc.

the values of a, c and δT are then to be found by means of the conditional equations, which are f the form

$$\delta T+a\,A+b\,B+c\,C+r\,(\alpha-T_0)=\alpha-T-\Delta T$$

but b is never and r but rarely determined by means of conditional and normal equations. From these conditional equations we form the normal equations—

$$\Sigma\,\delta T \;+\Sigma aA \;\;+\Sigma cC \;\;=\Sigma d$$
$$\Sigma\,\delta TA+\Sigma aA^2 \;+\Sigma cCA=\Sigma dA$$
$$\Sigma\,\delta TC+\Sigma aAC \;+\Sigma cC^2 \;=\Sigma dC$$

It is essential for the proper use of these formulæ that the instrumental deviations should not have changed during the interval of observation of the group. If the equations are specially used for the determination of the instrumental constants, the stars entering into the group should differ widely in declination and the axis should be reversed near the middle of the group; stars observed at their lower culmination answer the same purpose as a reversal and should, if possible, be included. If there is reason to think that the azimuth of the instrument has changed by reversal, an additional unknown azimuthal deviation a' must be introduced into the system of equations. In general it is not desirable to increase the number of unknown quantities and equations for the purpose of finding from them a most probable value for the rate of the time-keeper, but to deduce it otherwise.

Stars observed near and on both sides of the zenith, or between it and the equator and with the transit axis in a direct and reversed position, may give the most accurate determination of the chronometer correction.

If the collimation error is already known and the observed times are corrected for it, a and δT only require to be found; in this case, the above equations become—

$$\Sigma\delta T \;\;+\Sigma aA \;=\Sigma d$$
$$\Sigma\delta TA+\Sigma aA^2=\Sigma dA$$

Probable error of transit observations.

According to Chauvenet, the weight, w, of a given observation with respect to the number of threads observed may be represented by $w=\frac{n(N+3)}{N(n+3)}$, where N=the total number of threads and n=number of observed threads. The following table contains the values of w for the two cases of 5 and 7 threads in the diaphragm.

n	w	w
1	0.40	0.36
2	0.64	0.57
3	0.80	0.71
4	0.92	0.82
5	1.00	0.90
6	....	0.95
7	....	1.00

Weights are introduced by multiplying the respective conditional equations with their proper value of $\sqrt{w}$ before we proceed to the formation of the normal equations.

The probable error of the deduced chronometer correction is found as follows: Substitute the values found for the unknown quantities in the conditional equations, and form the residuals $[v]$ and the sum of their squares $[vv]$. All residuals from slow-moving stars, however, are to be excluded. If m=the number of conditional and μ the number of normal equations, compute the probable error of a single observation ε by the formula

$$\varepsilon=0.675\sqrt{\frac{[vv]}{m-\mu}}$$

Next find the weight p of the quantity δT by aid of the normal equations, as explained in works on the method of least squares;* the probable error ε_0 of the chronometer correction $\varDelta T_0$ will be given by

$$\varepsilon_0=\frac{\varepsilon}{\sqrt{p}}$$

There is, however, a limit to the value of ε_0, which is soon reached, below which the probable error cannot be reduced by the use of any number of stars; it is perhaps not far from $\pm0^s.02$

If we simply make use of the residuals $[v]$ of the mean chronometer correction and that deduced from each individual star, the probable error ε_0 of the chronometer correction $\varDelta T_0$ may be found by

$$\varepsilon_0=0.675\sqrt{\frac{[w.vv]}{(m-\mu)\,[w]}}$$

where m=the number of stars and μ the number of instrumental constants determined. The value ε_0 is limited as above.

The numerical values of the factors

$$A=\sin(\varphi-\delta)\sec\delta$$
$$B=\cos(\varphi-\delta)\sec\delta$$
$$C=\sec\delta$$

are given in the appended table.

* See example, paragraph (7), further on.

(7.) EXAMPLE.

TELEGRAPH HILL, SAN FRANCISCO, CAL., *June* 19, 1853.

$\phi = 37° 48'.0$ $\lambda = 122° 24'.3$ west of Greenwich. Transit No. 7. Sidereal chronometer No. 5038. G. D., observer.

Star	α Virginis	η Urs. Maj.	η Bootis	1125 T. Y. C.	1131 T. Y. C.	α Bootis
Appearance	dif. m.—st.	m.—st.	m.—st. thr. cl'ds	m.—st. high wind	m.—st. high wind	m.—st. flam.
Declination	− 10° 24′	+ 50° 03′	+ 19° 08′	+ 65° 07′	− 9° 33′	+ 19° 57′
Position, clamp	W.	W.	W.	E.	E.	E.
Level, west and east	26.6 22.2	29.6 20.7	. . . . . .	26.3 26.1	. . . . . .	29.3 23.7
(After reversal)	28.0 21.4	28.4 22.6	. . . . . .	29.3 23.7	. . . . . .	27.0 26.3
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Threads I	. . . . . .	39 55.6	46 23.6	13 62 43.1	14 05 56.4	14 09 53.2
II	. . . . . .	40 28.2	46 45.6	61 53.7	05 35.4	09 31.2
III	. . . . . .	41 01.7	47 08.3	61 02.5	05 13.6	09 08.2
IV	17 16.6	41 33.5	47 30.2	60 14.1	04 52.7	08 46.5
V	17 37.8	42 06.4	47 52.2	59 23.7	04 31.3	08 23.7
VI	17 58.7	42 38.2	48 14.2	58 34.4	04 10.2	08 02.1
VII	13 18 20.3	13 43 11.2	13 48 36.2	57 44.7	03 49.3	. . . . . .
Mean	13 17 16.49	13 41 33.54	13 47 30.04	14 00 13.74	14 04 52.70	14 08 46.38
Correction for rate	− 0.01	− 0.01	0.00	0.00	0.00	0.00
Correction for inclination	+ 0.18	+ 0.54	+ 0.37	+ 0.30	+ 0.10	+ 0.15
Correction for collimation	− 0.17	− 0.27	− 0.18	+ 0.40	+ 0.17	+ 0.18
Correction for deviation	− 0.27	+ 0.12	− 0.12	+ 0.38	− 0.26	− 0.12
Reduced transit	13 17 16.22	13 41 33.92	13 47 30.11	14 00 14.82	14 04 52.71	14 08 46.59
Tabular right ascension	13 17 28.05	13 41 45.89	13 47 42.15	14 00 26.76	14 05 04.75	14 08 58.54
Correction of chronometer	+ 11.83	+ 11.97	+ 12.04	+ 11.94	+ 12.04	+ 11.95

Interval of threads, clamp W:

	s.
I.	−62.80
II.	−42.05
III.	−20.51
IV.	+ 0.01
V.	+21.04
VI.	+41.72
VII.	+62.62

One division of level-scale$=0^s.0955$

Approximate hourly rate of chronometer$=+0^s.02$

The reduction of the above transits may be proceeded with as follows:

Reduction of imperfect transit of α Virginis:

Sum of equatorial intervals of missed threads$=-125^s.36$

log sum	2.09816*n*	
log sec δ	0.00719	
co-log 4	9.39794	
	1.50329*n*	$-31^s.86$

Mean of observed threads, $13^h\ 17^m\ 48^s.35$

Time over mean thread, $13^h\ 17^m\ 16^s.49$

Reduction of imperfect transit of α Bootis:

log interval	1.79671*n*	
log sec δ	0.02688	
co-log 6	9.22185	
	1.04544*n*	$-11^s.10$

Mean of observed threads, $14^h\ 08^m\ 57^s.48$

Time over mean thread, $14^h\ 08^m\ 46^s.38$

Correction for inclination:

For α Virginis, $b=+0.26$; from the table, $B=0.68$; correction $bB=+0^s.18$ etc. For η Bootis, b (interpolated) $=+0.37$, and from 1131 T. Y. C., $b=+0.15$

Azimuthal deviation from a high and low star:

For the stars 1125 and 1131 T. Y. C., we have

$\alpha'-\alpha=4^m\ 37^s.99$ and by the table $A'=+0.74$ and $A=-1.08$

$t'-t=4^m\ 38^s.76$ supposing for the present the collimation zero,

$a=-\ 0^s.77:1.82=-0^s.42$ (The value of a will be finally determined by means of the method of least squares.)

For this method, we assume $T_0=14^h$, also $\Delta T=+12^s$;

we next form $\tau_1=+11^s.39$, etc. . . . $\tau_6=+12^s.01$

and $d_1=-\ 0^s.61$, etc. . . . $d_6=+\ 0^s.01$

The values of A and C are taken from the table; with respect to the sign of C, it has been assumed + for clamp east and upper culmination.

If we give equal weight to each star, the following arrangement will be found convenient:

Star.	τ	d	A	C	d A	d C	A^2	A C	C^2
	h. m. s.								
α Virginis	+ 0 00 11.39	− 0.61	+ 0.76	− 1.02	− 0.46	+ 0.62	0.58	− 0.78	1.04
η Urs. Majoris	11.82	− 0.18	− 0.33	− 1.56	+ 0.06	+ 0.28	0.11	+ 0.51	2.43
η Bootis	11.74	− 0.26	+ 0.34	− 1.06	− 0.09	+ 0.28	0.12	− 0.36	1.12
1125 T. Y. C	11.72	+ 0.72	− 1.08	+ 2.38	− 0.78	+ 1.71	1.17	− 2.57	5.66
1131 T. Y. C	11.95	− 0.05	+ 0.74	+ 1.02	− 0.04	− 0.05	0.55	+ 0.75	1.04
α Bootis	12.01	+ 0.01	+ 0.33	+ 1.06	0.00	+ 0.01	0.11	+ 0.35	1.12
	Σ =	− 0.37	+ 0.76	+ 0.82	− 1.31	+ 2.85	2.64	− 2.10	12.41

Hence the normal equations

$$\begin{aligned} 6\ \delta T+0.76\ a+\ 0.82\ c&=-0.37\\ +0.76\ \delta T+2.64\ a-\ 2.10\ c&=-1.31\\ +0.82\ \delta T-2.10\ a+12.41\ c&=+2.85 \end{aligned}$$

solving these we find $a=-0^s.35$, $c=+0^s.17$, $\delta T=-0^s.04$; hence, $\Delta T_0=+11^s.96$

If we introduce weights on account of the imperfect transits, that of the first star has $w=0.82$ and of the last 0.95, and the conditional equations of the form

$$\delta T+a\,A+c\,C=d$$

require to be multiplied by $\sqrt{w}$; but it is more convenient, first, to form the products as usual and, before summing, to multiply by w; our normal equations then change to

$$\begin{aligned} 5.77\ \delta T+0.61\ a+\ 0.95\ c&=-0.26\\ +0.61\ \delta T+2.53\ a-\ 1.97\ c&=-1.23\\ +0.95\ \delta T-1.97\ a+12.17\ c&=+2.73 \end{aligned}$$

which give $a=-0^s.35$, $c=+0^s.17$, and $\delta T=-0^s.04$. In this case the introduction of weights affects only the third place of decimals in the results.

If we introduce the corrections aA and cC, and work out the chronometer corrections for each star, we find the quantity v as follows: $-0^s.13$, $+0^s.01$, $+0^s.08$, $-0^s.02$, $+0^s.08$ and $-0^s.01$. Assuming an equal weight for each star, or $w=1$, we find from $\varepsilon=\sqrt{\frac{.455\,\Sigma v^2}{n_o-\mu_o}}$, where ε = probable error of an observation, n_o=number of stars observed, and μ_o=number of normal equations, the value $\varepsilon=\sqrt{\frac{.455\times 0.0303}{3}}=\pm 0.068$.

Next solving the weight equations

$$\begin{aligned} 6\ Q+0.76\ q+\ 0.82\ q_1&=1\\ 0.76\ Q+2.64\ q-\ 2.10\ q_1&=0\\ 0.82\ Q-2.10\ q+12.41\ q_1&=0 \end{aligned}$$

we have Q=.179; hence the weight of the time determination $P=\frac{1}{Q}$ and the probable error of $\Delta T_0=\varepsilon\sqrt{Q}=\varepsilon_0=\pm 0^s.029$

In connection with the telegraphic determination of longitude, which demands a most rigid method of reduction of transits, the introduction of special weight for each star depending upon its declination, as well as the weights of incomplete transits, has been made the subject of special investigation and the reader may be referred to Part II of this paper for its exposition and practical application.

The following observations at Telegraph Hill, October 26, 1863, instruments and observer as before, furnish an example of the computation of the collimation constant for transits of a circumpolar star:

867 T. Y. C. at lower culmination.
$\delta=85^{\circ}\ 00'$.

Clamp west.		Clamp east.	
32.8	26.5	31.0	27.2
32.7	26.5	30.7	27.6

h.	*m.*	*s.*		*h.*	*m.*	*s.*
22	04	25.7	IV		—	—
	00	24.8	V		08	27.6
—	—	—	VI		—	—
	52	26.8	VII	22	16	22.2

We have $\Delta T_0=+3^m\ 07^s.9$, also $b=+0.30$ and $+0.17$ for west and east, and $B=-6.22$; hence correction bB to times, clamp west and east $-1^s.9$ and $-1^s.1$ We now refer each thread to the mean thread. For thread VII we have:

	h.	*m.*		
Observed time - -	21	52.4	log $\sqrt[3]{\text{Sec.}\ \tau}$ - - - -	0.0002
δT_0 - - - - -	+	3.1	log i_{vii} - - - - -	1.7967
Observed sid. time -	21	55.5	log sec δ - - - - -	1.0597
$\alpha+12^h$ - - - - -	22	07.6		2.8566 $718^s.8$
τ - - - - - -		12.1		

	h.	*m.*	*s.*	*h.*	*m.*	*s.*
Observed time over VII corrected for inclination -	21	52	24.9	22	16	21.1
Reduction to mean thread - - - - - - - -	+	11	58.8	−	11	58.8
Transit over mean thread - - - - - - -	22	04	23.7	22	04	22.3
From thread V we find similarly - - - - -			24.3			25.1
From thread IV we find similarly - - - - -			23.9			
	$t=22$	04	24.0	$t'=22$	04	23.7

log $(t-t')$	9.477
log cos δ	8.940
co-log 2	9.699
log c	8.116

$c=+0^s.013$ for clamp west.

(8.) *Preparation for observing transits.*—The observer will always find it convenient to prepare a working ephemeris to contain, for the locality and time proposed for observing, the stars selected, their position, magnitude, right ascension (to which the clock correction on each night can readily be applied) and setting on the finders for illumination, west and east, according to the graduation of the circle or circles of his instrument. He will do well to start the clock at such a time as to indicate, as nearly as may be, sidereal time and to regulate the rate, in order to make it as small as possible. The following ephemeris may serve as a specimen.

SPRINGFIELD, ILL., *August*, 1869.

$\phi = 39° 49'$ $\lambda = 89° 38'$

Star.	Position.	Culmination.	Magnitude.	α	δ	Setting. Lamp W. Zen. dist.	Setting. Lamp E. Altitude.
				h. m. s.	° ′	° ′	° ′
Groombridge, 2320		U.	5.6	16 05 58	+68 09	61 40	28 20
δ Ophiuchi	S.		3	07 29	− 3 21	43 10	46 50
τ Herculis	N.		3.4	15 48	+46 38	83 11	6 49
α Scorpii	S.		1.2	21 23	−26 08	65 57	24 03
η Draconis	N.		2.3	16 22 14	+61 49	68 00	22 00
15 Draconis		U.	5.3	28 15	+69 03	60 46	29 14
ζ Ophiuchi	S.		2.3	29 57	−10 18	50 07	39 53
η Herculis	S.		3	38 24	+39 10	0 39	89 21
α Camelopardalis		L.	4	41 02	+66 07	15 56	74 04
κ Ophiuchi	S.		3.4	16 51 28	+ 9 35	30 14	59 46
d Herculis	S.		5	56 46	+33 46	6 03	83 57
ε Ursæ Minoris		U.	4.5	59 29	+82 15	47 34	42 26
α¹ Herculis	S.		Var.	17 08 41	+14 32	25 17	64 43
b Ophiuchi	S.		5	18 22	−24 03	63 52	26 08
Groombridge, 966		L.	6.7	17 22 14	+74 57	24 46	65 14
β Draconis	N.		2.3	27 28	+52 24	77 25	12 35
α Ophiuchi	S.		2	28 51	+12 39	27 10	62 50
ω Draconis		U.	5	37 43	+68 49	61 00	29 00
μ Herculis	S.		3.4	41 19	+27 48	12 01	77 59
ψ¹ Draconis (pr.)		U.	4.5	17 44 16	+72 13	57 36	32 24
γ Draconis	N.		2.3	53 34	+51 30	78 19	11 41
γ² Sagittarii	S.		3.4	57 23	−30 25	70 14	19 46
22 Camelopardalis		L.	4.5	18 04 24	+69 22	19 11	70 49
μ¹ Sagittarii	S.		4	05 56	−21 05	60 54	29 06
Etc.							

To (5.) *Example of record and computation of inequality of pivots.*

Let b_w and b_e designate the inclination, as given by the level readings, for clamp west and east, respectively; β_w and β_e the same, when corrected for pivot inequality p; then

$$p = \frac{\beta_e - \beta_w}{4} \text{ and } \begin{cases} \beta_w = b_w + p \text{ for clamp west,} \\ \beta_e = b_e - p \text{ for clamp east,} \end{cases}$$

supposing the V-bearings of instrument and level to have the same angular opening and the pivots to be circular in form.

Observations for inequality of pivots of Transit No. 4.

Station, Seaton, Washington.—G. W. D., observer.—June 19, 1867.

Altitude.	Time.	Temperature, Fahr.	Clamp west. Object-glass S. Level. W. end.	Clamp west. Object-glass S. Level. E. end.	Clamp west. $\frac{1}{2}(\Sigma w - \Sigma e)$ b_w	Clamp east. Object-glass N. Level. W. end.	Clamp east. Object-glass N. Level. E. end.	Clamp east. $\frac{1}{2}(\Sigma w - \Sigma e)$ b_e	$\frac{b_e - b_w}{4} = p$
°	*h. m.*	°	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
55	10 30 a. m.	73	60.0	64.0	+0.600	59.0	65.2	−0.425	0.256
			65.2	58.8		64.0	59.5		
50	45 a. m.	72	65.0	59.0	+0.950	64.0	59.5	−0.250	−0.300
			60.8	63.0		59.0	64.5		
45	50 a. m.	72.5	60.8	63.0	+1.450	59.5	64.0	−0.125	−0.394
			66.0	58.0		64.0	60.0		
40	11 00 a. m.	72.8	65.0	58.8	+1.050	64.0	60.0	−0.175	−0.306
			61.0	63.0		59.3	64.0		
35	05 a. m.	73	60.5	63.0	+1.200	59.2	64.0	−0.575	−0.444
			65.5	58.2		63.0	60.5		

Observations for inequality of pivots of Transit No. 4—Continued.

Altitude.	Time.	Temperature, Fahr.	CLAMP WEST. Object-glass S. Level. W. end.	E. end.	$\frac{1}{2}(\Sigma w-\Sigma e)$ b_w	CLAMP EAST. Object-glass N. Level. W. end.	E. end.	$\frac{1}{2}(\Sigma w-\Sigma e)$ b_e	$\frac{b_e-b_w}{4}=p$
°	*h. m.*	°	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
30	11 15 a. m.	73.2	63.5	58.0	+1.000	63.0	60.5	−0.125	−0.281
			60.5	62.0		60.0	63.0		
25	20 a. m.	73.8	60.5	62.0	+1.125	59.0	63.0	−0.125	−0.312
			64.0	58.0		62.5	59.0		
20	30 a. m.	74	62.0	57.5	+1.500	62.0	59.0	0.000	−0.375
			60.8	59.3		59.0	62.0		
15	40 a. m.	74.5	60.0	60.0	+1.375	58.0	61.0	−0.125	−0.375
			62.5	57.0		60.5	58.0		
10	50 a. m.	75	62.0	57.0	+1.750	60.5	58.0	0.000	−0.437
			60.0	58.0		58.0	60.5		
5	12 00 m....	76	58.5	59.0	+1.250	58.0	60.5	−0.125	−0.344
			61.5	56.0		59.0	57.0		
0	0 10 p. m.	76	60.0	57.0	+0.875	59.0	57.0	0.000	−0.219
			58.5	58.0		57.0	59.0		

Value of 1 division of level = 1″.05.

$$\text{Mean value of } p = -0^d.337 \pm 0^d.013$$
$$= -0^s.024 \pm 0^s.001$$

To allow for inequality of pivots for position clamp west, the value + β, as found by the level, must therefore be diminished numerically and for position clamp east, it must be numerically increased. Irregularities in the figure of the pivots will appear by successive level readings for every 10° of zenith distance north and south and, by comparing with the mean of all readings, a correction can be deduced for any given position of the telescope and clamp. When the transit instruments are accompanied by a hanging level (as in the meridian telescope), the pivots may be tested for any zenith distance; instruments not provided with such a level may sometimes be tested by unscrewing the tubes carrying the object- and eye-lenses, after which the usual observations can be made as above.

Specimen of record for value of one division of level by means of a level-trier.

Coast Survey Office, December 8, 1868.—Determination of value of 1 division of level B belonging to Transit No. 6.—Value of 1 division of level trier = 0″.99—A. T. M., observer.

	Level trier, forward.	Level B. R	L	Change for + 10d of trier.	Temperature.	Temperature.	Level trier, backward.	Level B. R	L	Change for 10d of trier.	
h. m.		*d.*	*d.*	*d.*	°	°		*d.*	*d.*	*d.*	*h. m.*
12 39	210	91.5	9.0		62.5	62.5	210	90.5	6.0		1 04
				10.75						12.50	
	220	80.5	19.5				220	78.0	18.5		
				12.00						12.25	
	230	68.5	31.5				230	66.0	31.0		
				11.25						10.00	
	240	57.0	42.5				240	56.0	41.0		
				9.25						10.00	
	250	47.5	51.5				250	46.0	51.0		
				9.00						8.50	
	260	38.5	60.5				260	37.5	59.5		
				9.25						9.00	
	270	29.0	69.5				270	28.5	68.5		
				8.75						8.50	
	280	20.0	78.0				280	20.0	77.0		
				8.75						9.25	
12 52	290	11.0	86.5		62.5	62.5	290	11.0	86.5		12 52

Specimen of record for value of one division of level by means of a level trier—Continued.

	Difference by level trier from the mean 250.	Corresponding difference of level B.		
		Forward.	Backward.	
		d.	*d.*	
	40	43.25	44.75	
	30	32.50	32.25	
	20	20.50	20.00	
	10	9.25	10.00	400 div. = 389d.75 of B = 396″ } on the average.
	10	9.00	8.50	1d of B = 1″.02 } on the average.
	20	18.25	17.50	
	30	27.00	26.00	
	40	35.75	35.25	
Sum..	200	195.50	194.25	

The above level is evidently irregular, its curvature being different at different parts and flattest near the marked end. For the portion of the scale near the middle, which is ordinarily used, we obtain the value 1″.08, derived from the four central differences corresponding to 10 whence 40 divisions of trier = 36.75 div.

The observations should be made at different and extreme temperatures, in order to ascertain any possible effect of temperature on the curvature or level value. When the level is furnished with a chamber, the bubble, during ordinary observations, should be kept at nearly the same length that was given to it in the experiments for value of level scale.

To (6.) *Tabulation of factors.*

The reduction of transits will be facilitated by a tabulation of the factors A, B, C (for which see appended tables), and it will be noted that A will be + except for stars between the zenith and pole, B will be + except for stars at lower culmination and C will be + except for stars at lower culmination; or B and C will have the same sign. In 1874 the Coast Survey published, in pamphlet form, more extended tables (the star factors A, B, C, for reducing transit observations) than those appended; they are given to three places of decimals. These tables were arranged by Assistant George Davidson.

Table of star factors.

SPRINGFIELD, ILL., 1869.

		A	B	C	A^2	C^2	A C
Groombridge, 2320	U.	−1.27	+2.36	+2.69	1.61	7.24	−3.42
δ Ophiuchi		+0.68	+0.73	+1.00	.46	1.00	+ .68
τ Herculis		−0.18	+1.45	+1.45	.03	2.10	− .26
α Scorpii		+1.02	+0.45	+1.11	1.04	1.23	+1.13
η Draconis		−0.80	+1.96	+2.12	.64	4.49	−1.70
15 Draconis	U.	−1.36	+2.44	+2.79	1.85	7.78	−3.79
ζ Ophiuchi		+0.78	+0.65	+1.02	.61	1.04	+ .80
η Herculis		+0.02	+1.29	+1.29	.00	1.66	+ .03
α Camelopardalis	L.	+2.37	−0.68	−2.47	5.62	6.10	−5.85
Etc.							

C and A change sign by reversal of instrument.

UNITED STATES COAST AND GEODETIC SURVEY.—TABLE OF FACTORS FOR REDUCTION OF TRANSIT OBSERVATIONS.

Azimuth factor A = sin ζ sec. δ. Star's declination ± δ. Inclination factor B = cos ζ sec. δ.

ζ	0°	10°	15°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	ζ
1°	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.03	.03	.03	.03	89°
2	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	88
3	.05	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.07	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	87
4	.07	.87	.07	.07	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	86
5	.09	.09	.09	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	.11	.11	.12	.12	.12	.12	.13	.13	.13	.13	.13	85
6	.11	.11	.11	.11	.11	.11	.12	.12	.12	.12	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	84
7	.12	.12	.13	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.16	.16	.16	.17	.17	.17	.18	.18	.18	.19	.19	83
8	.14	.14	.14	.15	.15	.15	.16	.16	.16	.16	.17	.17	.18	.18	.18	.19	.19	.19	.20	.20	.20	.21	.21	.22	82
9	.16	.16	.16	.17	.17	.17	.17	.18	.18	.18	.19	.19	.20	.20	.21	.21	.21	.22	.22	.22	.23	.23	.24	.24	81
10	.17	.18	.18	.19	.19	.19	.19	.20	.20	.21	.21	.21	.22	.23	.23	.23	.24	.24	.25	.25	.25	.26	.26	.27	**80**
11	.10	.19	.20	.20	.21	.21	.21	.22	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27	.27	.28	.28	.28	.29	.30	79
12	.21	.21	.22	.22	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27	.27	.28	.28	.29	.29	.30	.30	.31	.32	.32	78
13	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27	.27	.28	.29	.29	.30	.30	.31	.31	.32	.32	.33	.34	.34	.35	77
14	.24	.25	.25	.26	.26	.27	.27	.27	.28	.29	.29	.30	.31	.32	.32	.33	.33	.34	.34	.35	.35	.36	.37	.38	76
15	.26	.26	.27	.28	.28	.28	.29	.29	.30	.31	.31	.32	.33	.34	.34	.35	.35	.36	.37	.37	.38	.39	.39	.40	75
16	.28	.28	.29	.29	.30	.30	.31	.31	.32	.33	.33	.34	.35	.36	.37	.37	.38	.38	.39	.40	.40	.41	.42	.43	74
17	.29	.30	.30	.31	.31	.32	.33	.33	.34	.34	.35	.36	.37	.38	.39	.39	.40	.41	.41	.42	.43	.44	.45	.45	73
18	.31	.31	.32	.33	.33	.33	.34	.35	.36	.36	.37	.38	.39	.40	.41	.42	.42	.43	.44	.44	.45	.46	.47	.48	72
19	.33	.33	.34	.35	.35	.36	.36	.37	.38	.38	.39	.40	.41	.42	.43	.44	.45	.45	.46	.47	.48	.49	.50	.51	71
20	.34	.35	.35	.36	.37	.37	.38	.39	.40	.40	.41	.42	.43	.45	.45	.46	.47	.48	.48	.49	.50	.51	.52	.53	**70**
21	.36	.36	.37	.38	.39	.39	.40	.41	.41	.42	.43	.44	.45	.47	.47	.48	.49	.50	.51	.52	.52	.54	.55	.56	69
22	.37	.38	.39	.40	.40	.41	.42	.42	.43	.44	.45	.46	.48	.49	.50	.50	.51	.52	.53	.54	.55	.56	.57	.58	68
23	.39	.40	.41	.42	.42	.43	.44	.44	.45	.46	.47	.48	.50	.51	.52	.53	.53	.54	.55	.56	.57	.58	.60	.61	67
24	.41	.41	.42	.43	.44	.45	.45	.46	.47	.48	.49	.50	.52	.53	.54	.55	.56	.57	.58	.59	.60	.61	.62	.63	66
25	.42	.43	.44	.45	.46	.46	.47	.48	.49	.50	.51	.52	.54	.55	.56	.57	.58	.59	.60	.61	.62	.63	.64	.66	65
26	.44	.45	.45	.47	.47	.48	.49	.50	.51	.52	.53	.54	.56	.57	.58	.59	.60	.61	.62	.63	.64	.65	.67	.68	64
27	.45	.46	.47	.48	.49	.50	.51	.51	.52	.54	.55	.56	.58	.59	.60	.61	.62	.63	.64	.65	.67	.68	.69	.71	63
28	.47	.48	.49	.50	.51	.51	.52	.53	.54	.55	.57	.58	.60	.61	.62	.63	.64	.65	.66	.68	.69	.70	.72	.73	62
29	.48	.49	.50	.52	.52	.53	.54	.55	.56	.57	.58	.60	.61	.63	.64	.65	.66	.67	.69	.70	.71	.72	.74	.75	61
30	.50	.51	.52	.53	.54	.55	.56	.57	.58	.59	.60	.62	.63	.65	.66	.67	.68	.69	.71	.72	.73	.75	.76	.78	**60**
31	.52	.52	.53	.55	.56	.56	.57	.58	.59	.61	.62	.64	.65	.67	.68	.69	.70	.72	.73	.74	.75	.77	.78	.80	59
32	.53	.54	.55	.56	.67	.58	.59	.60	.61	.63	.64	.65	.67	.69	.70	.71	.72	.74	.75	.76	.78	.79	.81	.82	58
33	.55	.55	.56	.58	.59	.60	.61	.62	.63	.64	.66	.67	.69	.71	.72	.73	.74	.76	.77	.78	.80	.81	.83	.85	57
34	.56	.57	.58	.59	.60	.61	.62	.63	.65	.66	.67	.69	.71	.73	.74	.75	.76	.78	.79	.80	.82	.84	.85	.87	56
35	.57	.58	.59	.61	.62	.63	.64	.65	.66	.68	.69	.71	.73	.75	.76	.77	.78	.80	.81	.83	.84	.86	.87	.89	55
36	.59	.60	.61	.63	.63	.64	.65	.67	.68	.69	.71	.73	.75	.77	.78	.79	.80	.82	.83	.85	.86	.88	.90	.91	54
37	.60	.61	.62	.64	.65	.66	.67	.68	.70	.71	.73	.74	.76	.79	.80	.81	.82	.84	.85	.87	.88	.90	.92	.94	53
38	.62	.63	.64	.66	.66	.67	.69	.70	.71	.73	.74	.76	.78	.80	.82	.83	.84	.86	.87	.89	.90	.92	.94	.96	52
39	.63	.64	.65	.67	.68	.69	.70	.71	.73	.74	.76	.78	.80	.82	.83	.85	.86	.87	.89	.91	.92	.94	.96	.98	51
40	.64	.65	.67	.68	.69	.70	.72	.73	.74	.76	.77	.79	.82	.84	.85	.86	.88	.89	.91	.93	.94	.96	.98	1.00	**50**
41	.66	.07	.68	.70	.71	.72	.73	.74	.76	.77	.79	.81	.83	.86	.87	.88	.90	.91	.93	.94	.96	.98	1.00	1.02	49
42	.67	.68	.69	.71	.72	.73	.74	.76	.77	.79	.81	.83	.85	.87	.89	.90	.91	.93	.95	.96	.98	1.00	1.02	1.04	48
43	.68	.69	.71	.73	.74	.75	.76	.77	.79	.80	.82	.84	.86	.89	.90	.92	.93	.95	.96	.98	1.00	1.02	1.04	1.06	47
44	.69	.71	.72	.74	.75	.76	.77	.79	.80	.82	.84	.86	.88	.91	.92	.93	.95	.97	.98	1.00	1.02	1.04	1.06	1.08	46
45	.71	.72	.73	.75	.76	.77	.79	.80	.82	.83	.85	.87	.90	.92	.94	.95	.97	.98	1.00	1.02	1.04	1.06	1.08	1.10	45

ζ	0°	10°	15°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	41°	42°	43°	44°	45°	46°	47°	48°	49°	50°	ζ
46°	.72	.73	.74	.77	.78	.79	.80	.82	.83	.85	.87	.89	.91	.94	.95	.97	.98	1.00	1.02	1.04	1.05	1.07	1.10	1.12	44°
47	.73	.74	.76	.78	.79	.80	.81	.83	.84	.86	.88	.90	.93	.95	.97	.98	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.14	43
48	.74	.76	.77	.79	.80	.81	.83	.84	.86	.88	.90	.92	.94	.97	.98	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.16	42
49	.75	.77	.78	.80	.81	.83	.84	.86	.87	.89	.91	.93	.96	.99	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	41
50	.77	.78	.79	.82	.83	.84	.85	.87	.89	.90	.92	.95	.97	1.00	1.01	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.17	1.19	**40**
51	.78	.79	.80	.83	.84	.85	.87	.88	.90	.92	.94	.96	.99	1.01	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.21	39
52	.79	.80	.82	.84	.85	.86	.88	.89	.91	.93	.95	.97	1.90	1.03	1.04	1.06	1.08	1.10	1.11	1.13	1.15	1.18	1.20	1.23	38
53	.80	.81	.83	.85	.86	.87	.89	.91	.92	.94	.96	.99	1.01	1.04	1.06	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.22	1.24	37
54	.81	.82	.84	.86	.87	.89	.90	.92	.93	.95	.98	1.00	1.03	1.06	1.07	1.09	1.11	1.12	1.14	1.16	1.19	1.21	1.23	1.26	36
55	.82	.83	.85	.87	.88	.90	.91	.93	.95	.97	.99	1.01	1.04	1.07	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.25	1.27	35
56	.83	.84	.86	.88	.89	.91	.92	.94	.96	.98	1.00	1.02	1.05	1.08	1.10	1.12	1.13	1.15	1.17	1.19	1.22	1.24	1.26	1.29	34
57	.84	.85	.87	.89	.90	.92	.93	.95	.97	.99	1.01	1.04	1.06	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.28	1.31	33
58	.85	.86	.88	.90	.91	.93	.94	.96	.98	1.00	1.02	1.05	1.08	1.11	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.27	1.29	1.32	32
59	.86	.87	.89	.91	.92	.94	.95	.97	.99	1.01	1.03	1.06	1.09	1.12	1.14	1.15	1.17	1.19	1.21	1.23	1.26	1.28	1.31	1.33	31
60	.87	.88	.90	.92	.93	.95	.96	.98	1.00	1.02	1.04	1.07	1.10	1.13	1.15	1.17	1.18	1.20	1.22	1.25	1.27	1.29	1.32	1.35	**30**
61	.87	.89	.91	.93	.94	.96	.97	.99	1.01	1.03	1.06	1.08	1.11	1.14	1.16	1.18	1.20	1.22	1.24	1.26	1.28	1.31	1.33	1.36	29
62	.88	.90	.91	.94	.95	.97	.98	1.00	1.02	1.04	1.06	1.09	1.12	1.15	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.32	1.35	1.37	28
63	.89	.91	.92	.95	.96	.98	.99	1.01	1.03	1.05	1.07	1.10	1.13	1.16	1.18	1.20	1.22	1.24	1.26	1.28	1.31	1.33	1.36	1.39	27
64	.90	.91	.93	.96	.97	.98	1.00	1.02	1.04	1.06	1.08	1.11	1.14	1.17	1.19	1.21	1.23	1.25	1.27	1.29	1.32	1.34	1.37	1.40	26
65	.91	.92	.94	.96	.98	.99	1.01	1.03	1.05	1.07	1.09	1.12	1.15	1.18	1.20	1.22	1.24	1.26	1.28	1.30	1.33	1.35	1.38	1.41	25
66	.91	.93	.95	.97	.99	1.00	1.02	1.04	1.06	1.08	1.10	1.13	1.16	1.19	1.21	1.23	1.25	1.27	1.29	1.32	1.34	1.37	1.39	1.42	24
67	.92	.94	.95	.98	.99	1.01	1.02	1.04	1.06	1.09	1.11	1.14	1.17	1.20	1.22	1.24	1.26	1.28	1.30	1.33	1.35	1.38	1.40	1.43	23
68	.93	.94	.96	.99	1.00	1.02	1.03	1.05	1.07	1.09	1.12	1.15	1.18	1.21	1.23	1.25	1.27	1.29	1.31	1.33	1.36	1.39	1.41	1.44	22
69	.93	.95	.97	.99	1.01	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.18	1.22	1.24	1.26	1.28	1.30	1.32	1.34	1.37	1.40	1.42	1.45	21
70	.94	.95	.97	1.00	1.01	1.03	1.05	1.06	1.09	1.11	1.13	1.16	1.19	1.23	1.25	1.26	1.28	1.31	1.33	1.35	1.38	1.40	1.43	1.46	**20**
71	.95	.96	.98	1.01	1.02	1.04	1.05	1.07	1.09	1.12	1.14	1.17	1.20	1.23	1.25	1.27	1.29	1.31	1.34	1.36	1.39	1.41	1.44	1.47	19
72	.95	.97	.98	1.01	1.03	1.04	1.06	1.08	1.10	1.12	1.15	1.17	1.21	1.24	1.26	1.28	1.30	1.32	1.34	1.37	1.39	1.42	1.45	1.48	18
73	.96	.97	.99	1.02	1.03	1.05	1.06	1.08	1.10	1.13	1.16	1.18	1.21	1.25	1.27	1.29	1.31	1.33	1.35	1.38	1.40	1.43	1.46	1.49	17
74	.96	.98	1.00	1.02	1.04	1.05	1.07	1.09	1.11	1.13	1.16	1.19	1.22	1.25	1.27	1.29	1.31	1.34	1.36	1.38	1.41	1.44	1.46	1.49	16
75	.97	.98	1.00	1.03	1.04	1.06	1.08	1.09	1.12	1.14	1.16	1.19	1.23	1.26	1.28	1.30	1.32	1.34	1.37	1.39	1.42	1.44	1.47	1.50	15
76	.97	.99	1.00	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.17	1.20	1.23	1.27	1.29	1.31	1.33	1.35	1.37	1.40	1.42	1.45	1.48	1.51	14
77	.97	.99	1.01	1.04	1.05	1.07	1.08	1.10	1.13	1.15	1.17	1.20	1.24	1.27	1.20	1.31	1.33	1.35	1.38	1.40	1.43	1.46	1.48	1.52	13
78	.98	.99	1.01	1.04	1.05	1.07	1.09	1.11	1.13	1.15	1.18	1.21	1.24	1.28	1.30	1.32	1.34	1.36	1.38	1.41	1.43	1.46	1.49	1.52	12
79	.98	1.00	1.02	1.04	1.06	1.08	1.09	1.11	1.13	1.16	1.18	1.21	1.25	1.28	1.30	1.32	1.34	1.36	1.39	1.41	1.44	1.47	1.50	1.53	11
80	.98	1.00	1.02	1.05	1.06	1.08	1.10	1.12	1.14	1.16	1.19	1.22	1.25	1.29	1.30	1.33	1.35	1.37	1.39	1.42	1.44	1.47	1.50	1.53	**10**
81	.99	1.00	1.02	1.05	1.07	1.08	1.10	1.12	1.14	1.17	1.19	1.22	1.25	1.29	1.31	1.33	1.35	1.37	1.40	1.42	1.45	1.48	1.51	1.54	9
82	.99	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.17	1.19	1.22	1.26	1.29	1.31	1.33	1.35	1.38	1.40	1.43	1.45	1.48	1.51	1.54	8
83	.99	1.01	1.03	1.06	1.07	1.09	1.10	1.12	1.15	1.17	1.20	1.23	1.26	1.30	1.32	1.34	1.36	1.38	1.40	1.43	1.46	1.48	1.51	1.54	7
84	.99	1.01	1.03	1.06	1.07	1.09	1.11	1.13	1.15	1.17	1.20	1.23	1.26	1.30	1.32	1.34	1.36	1.38	1.41	1.43	1.46	1.49	1.52	1.55	6
85	1.00	1.01	1.03	1.06	1.07	1.09	1.11	1.13	1.15	1.17	1.20	1.23	1.26	1.30	1.32	1.34	1.36	1.38	1.41	1.43	1.46	1.49	1.52	1.55	5
86	1.00	1.01	1.03	1.06	1.08	1.09	1.11	1.13	1.15	1.18	1.20	1.23	1.27	1.30	1.32	1.34	1.36	1.39	1.41	1.44	1.46	1.49	1.52	1.55	4
87	1.00	1.01	1.03	1.06	1.08	1.09	1.11	1.13	1.15	1.18	1.20	1.23	1.27	1.30	1.32	1.34	1.37	1.39	1.41	1.44	1.46	1.49	1.52	1.55	3
88	1.00	1.01	1.03	1.06	1.08	1.09	1.11	1.13	1.15	1.18	1.20	1.23	1.27	1.30	1.32	1.34	1.37	1.39	1.41	1.44	1.46	1.49	1.52	1.55	2
89	1.00	1.02	1.04	1.06	1.08	1.09	1.11	1.13	1.15	1.18	1.21	1.24	1.27	1.31	1.32	1.35	1.37	1.39	1.41	1.44	1.47	1.49	1.52	1.56	1
90	1.00	1.02	1.04	1.06	1.08	1.09	1.11	1.13	1.15	1.18	1.21	1.24	1.27	1.31	1.32	1.35	1.37	1.39	1.41	1.44	1.47	1.49	1.52	1.56	**0**

For collimation factor C = sec. δ see last or bottom line.

UNITED STATES COAST AND GEODETIC SURVEY.—TABLE OF FACTORS FOR REDUCTION OF TRANSIT OBSERVATIONS—Continued.

Azimuth factor A=sin ζ sec. δ. Star's declination ± δ. Inclination factor B=cos ζ sec. δ.

ζ	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°	60½°	61°	61½°	62°	62½°	63°	63½°	64°	64½°	65°	65½°	66°	66½°	67°	ζ
1°	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	.04	89°
2	.06	.06	.06	.06	.06	.06	.06	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	88
3	.08	.08	.09	.09	.09	.09	.10	.10	.10	.10	.11	.11	.11	.11	.11	.12	.12	.12	.12	.12	.13	.13	.13	.13	87
4	.11	.11	.12	.12	.12	.12	.13	.13	.14	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.17	.17	.17	.18	.18	86
5	.14	.14	.14	.15	.15	.16	.16	.16	.17	.17	.18	.18	.18	.19	.19	.19	.19	.20	.20	.21	.21	.21	.22	.22	85
6	.17	.17	.17	.18	.18	.19	.19	.20	.20	.21	.21	.22	.22	.22	.23	.23	.23	.24	.24	.25	.25	.26	.26	.27	84
7	.19	.20	.20	.21	.21	.22	.22	.23	.24	.24	.25	.25	.26	.26	.26	.27	.27	.28	.28	.29	.29	.30	.31	.31	83
8	.22	.23	.23	.24	.24	.25	.26	.26	.27	.28	.28	.29	.29	.30	.30	.31	.31	.32	.32	.33	.34	.34	.35	.36	82
9	.25	.25	.26	.26	.27	.28	.29	.29	.30	.31	.32	.32	.33	.33	.34	.35	.35	.36	.36	.37	.38	.39	.39	.40	81
10	.28	.28	.29	.30	.30	.31	.32	.33	.34	.35	.35	.36	.36	.37	.38	.38	.39	.40	.40	.41	.42	.43	.43	.44	80
11	.30	.31	.32	.32	.33	.34	.35	.36	.37	.38	.39	.39	.40	.41	.41	.42	.43	.44	.44	.45	.46	.47	.48	.49	79
12	.33	.34	.35	.35	.36	.37	.38	.39	.40	.42	.42	.43	.44	.44	.45	.46	.47	.47	.48	.49	.50	.51	.52	.53	78
13	.36	.36	.37	.38	.39	.40	.41	.42	.44	.45	.46	.46	.47	.48	.49	.50	.50	.51	.52	.53	.54	.55	.56	.58	77
14	.38	.39	.40	.41	.42	.43	.44	.46	.47	.48	.49	.50	.51	.52	.52	.53	.54	.55	.56	.57	.58	.59	.61	.62	76
15	.41	.42	.43	.44	.45	.46	.48	.49	.50	.52	.53	.53	.54	.55	.56	.57	.58	.59	.60	.61	.62	.64	.65	.66	75
16	.44	.45	.46	.47	.48	.49	.51	.52	.54	.55	.56	.57	.58	.59	.60	.61	.62	.63	.64	.65	.66	.68	.69	.71	74
17	.46	.47	.49	.50	.51	.52	.54	.55	.57	.58	.59	.60	.61	.62	.63	.64	.66	.67	.68	.69	.70	.72	.73	.75	73
18	.49	.50	.51	.53	.54	.55	.57	.58	.60	.62	.63	.64	.65	.66	.67	.68	.69	.70	.72	.73	.74	.76	.77	.79	72
19	.52	.53	.54	.55	.57	.58	.60	.61	.63	.65	.66	.67	.68	.69	.70	.72	.73	.74	.76	.77	.78	.80	.82	.83	71
20	.54	.56	.57	.58	.60	.61	.63	.64	.66	.68	.69	.70	.72	.73	.74	.75	.77	.79	.79	.81	.83	.84	.86	.88	70
21	.57	.58	.59	.61	.62	.64	.66	.68	.70	.72	.73	.74	.75	.76	.78	.79	.80	.82	.83	.85	.86	.88	.90	.92	69
22	.60	.61	.62	.64	.65	.67	.69	.71	.73	.75	.76	.77	.78	.80	.81	.82	.84	.85	.87	.89	.90	.92	.94	.96	68
23	.62	.63	.65	.66	.68	.70	.72	.74	.76	.78	.79	.81	.82	.83	.85	.86	.88	.89	.91	.92	.94	.96	.98	1.00	67
24	.65	.66	.68	.69	.71	.73	.75	.77	.79	.81	.83	.84	.85	.87	.88	.90	.91	.93	.94	.96	.98	1.00	1.02	1.04	66
25	.67	.69	.70	.72	.74	.76	.78	.80	.82	.85	.86	.87	.89	.90	.92	.93	.95	.96	.98	1.00	1.02	1.04	1.06	1.08	65
26	.70	.71	.73	.75	.76	.78	.80	.83	.85	.88	.89	.90	.92	.93	.95	.97	.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	64
27	.72	.74	.75	.77	.79	.81	.83	.86	.88	.91	.92	.94	.95	.97	.98	1.00	1.02	1.04	1.05	1.07	1.09	1.12	1.14	1.16	63
28	.75	.76	.78	.80	.82	.84	.86	.89	.91	.94	.95	.97	.98	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.18	1.20	62
29	.77	.79	.81	.82	.84	.87	.89	.91	.94	.97	.98	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.22	1.24	61
30	.79	.81	.83	.85	.87	.89	.92	.94	.97	1.00	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.16	1.18	1.21	1.23	1.25	1.28	60
31	.82	.84	.86	.88	.90	.92	.95	.97	1.00	1.03	1.05	1.06	1.08	1.10	1.11	1.13	1.15	1.17	1.20	1.22	1.24	1.27	1.29	1.32	59
32	.84	.86	.88	.90	.92	.95	.97	1.00	1.03	1.06	1.08	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.33	1.36	58
33	.87	.88	.91	.93	.95	.97	1.00	1.03	1.06	1.09	1.11	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.26	1.29	1.31	1.34	1.37	1.39	57
34	.89	.91	.93	.95	.97	1.00	1.03	1.05	1.09	1.12	1.14	1.15	1.17	1.19	1.21	1.23	1.25	1.27	1.30	1.32	1.35	1.37	1.40	1.43	56
35	.91	.93	.95	.98	1.00	1.03	1.05	1.08	1.11	1.15	1.16	1.18	1.20	1.22	1.24	1.26	1.29	1.31	1.33	1.36	1.38	1.41	1.44	1.47	55
36	.93	.95	.98	1.00	1.03	1.05	1.08	1.11	1.14	1.18	1.19	1.21	1.23	1.25	1.27	1.30	1.32	1.34	1.37	1.39	1.42	1.45	1.47	1.51	54
37	.96	.98	1.00	1.02	1.05	1.08	1.10	1.14	1.17	1.20	1.22	1.24	1.26	1.28	1.30	1.33	1.35	1.37	1.40	1.42	1.45	1.48	1.51	1.54	53
38	.98	1.00	1.02	1.05	1.07	1.10	1.13	1.16	1.20	1.23	1.25	1.27	1.29	1.31	1.33	1.36	1.38	1.40	1.43	1.46	1.48	1.51	1.54	1.58	52
39	1.00	1.02	1.05	1.07	1.10	1.12	1.15	1.19	1.22	1.26	1.28	1.30	1.32	1.34	1.36	1.39	1.41	1.43	1.46	1.49	1.52	1.55	1.58	1.61	51
40	1.02	1.04	1.07	1.09	1.12	1.15	1.18	1.21	1.25	1.29	1.31	1.33	1.35	1.37	1.39	1.42	1.44	1.47	1.49	1.52	1.55	1.58	1.61	1.65	50
41	1.04	1.07	1.09	1.12	1.14	1.17	1.20	1.24	1.27	1.31	1.33	1.35	1.37	1.40	1.42	1.45	1.47	1.50	1.53	1.55	1.58	1.61	1.64	1.68	49
42	1.06	1.09	1.11	1.14	1.17	1.20	1.23	1.26	1.30	1.34	1.36	1.38	1.40	1.42	1.45	1.47	1.50	1.53	1.55	1.58	1.61	1.64	1.68	1.71	48
43	1.08	1.11	1.13	1.16	1.19	1.22	1.25	1.29	1.32	1.36	1.39	1.41	1.43	1.45	1.48	1.50	1.53	1.56	1.58	1.61	1.64	1.68	1.71	1.75	47
44	1.10	1.13	1.15	1.18	1.21	1.24	1.28	1.31	1.35	1.39	1.41	1.43	1.46	1.48	1.50	1.53	1.56	1.58	1.61	1.64	1.67	1.71	1.74	1.78	46
45	1.12	1.15	1.17	1.20	1.23	1.26	1.30	1.33	1.37	1.41	1.44	1.46	1.48	1.51	1.53	1.56	1.58	1.61	1.64	1.67	1.70	1.74	1.77	1.81	45

ζ	51°	52°	53°	54°	55°	56°	57°	58°	59°	60°	60½°	61°	61½°	62°	62½°	63°	63½°	64°	64½°	65°	65½°	66°	66½°	67°	ζ
46°	1.14	1.17	1.19	1.22	1.25	1.29	1.32	1.36	1.40	1.44	1.46	1.48	1.51	1.53	1.56	1.58	1.61	1.64	1.67	1.70	1.74	1.77	1.80	1.84	44°
47	1.16	1.19	1.21	1.24	1.27	1.31	1.34	1.38	1.42	1.46	1.49	1.51	1.53	1.56	1.58	1.61	1.64	1.67	1.70	1.73	1.76	1.80	1.83	1.87	43
48	1.18	1.21	1.23	1.26	1.30	1.33	1.36	1.40	1.44	1.48	1.50	1.53	1.55	1.58	1.60	1.63	1.66	1.69	1.72	1.75	1.79	1.82	1.86	1.90	42
49	1.20	1.23	1.25	1.28	1.32	1.35	1.39	1.42	1.47	1.51	1.53	1.56	1.58	1.61	1.63	1.66	1.69	1.72	1.75	1.79	1.82	1.86	1.89	1.93	41
50	1.22	1.24	1.27	1.30	1.34	1.37	1.41	1.44	1.49	1.53	1.56	1.58	1.60	1.63	1.66	1.69	1.72	1.75	1.78	1.81	1.85	1.88	1.92	1.96	**40**
51	1.23	1.26	1.29	1.32	1.35	1.39	1.43	1.47	1.51	1.55	1.58	1.60	1.63	1.66	1.68	1.71	1.74	1.77	1.80	1.84	1.87	1.91	1.95	1.99	39
52	1.25	1.28	1.31	1.34	1.37	1.41	1.45	1.49	1.53	1.58	1.60	1.63	1.65	1.68	1.71	1.74	1.77	1.80	1.83	1.86	1.90	1.94	1.98	2.02	38
53	1.27	1.30	1.33	1.36	1.39	1.43	1.47	1.51	1.55	1.60	1.62	1.65	1.67	1.70	1.73	1.76	1.79	1.82	1.85	1.89	1.93	1.96	2.00	2.04	37
54	1.29	1.31	1.34	1.38	1.41	1.45	1.49	1.53	1.57	1.62	1.64	1.67	1.69	1.72	1.75	1.78	1.81	1.85	1.88	1.91	1.95	1.99	2.03	2.07	36
55	1.30	1.33	1.36	1.39	1.43	1.46	1.50	1.55	1.59	1.64	1.66	1.69	1.72	1.74	1.77	1.80	1.84	1.87	1.90	1.94	1.98	2.01	2.05	2.10	35
56	1.32	1.35	1.38	1.41	1.45	1.48	1.52	1.56	1.61	1.66	1.68	1.71	1.74	1.77	1.80	1.83	1.86	1.89	1.93	1.96	2.00	2.04	2.08	2.12	34
57	1.33	1.36	1.39	1.43	1.46	1.50	1.54	1.58	1.63	1.68	1.70	1.73	1.76	1.79	1.82	1.85	1.88	1.91	1.95	1.98	2.02	2.06	2.10	2.15	33
58	1.35	1.38	1.41	1.44	1.48	1.52	1.56	1.60	1.65	1.70	1.72	1.75	1.78	1.81	1.84	1.87	1.90	1.93	1.97	2.01	2.05	2.08	2.13	2.17	32
59	1.36	1.39	1.42	1.46	1.49	1.53	1.57	1.62	1.66	1.71	1.74	1.77	1.80	1.83	1.86	1.89	1.92	1.95	1.99	2.03	2.07	2.11	2.15	2.19	31
60	1.38	1.41	1.44	1.47	1.51	1.55	1.59	1.63	1.68	1.73	1.76	1.79	1.81	1.84	1.88	1.91	1.94	1.97	2.01	2.05	2.09	2.13	2.17	2.22	**30**
61	1.39	1.42	1.45	1.49	1.53	1.56	1.61	1.65	1.70	1.75	1.78	1.80	1.83	1.86	1.89	1.93	1.96	2.00	2.03	2.07	2.11	2.15	2.19	2.24	29
62	1.40	1.43	1.47	1.50	1.54	1.58	1.62	1.67	1.71	1.77	1.79	1.82	1.85	1.88	1.91	1.94	1.98	2.01	2.05	2.09	2.13	2.17	2.21	2.26	28
63	1.42	1.45	1.48	1.52	1.55	1.59	1.64	1.68	1.73	1.78	1.81	1.84	1.87	1.90	1.93	1.96	2.00	2.03	2.07	2.11	2.15	2.19	2.23	2.28	27
64	1.43	1.46	1.49	1.53	1.57	1.61	1.65	1.70	1.75	1.80	1.83	1.85	1.88	1.91	1.95	1.98	2.02	2.05	2.09	2.13	2.17	2.21	2.25	2.30	26
65	1.44	1.47	1.51	1.54	1.58	1.62	1.66	1.71	1.76	1.81	1.84	1.87	1.90	1.93	1.96	2.00	2.03	2.07	2.11	2.14	2.19	2.23	2.27	2.32	25
66	1.45	1.48	1.52	1.55	1.59	1.63	1.68	1.72	1.77	1.83	1.85	1.88	1.91	1.95	1.98	2.01	2.05	2.08	2.12	2.16	2.20	2.25	2.29	2.34	24
67	1.46	1.50	1.53	1.57	1.60	1.65	1.69	1.74	1.79	1.84	1.87	1.90	1.93	1.96	1.99	2.03	2.06	2.10	2.14	2.18	2.22	2.26	2.31	2.36	23
68	1.47	1.51	1.54	1.58	1.62	1.66	1.70	1.75	1.80	1.85	1.88	1.91	1.94	1.97	2.01	2.04	2.08	2.11	2.15	2.19	2.24	2.28	2.32	2.37	22
69	1.48	1.52	1.55	1.59	1.63	1.67	1.71	1.76	1.81	1.87	1.90	1.93	1.96	1.99	2.02	2.06	2.09	2.13	2.17	2.21	2.25	2.30	2.34	2.39	21
70	1.49	1.53	1.56	1.60	1.64	1.68	1.73	1.77	1.82	1.88	1.91	1.94	1.97	2.00	2.03	2.07	2.11	2.14	2.18	2.22	2.27	2.31	2.36	2.40	**20**
71	1.50	1.54	1.57	1.61	1.65	1.69	1.74	1.78	1.84	1.89	1.92	1.95	1.98	2.01	2.05	2.08	2.12	2.16	2.20	2.24	2.28	2.32	2.37	2.42	19
72	1.51	1.54	1.58	1.62	1.66	1.70	1.75	1.80	1.85	1.90	1.93	1.96	1.99	2.03	2.06	2.09	2.13	2.17	2.21	2.25	2.29	2.34	2.38	2.43	18
73	1.52	1.55	1.59	1.63	1.67	1.71	1.76	1.80	1.86	1.91	1.94	1.97	2.00	2.04	2.07	2.11	2.14	2.18	2.22	2.26	2.31	2.35	2.40	2.45	17
74	1.53	1.56	1.60	1.63	1.68	1.72	1.76	1.81	1.87	1.92	1.95	1.98	2.01	2.05	2.08	2.12	2.15	2.19	2.23	2.27	2.32	2.36	2.41	2.46	16
75	1.53	1.57	1.60	1.64	1.68	1.73	1.77	1.82	1.88	1.93	1.96	1.99	2.02	2.06	2.09	2.13	2.16	2.20	2.24	2.29	2.33	2.37	2.42	2.47	15
76	1.54	1.58	1.61	1.65	1.69	1.73	1.78	1.83	1.88	1.94	1.97	2.00	2.03	2.07	2.10	2.14	2.17	2.21	2.25	2.30	2.34	2.39	2.43	2.48	14
77	1.55	1.58	1.62	1.66	1.70	1.74	1.79	1.84	1.89	1.95	1.98	2.01	2.04	2.07	2.11	2.15	2.18	2.22	2.26	2.31	2.35	2.40	2.44	2.49	13
78	1.55	1.59	1.62	1.66	1.70	1.75	1.80	1.85	1.90	1.96	1.99	2.02	2.05	2.08	2.12	2.15	2.19	2.23	2.27	2.31	2.36	2.40	2.45	2.50	12
79	1.56	1.59	1.63	1.67	1.71	1.76	1.80	1.85	1.91	1.96	1.99	2.02	2.06	2.09	2.13	2.16	2.20	2.24	2.28	2.32	2.37	2.41	2.46	2.51	11
80	1.56	1.60	1.64	1.67	1.72	1.76	1.81	1.86	1.91	1.97	2.00	2.03	2.06	2.10	2.13	2.17	2.21	2.25	2.29	2.33	2.38	2.42	2.47	2.52	**10**
81	1.57	1.60	1.64	1.68	1.72	1.77	1.81	1.86	1.92	1.98	2.01	2.04	2.07	2.10	2.14	2.18	2.21	2.25	2.29	2.34	2.38	2.43	2.48	2.53	9
82	1.57	1.61	1.64	1.68	1.73	1.77	1.82	1.87	1.92	1.98	2.01	2.04	2.08	2.11	2.15	2.18	2.22	2.26	2.30	2.34	2.39	2.43	2.48	2.53	8
83	1.58	1.61	1.65	1.69	1.73	1.77	1.82	1.87	1.93	1.99	2.02	2.05	2.08	2.12	2.15	2.19	2.22	2.26	2.31	2.35	2.39	2.44	2.49	2.54	7
84	1.58	1.62	1.65	1.69	1.73	1.78	1.83	1.88	1.93	1.99	2.02	2.05	2.08	2.12	2.15	2.19	2.23	2.27	2.31	2.35	2.40	2.45	2.49	2.55	6
85	1.58	1.62	1.65	1.69	1.74	1.78	1.83	1.88	1.93	1.99	2.02	2.05	2.09	2.12	2.16	2.19	2.23	2.27	2.31	2.36	2.40	2.45	2.50	2.55	5
86	1.59	1.62	1.66	1.70	1.74	1.78	1.83	1.88	1.94	2.00	2.03	2.06	2.09	2.13	2.16	2.20	2.24	2.28	2.32	2.36	2.41	2.45	2.50	2.55	4
87	1.59	1.62	1.66	1.70	1.74	1.79	1.83	1.88	1.94	2.00	2.03	2.06	2.09	2.13	2.16	2.20	2.24	2.28	2.32	2.36	2.41	2.46	2.50	2.56	3
88	1.59	1.62	1.66	1.70	1.74	1.79	1.83	1.89	1.94	2.00	2.03	2.06	2.09	2.13	2.16	2.20	2.24	2.28	2.32	2.36	2.41	2.46	2.51	2.56	2
89	1.59	1.62	1.66	1.70	1.74	1.79	1.84	1.89	1.94	2.00	2.03	2.06	2.10	2.13	2.17	2.20	2.24	2.28	2.32	2.37	2.41	2.46	2.51	2.56	1
90	1.59	1.62	1.66	1.70	1.74	1.79	1.84	1.89	1.94	2.00	2.03	2.06	2.10	2.13	2.17	2.20	2.24	2.28	2.32	2.37	2.41	2.46	2.51	2.56	**0**

For collimation factor = sec. δ see last or bottom line.

UNITED STATES COAST AND GEODETIC SURVEY.—TABLE OF FACTORS FOR REDUCTION OF TRANSIT OBSERVATIONS—Continued.

Azimuth factor A = sin ζ sec. δ. Star's declination ± δ. Inclination factor B = cos ζ sec. δ.

ζ	67½°	68°	68½°	69°	69½°	70°	70¼°	70½°	70¾°	71°	71¼°	71½°	71¾°	72°	72¼°	72½°	72¾°	73°	73¼°	73½°	73¾°	74°	74¼°	ζ
1°	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	89°
2	.09	.09	.10	.10	.10	.10	.10	.10	.11	.11	.11	.11	.11	.11	.11	.12	.12	.12	.12	.12	.12	.13	.13	88
3	.14	.14	.14	.15	.15	.15	.15	.16	.16	.16	.16	.16	.17	.17	.17	.17	.18	.18	.18	.18	.19	.19	.19	87
4	.18	.19	.19	.20	.20	.20	.21	.21	.21	.21	.22	.22	.22	.23	.23	.23	.23	.24	.24	.24	.25	.25	.26	86
5	.23	.23	.24	.24	.25	.25	.26	.26	.26	.27	.27	.27	.28	.28	.29	.29	.29	.30	.30	.31	.31	.32	.32	85
6	.27	.28	.28	.29	.30	.31	.31	.31	.32	.32	.33	.33	.33	.34	.34	.35	.35	.36	.36	.37	.37	.38	.39	84
7	.32	.33	.33	.34	.35	.36	.36	.37	.37	.37	.38	.38	.39	.39	.40	.41	.41	.42	.42	.43	.44	.44	.45	83
8	.36	.37	.38	.39	.40	.41	.41	.42	.42	.43	.43	.44	.44	.45	.46	.46	.47	.48	.48	.49	.50	.50	.51	82
9	.41	.42	.43	.44	.45	.46	.46	.47	.47	.48	.49	.49	.50	.51	.51	.52	.53	.53	.54	.55	.56	.57	.58	81
10	.45	.46	.47	.49	.50	.61	.51	.52	.53	.53	.54	.55	.55	.56	.57	.58	.59	.60	.00	.01	.62	.63	.64	80
11	.50	.51	.52	.53	.54	.56	.56	.57	.58	.59	.59	.60	.61	.62	.63	.63	.64	.65	.66	.67	.68	.69	.70	79
12	.54	.56	.57	.58	.59	.61	.62	.62	.63	.64	.65	.66	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75	.77	78
13	.59	.60	.61	.63	.64	.66	.67	.67	.68	.69	.70	.71	.72	.73	.74	.75	.76	.77	.78	.79	.80	.82	.83	77
14	.63	.65	.66	.68	.69	.71	.72	.72	.73	.74	.75	.76	.77	.78	.79	.80	.82	.83	.84	.85	.87	.88	.89	76
15	.68	.69	.71	.72	.74	.76	.77	.78	.78	.79	.80	.81	.83	.84	.85	.86	.87	.89	.90	.91	.93	.94	.95	75
16	.72	.74	.75	.77	.79	.81	.82	.83	.84	.85	.86	.87	.88	.89	.91	.92	.93	.94	.96	.97	.99	1.00	1.02	74
17	.76	.78	.80	.81	.83	.85	.86	.88	.89	.90	.91	.92	.93	.95	.96	.97	.99	1.00	1.01	1.03	1.05	1.06	1.08	73
18	.81	.83	.84	.86	.88	.90	.91	.93	.94	.95	.96	.97	.99	1.00	1.01	1.03	1.04	1.06	1.07	1.09	1.10	1.12	1.14	72
19	.85	.87	.89	.91	.93	.95	.96	.98	.99	1.00	1.01	1.03	1.04	1.05	1.07	1.08	1.10	1.11	1.13	1.15	1.16	1.18	1.20	71
20	.89	.91	.93	.95	.98	1.00	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12	1.14	1.15	1.17	1.19	1.20	1.22	1.24	1.26	70
21	.94	.96	.98	1.00	1.02	1.05	1.06	1.07	1.09	1.10	1.11	1.13	1.14	1.16	1.17	1.19	1.21	1.22	1.24	1.26	1.28	1.30	1.32	69
22	.98	1.00	1.02	1.05	1.07	1.09	1.11	1.12	1.14	1.15	1.17	1.18	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	68
23	1.02	1.04	1.07	1.09	1.12	1.14	1.16	1.17	1.19	1.20	1.21	1.23	1.25	1.26	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	67
24	1.06	1.09	1.11	1.14	1.16	1.19	1.20	1.22	1.23	1.25	1.27	1.28	1.30	1.32	1.33	1.35	1.37	1.39	1.41	1.43	1.45	1.48	1.50	66
25	1.10	1.13	1.15	1.18	1.21	1.24	1.25	1.27	1.28	1.30	1.31	1.33	1.35	1.37	1.39	1.41	1.42	1.45	1.47	1.49	1.51	1.53	1.56	65
26	1.15	1.17	1.20	1.22	1.25	1.28	1.30	1.31	1.33	1.35	1.36	1.38	1.40	1.42	1.44	1.46	1.48	1.50	1.52	1.54	1.57	1.59	1.61	64
27	1.19	1.21	1.24	1.27	1.30	1.33	1.34	1.36	1.38	1.39	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.58	1.60	1.62	1.65	1.67	63
28	1.23	1.25	1.28	1.31	1.34	1.37	1.39	1.41	1.42	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.63	1.65	1.68	1.70	1.73	62
29	1.27	1.29	1.32	1.35	1.38	1.42	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.57	1.59	1.61	1.63	1.66	1.68	1.71	1.73	1.76	1.79	61
30	1.31	1.33	1.36	1.39	1.43	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.69	1.71	1.73	1.76	1.79	1.81	1.84	60
31	1.35	1.38	1.40	1.44	1.47	1.51	1.52	1.54	1.56	1.58	1.60	1.62	1.64	1.67	1.69	1.71	1.74	1.76	1.79	1.81	1.84	1.87	1.90	59
32	1.39	1.42	1.45	1.48	1.51	1.55	1.57	1.59	1.61	1.63	1.65	1.67	1.69	1.71	1.74	1.76	1.79	1.81	1.84	1.87	1.89	1.92	1.95	58
33	1.42	1.45	1.49	1.52	1.55	1.59	1.61	1.63	1.65	1.67	1.69	1.72	1.74	1.76	1.79	1.81	1.84	1.86	1.89	1.92	1.95	1.98	2.01	57
34	1.46	1.49	1.53	1.56	1.60	1.63	1.65	1.68	1.70	1.72	1.74	1.76	1.79	1.81	1.83	1.86	1.89	1.91	1.94	1.97	2.00	2.03	2.06	56
35	1.50	1.53	1.56	1.60	1.64	1.68	1.70	1.72	1.74	1.76	1.78	1.81	1.83	1.86	1.88	1.91	1.93	1.96	1.99	2.02	2.05	2.08	2.11	55
36	1.54	1.57	1.60	1.64	1.68	1.72	1.74	1.76	1.78	1.80	1.83	1.85	1.88	1.90	1.93	1.95	1.98	2.01	2.04	2.07	2.10	2.13	2.16	54
37	1.57	1.61	1.64	1.68	1.72	1.76	1.78	1.80	1.83	1.85	1.87	1.90	1.92	1.95	1.97	2.00	2.03	2.06	2.09	2.12	2.15	2.18	2.22	53
38	1.61	1.64	1.68	1.72	1.76	1.80	1.82	1.84	1.87	1.89	1.91	1.94	1.97	1.99	2.02	2.05	2.08	2.11	2.14	2.17	2.20	2.23	2.27	52
39	1.65	1.68	1.72	1.75	1.80	1.84	1.86	1.88	1.91	1.93	1.96	1.98	2.01	2.04	2.06	2.09	2.12	2.15	2.18	2.22	2.25	2.28	2.32	51
40	1.68	1.72	1.75	1.79	1.84	1.88	1.90	1.93	1.95	1.97	2.00	2.03	2.05	2.08	2.11	2.14	2.17	2.20	2.23	2.26	2.30	2.33	2.37	50
41	1.71	1.75	1.79	1.83	1.87	1.92	1.94	1.96	1.99	2.01	2.04	2.07	2.09	2.12	2.15	2.18	2.21	2.24	2.28	2.31	2.34	2.38	2.42	49
42	1.75	1.79	1.83	1.87	1.91	1.96	1.98	2.00	2.03	2.05	2.08	2.11	2.14	2.16	2.19	2.22	2.26	2.29	2.32	2.36	2.39	2.43	2.46	48
43	1.78	1.82	1.86	1.90	1.95	1.99	2.02	2.04	2.07	2.09	2.12	2.15	2.18	2.21	2.24	2.27	2.30	2.33	2.37	2.40	2.44	2.47	2.51	47
44	1.82	1.85	1.90	1.94	1.98	2.03	2.06	2.08	2.11	2.13	2.16	2.19	2.22	2.25	2.28	2.31	2.34	2.38	2.41	2.45	2.48	2.52	2.56	46
45	1.85	1.89	1.93	1.97	2.02	2.07	2.09	2.12	2.14	2.17	2.20	2.23	2.26	2.29	2.32	2.35	2.38	2.42	2.45	2.49	2.53	2.56	2.60	45

S. Ex. 12——29

ζ	67½°	68°	68½°	69°	69½°	70°	70¼°	70½°	70¾°	71°	71¼°	71½°	71¾°	72°	72¼°	72½°	72¾°	73°	73¼°	73½°	73¾°	74°	74¼°	ζ
46°	1.88	1.92	1.96	2.01	2.05	2.10	2.13	2.15	2.18	2.21	2.24	2.27	2.30	2.33	2.36	2.39	2.42	2.46	2.49	2.53	2.57	2.61	2.65	44°
47	1.91	1.95	2.00	2.04	2.09	2.14	2.16	2.19	2.22	2.25	2.27	2.30	2.33	2.37	2.40	2.43	2.47	2.50	2.54	2.57	2.61	2.65	2.69	43
48	1.94	1.98	2.02	2.07	2.12	2.17	2.19	2.22	2.25	2.28	2.31	2.34	2.37	2.40	2.44	2.47	2.51	2.54	2.58	2.62	2.66	2.70	2.74	42
49	1.97	2.01	2.06	2.11	2.16	2.21	2.23	2.26	2.29	2.32	2.35	2.38	2.41	2.44	2.48	2.51	2.55	2.58	2.62	2.66	2.70	2.74	2.78	41
50	2.00	2.04	2.09	2.14	2.19	2.24	2.27	2.29	2.32	2.35	2.38	2.41	2.45	2.48	2.51	2.55	2.58	2.62	2.66	2.70	2.74	2.78	2.82	**40**
51	2.03	2.07	2.12	2.17	2.22	2.27	2.30	2.33	2.36	2.39	2.42	2.45	2.48	2.51	2.55	2.58	2.62	2.66	2.70	2.74	2.78	2.82	2.86	39
52	2.06	2.10	2.15	2.20	2.25	2.30	2.33	2.36	2.39	2.42	2.45	2.48	2.52	2.55	2.58	2.62	2.66	2.69	2.73	2.77	2.82	2.86	2.90	38
53	2.09	2.13	2.18	2.23	2.28	2.33	2.36	2.39	2.42	2.45	2.48	2.52	2.55	2.58	2.62	2.66	2.69	2.73	2.77	2.81	2.85	2.90	2.94	37
54	2.11	2.16	2.21	2.26	2.31	2.37	2.39	2.42	2.45	2.48	2.52	2.55	2.58	2.62	2.65	2.69	2.73	2.77	2.81	2.85	2.89	2.94	2.98	36
55	2.14	2.19	2.23	2.29	2.34	2.40	2.42	2.45	2.48	2.52	2.55	2.58	2.62	2.65	2.69	2.72	2.76	2.80	2.84	2.88	2.93	2.97	3.02	35
56	2.17	2.21	2.26	2.31	2.37	2.42	2.45	2.48	2.51	2.55	2.58	2.61	2.65	2.68	2.72	2.76	2.80	2.84	2.88	2.92	2.96	3.01	3.05	34
57	2.19	2.24	2.29	2.34	2.39	2.45	2.48	2.51	2.54	2.58	2.61	2.64	2.68	2.71	2.75	2.79	2.83	2.87	2.91	2.95	3.00	3.04	3.09	33
58	2.22	2.26	2.31	2.37	2.42	2.48	2.51	2.54	2.57	2.61	2.64	2.67	2.71	2.74	2.78	2.82	2.86	2.90	2.94	2.99	3.03	3.08	3.12	32
59	2.24	2.29	2.34	2.39	2.45	2.51	2.54	2.57	2.60	2.63	2.67	2.70	2.74	2.77	2.81	2.85	2.89	2.93	2.97	3.02	3.06	3.11	3.16	31
60	2.26	2.31	2.36	2.42	2.47	2.53	2.56	2.59	2.63	2.66	2.69	2.73	2.76	2.80	2.84	2.88	2.92	2.96	3.01	3.05	3.09	3.14	3.19	**30**
61	2.29	2.33	2.39	2.44	2.50	2.56	2.59	2.62	2.65	2.69	2.72	2.76	2.79	2.83	2.87	2.91	2.95	2.99	3.04	3.08	3.13	3.17	3.22	29
62	2.31	2.36	2.41	2.46	2.52	2.58	2.61	2.64	2.68	2.71	2.75	2.78	2.82	2.86	2.90	2.94	2.98	3.02	3.06	3.11	3.16	3.20	3.25	28
63	2.33	2.38	2.43	2.49	2.54	2.60	2.64	2.67	2.70	2.74	2.77	2.81	2.84	2.88	2.92	2.96	3.00	3.05	3.09	3.14	3.18	3.23	3.28	27
64	2.35	2.40	2.45	2.51	2.57	2.63	2.66	2.69	2.73	2.76	2.80	2.83	2.87	2.91	2.95	2.99	3.03	3.07	3.12	3.16	3.21	3.26	3.31	26
65	2.37	2.42	2.47	2.53	2.59	2.65	2.68	2.71	2.75	2.78	2.82	2.86	2.89	2.93	2.97	3.01	3.06	3.10	3.14	3.19	3.24	3.29	3.34	25
66	2.39	2.44	2.49	2.55	2.61	2.67	2.70	2.74	2.77	2.81	2.84	2.88	2.92	2.96	3.00	3.04	3.08	3.13	3.17	3.22	3.27	3.31	3.37	24
67	2.41	2.46	2.51	2.57	2.63	2.69	2.72	2.76	2.79	2.83	2.86	2.90	2.94	2.98	3.02	3.06	3.10	3.15	3.20	3.24	3.29	3.34	3.39	23
68	2.42	2.47	2.53	2.59	2.65	2.71	2.74	2.78	2.81	2.85	2.88	2.92	2.96	3.00	3.04	3.08	3.13	3.17	3.22	3.26	3.31	3.36	3.42	22
69	2.44	2.49	2.55	2.61	2.67	2.73	2.76	2.80	2.83	2.87	2.90	2.94	2.98	3.02	3.06	3.10	3.15	3.19	3.24	3.29	3.34	3.39	3.44	21
70	2.46	2.51	2.56	2.62	2.68	2.75	2.78	2.81	2.85	2.89	2.92	2.96	3.00	3.04	3.08	3.12	3.17	3.21	3.25	3.31	3.36	3.41	3.46	**20**
71	2.47	2.52	2.58	2.64	2.70	2.77	2.80	2.83	2.87	2.90	2.94	2.98	3.02	3.06	3.10	3.14	3.19	3.24	3.28	3.33	3.38	3.43	3.48	19
72	2.49	2.54	2.59	2.65	2.72	2.78	2.81	2.85	2.88	2.92	2.96	3.00	3.04	3.08	3.12	3.16	3.21	3.25	3.30	3.35	3.40	3.45	3.50	18
73	2.50	2.55	2.61	2.67	2.73	2.80	2.83	2.86	2.90	2.94	2.97	3.01	3.05	3.09	3.14	3.18	3.22	3.27	3.32	3.37	3.42	3.47	3.52	17
74	2.51	2.57	2.62	2.68	2.74	2.81	2.84	2.88	2.92	2.95	2.99	3.03	3.07	3.11	3.15	3.20	3.24	3.29	3.33	3.38	3.44	3.49	3.54	16
75	2.52	2.58	2.64	2.70	2.76	2.82	2.86	2.89	2.93	2.97	3.00	3.04	3.08	3.13	3.17	3.21	3.26	3.30	3.35	3.40	3.45	3.50	3.56	15
76	2.54	2.59	2.65	2.71	2.77	2.84	2.87	2.91	2.95	2.99	3.02	3.06	3.10	3.15	3.18	3.23	3.28	3.32	3.37	3.42	3.47	3.53	3.58	14
77	2.55	2.60	2.66	2.72	2.78	2.85	2.88	2.92	2.95	2.99	3.03	3.07	3.11	3.15	3.19	3.24	3.29	3.33	3.38	3.43	3.48	3.54	3.59	13
78	2.56	2.61	2.67	2.73	2.79	2.86	2.89	2.93	2.97	3.00	3.04	3.08	3.12	3.16	3.21	3.25	3.30	3.34	3.39	3.44	3.49	3.55	3.60	12
79	2.57	2.62	2.68	2.74	2.80	2.87	2.91	2.94	2.98	3.02	3.05	3.09	3.13	3.18	3.22	3.26	3.31	3.36	3.41	3.46	3.51	3.56	3.62	11
80	2.57	2.63	2.69	2.75	2.81	2.88	2.91	2.95	2.99	3.02	3.06	3.10	3.14	3.19	3.23	3.27	3.32	3.37	3.42	3.47	3.52	3.57	3.63	**10**
81	2.58	2.64	2.69	2.76	2.82	2.89	2.92	2.96	3.00	3.03	3.07	3.11	3.15	3.20	3.24	3.28	3.33	3.38	3.43	3.48	3.53	3.58	3.64	9
82	2.59	2.64	2.70	2.76	2.83	2.90	2.93	2.97	3.00	3.04	3.08	3.12	3.16	3.20	3.25	3.29	3.34	3.39	3.44	3.49	3.54	3.59	3.65	8
83	2.59	2.65	2.71	2.77	2.83	2.90	2.94	2.97	3.01	3.05	3.09	3.13	3.17	3.21	3.26	3.30	3.35	3.40	3.45	3.49	3.55	3.60	3.66	7
84	2.60	2.66	2.71	2.78	2.84	2.91	2.94	2.98	3.02	3.06	3.09	3.13	3.18	3.22	3.26	3.31	3.35	3.40	3.45	3.50	3.55	3.61	3.66	6
85	2.60	2.66	2.72	2.78	2.84	2.91	2.95	2.98	3.02	3.06	3.10	3.14	3.18	3.22	3.27	3.31	3.36	3.41	3.46	3.51	3.56	3.61	3.67	5
86	2.61	2.66	2.72	2.78	2.85	2.92	2.95	2.99	3.03	3.06	3.10	3.14	3.19	3.23	3.27	3.32	3.36	3.41	3.46	3.51	3.57	3.62	3.68	4
87	2.61	2.67	2.72	2.79	2.85	2.92	2.95	2.99	3.03	3.07	3.11	3.15	3.19	3.23	3.28	3.32	3.37	3.42	3.47	3.52	3.57	3.62	3.68	3
88	2.61	2.67	2.73	2.79	2.85	2.92	2.96	2.99	3.03	3.07	3.11	3.15	3.19	3.23	3.28	3.32	3.37	3.42	3.47	3.52	3.57	3.62	3.68	2
89	2.61	2.67	2.73	2.79	2.86	2.92	2.96	3.00	3.03	3.07	3.11	3.15	3.19	3.24	3.28	3.33	3.37	3.42	3.47	3.52	3.57	3.63	3.68	1
90	2.61	2.67	2.73	2.79	2.86	2.92	2.96	3.00	3.03	3.07	3.11	3.15	3.19	3.24	3.28	3.33	3.37	3.42	3.47	3.52	3.57	3.63	3.68	**0**

For collimation factor C = sec. δ see last or bottom line.

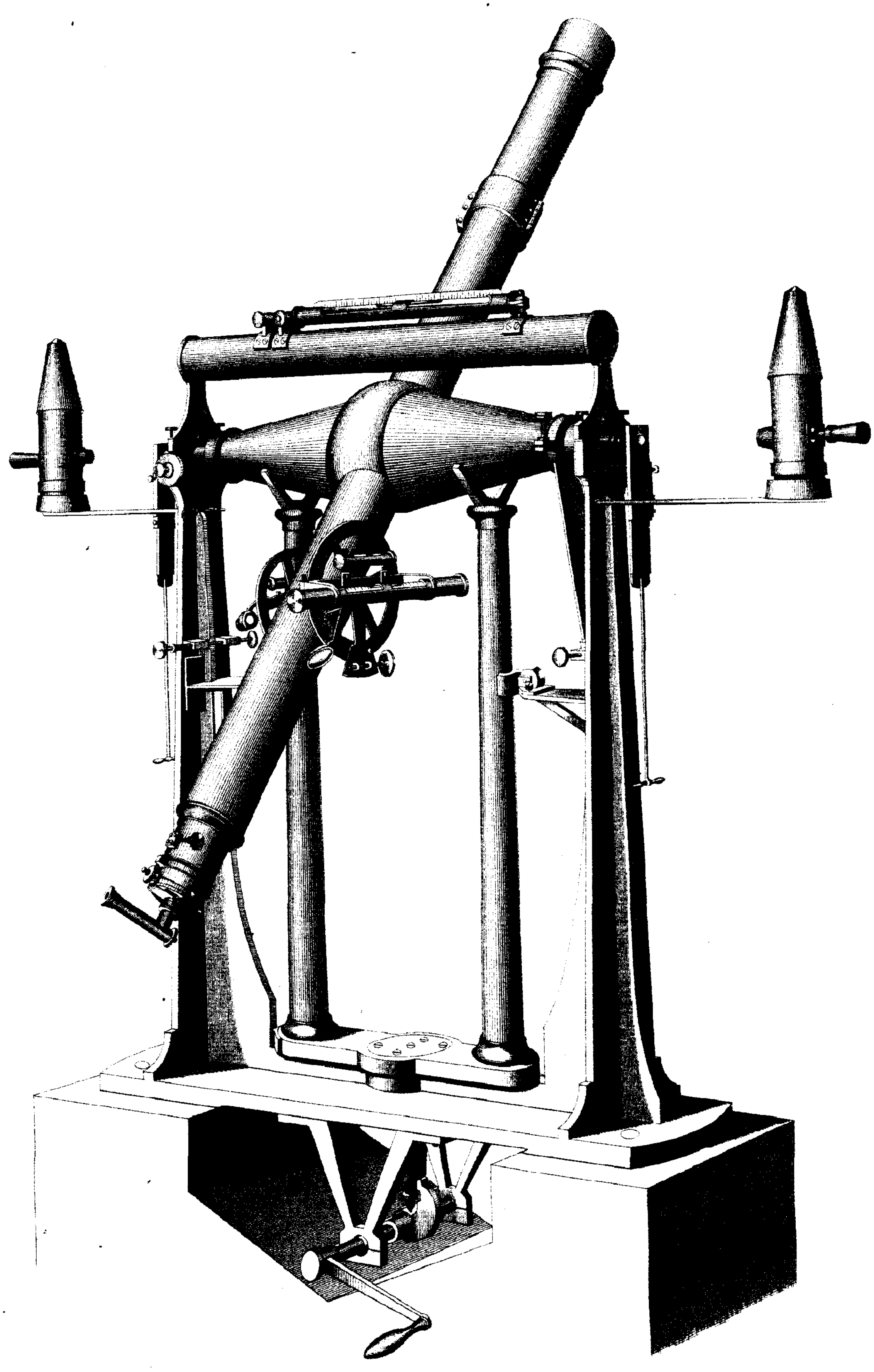
UNITED STATES COAST AND GEODETIC SURVEY.—TABLE OF FACTORS FOR REDUCTION OF TRANSIT OBSERVATIONS—Continued.

Azimuth factor A = sin ζ sec. δ. Star's declination ± δ. Inclination factor B = cos ζ sec. δ.

ζ	74½°	74¾°	75°	75¼°	75½°	75¾°	76°	76¼°	76½°	76¾°	77°	77¼°	77½°	77¾°	78°	78¼°	78½°	78¾°	79°	79¼°	79½°	79¾°	80°	ζ
1°	.06	.07	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.10	.10	.10	89°
2	.13	.13	.13	.14	.14	.14	.14	.15	.15	.15	.16	.16	.16	.16	.17	.17	.18	.18	.18	.19	.19	.20	.20	88
3	.20	.20	.20	.21	.21	.21	.22	.22	.22	.23	.23	.24	.24	.25	.25	.26	.26	.27	.27	.28	.29	.29	.30	87
4	.20	.27	.27	.27	.28	.28	.29	.29	.30	.30	.31	.32	.32	.33	.34	.34	.35	.36	.37	.37	.38	.39	.40	86
5	.33	.33	.34	.34	.35	.35	.36	.37	.37	.38	.39	.40	.40	.41	.42	.43	.44	.45	.46	.47	.48	.49	.50	85
6	.39	.40	.40	.41	.42	.42	.43	.44	.45	.46	.46	.47	.49	.49	.51	.51	.52	.54	.55	.56	.57	.59	.60	84
7	.46	.46	.47	.48	.49	.50	.50	.51	.52	.53	.54	.55	.56	.57	.59	.60	.61	.62	.64	.65	.67	.69	.70	83
8	.52	.53	.54	.55	.56	.57	.58	.59	.60	.61	.62	.63	.64	.66	.67	.68	.70	.71	.73	.75	.76	.78	.80	82
9	.58	.59	.60	.61	.62	.64	.65	.66	.67	.68	.70	.71	.72	.74	.75	.77	.78	.80	.82	.84	.86	.88	.90	81
10	.65	.66	67	.68	.69	.71	.72	.73	.74	.76	.77	.79	.80	.82	.84	.85	.87	.89	.91	.93	.95	.98	1.00	**80**
11	.71	.73	.74	.75	.76	.77	.79	.80	.82	.83	.85	.86	.88	.90	.92	.94	.96	.98	1.00	1.02	1.05	1.07	1.10	79
12	.78	.79	.80	.82	.83	.85	.86	.88	.89	.91	.92	.94	.96	.98	1.00	1.02	1.04	1.07	1.09	1.11	1.14	1.17	1.20	78
13	.84	.86	.87	.88	.90	.91	.93	.95	.96	.98	1.00	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.18	1.21	1.23	1.26	1.30	77
14	.91	.92	.94	.95	.97	.98	1.00	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.19	1.21	1.24	1.27	1.30	1.33	1.36	1.39	76
15	.97	.98	1.00	1.02	1.03	1.05	1.07	1.09	1.11	1.13	1.15	1.17	1.20	1.22	1.25	1.27	1.30	1.33	1.36	1.39	1.42	1.46	1.49	75
16	1.03	1.05	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.23	1.25	1.28	1.30	1.33	1.35	1.38	1.41	1.44	1.48	1.51	1.55	1.59	74
17	1.09	1.11	1.13	1.15	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.32	1.35	1.38	1.40	1.44	1.47	1.50	1.53	1.57	1.60	1.64	1.68	73
18	1.16	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.32	1.35	1.37	1.40	1.43	1.46	1.49	1.52	1.55	1.58	1.62	1.66	1.70	1.74	1.78	72
19	1.22	1.24	1.26	1.28	1.30	1.32	1.35	1.37	1.39	1.42	1.45	1.47	1.51	1.53	1.57	1.60	1.63	1.67	1.71	1.75	1.79	1.83	1.87	71
20	1.28	1.30	1.32	1.34	1.37	1.39	1.41	1.44	1.46	1.49	1.52	1.55	1.58	1.61	1.65	1.68	1.72	1.75	1.79	1.83	1.88	1.92	1.97	**70**
21	1.34	1.36	1.38	1.41	1.43	1.46	1.48	1.51	1.54	1.56	1.59	1.62	1.65	1.69	1.72	1.76	1.80	1.84	1.88	1.92	1.97	2.01	2.06	69
22	1.40	1.42	1.45	1.47	1.50	1.52	1.55	1.58	1.60	1.63	1.66	1.70	1.73	1.77	1.80	1.84	1.88	1.92	1.96	2.01	2.06	2.11	2.16	68
23	1.46	1.49	1.51	1.54	1.56	1.59	1.62	1.64	1.67	1.70	1.74	1.77	1.81	1.84	1.88	1.92	1.96	2.00	2.05	2.09	2.14	2.20	2.25	67
24	1.52	1.55	1.57	1.60	1.63	1.65	1.68	1.71	1.74	1.77	1.81	1.84	1.88	1.92	1.96	2.00	2.04	2.08	2.13	2.18	2.23	2.29	2.34	66
25	1.58	1.61	1.63	1.66	1.69	1.72	1.75	1.78	1.81	1.84	1.88	1.91	1.95	1.99	2.0	2.07	2.12	2.17	2.22	2.27	2.32	2.38	2.43	65
26	1.64	1.67	1.69	1.72	1.75	1.78	1.81	1.84	1.88	1.91	1.95	1.99	2.02	2.07	2.11	2.15	2.20	2.25	2.30	2.35	2.41	2.46	2.52	64
27	1.70	1.73	1.75	1.78	1.81	1.85	1.88	1.91	1.95	1.98	2.02	2.06	2.10	2.14	2.18	2.23	2.28	2.33	2.38	2.43	2.49	2.55	2.61	63
28	1.76	1.78	1.81	1.84	1.87	1.91	1.94	1.97	2.01	2.05	2.09	2.13	2.17	2.21	2.26	2.31	2.36	2.41	2.46	2.52	2.58	2.64	2.70	62
29	1.81	1.84	1.87	1.90	1.94	1.97	2.00	2.04	2.08	2.11	2.15	2.20	2.24	2.28	2.33	2.38	2.43	2.48	2.54	2.60	2.66	2.73	2.79	61
30	1.87	1.90	1.93	1.96	2.00	2.03	2.07	2.10	2.14	2.18	2.22	2.27	2.31	2.36	2.40	2.46	2.51	2.56	2.62	2.68	2.74	2.81	2.88	**60**
31	1.93	1.96	1.99	2.02	2.06	2.09	2.13	2.17	2.21	2.25	2.29	2.33	2.38	2.43	2.48	2.53	2.58	2.64	2.70	2.76	2.83	2.89	2.97	59
32	1.98	2.01	2.05	2.08	2.12	2.15	2.19	2.23	2.27	2.31	2.36	2.40	2.45	2.50	2.55	2.60	2.66	2.72	2.78	2.84	2.91	2.98	3.05	58
33	2.04	2.07	2.10	2.14	2.18	2.21	2.25	2.29	2.33	2.38	2.42	2.47	2.52	2.57	2.62	2.67	2.73	2.79	2.85	2.92	2.99	3.06	3.14	57
34	2.09	2.13	2.16	2.20	2.23	2.27	2.31	2.35	2.40	2.44	2.49	2.53	2.58	2.64	2.69	2.75	2.80	2.87	2.93	3.00	3.07	3.14	3.22	56
35	2.15	2.18	2.22	2.25	2.29	2.33	2.37	2.41	2.46	2.50	2.55	2.60	2.65	2.70	2.76	2.82	2.88	2.94	3.01	3.08	3.15	3.23	3.30	55
36	2.20	2.24	2.27	2.31	2.35	2.39	2.43	2.47	2.52	2.56	2.61	2.66	2.72	2.77	2.83	2.89	2.95	3.01	3.08	3.15	3.23	3.30	3.38	54
37	2.25	2.29	2.33	2.36	2.40	2.44	2.49	2.53	2.58	2.63	2.67	2.73	2.78	2.84	2.90	2.95	3.02	3.08	3.15	3.23	3.30	3.38	3.47	53
38	2.30	2.34	2.38	2.42	2.46	2.50	2.55	2.59	2.64	2.69	2.74	2.79	2.85	2.90	2.96	3.02	3.09	3.16	3.23	3.30	3.38	3.46	3.55	52
39	2.35	2.39	2.43	2.47	2.51	2.56	2.60	2.65	2.70	2.75	2.80	2.85	2.91	2.97	3.03	3.09	3.16	3.23	3.30	3.37	3.45	3.53	3.62	51
40	2.40	2.44	2.48	2.52	2.57	2.61	2.66	2.70	2.75	2.80	2.86	2.91	2.97	3.03	3.09	3.16	3.22	3.29	3.37	3.45	3.53	3.61	3.70	**50**
41	2.45	2.49	2.53	2.58	2.62	2.66	2.71	2.76	2.81	2.86	2.92	2.97	3.03	3.09	3.16	3.22	3.29	3.36	3.44	3.52	3.60	3.69	3.78	49
42	2.50	2.54	2.58	2.63	2.67	2.72	2.77	2.81	2.87	2.92	2.97	3.03	3.09	3.15	3.22	3.29	3.36	3.43	3.51	3.59	3.67	3.76	3.85	48
43	2.55	2.50	2.63	2.68	2.72	2.77	2.82	2.87	2.92	2.98	3.03	3.09	3.15	3.21	3.28	3.35	3.42	3.50	3.57	3.66	3.74	3.83	3.93	47
44	2.60	2.64	2.68	2.73	2.77	2.82	2.87	2.92	2.98	3.03	3.09	3.15	3.21	3.27	3.34	3.41	3.48	3.56	3.64	3.72	3.81	3.91	4.00	46
45	2.65	2.69	2.73	2.78	2.82	2.87	2.92	2.97	3.03	3.08	3.14	3.20	3.27	3.33	3.40	3.47	3.55	3.62	3.71	3.79	3.88	3.97	4.07	45

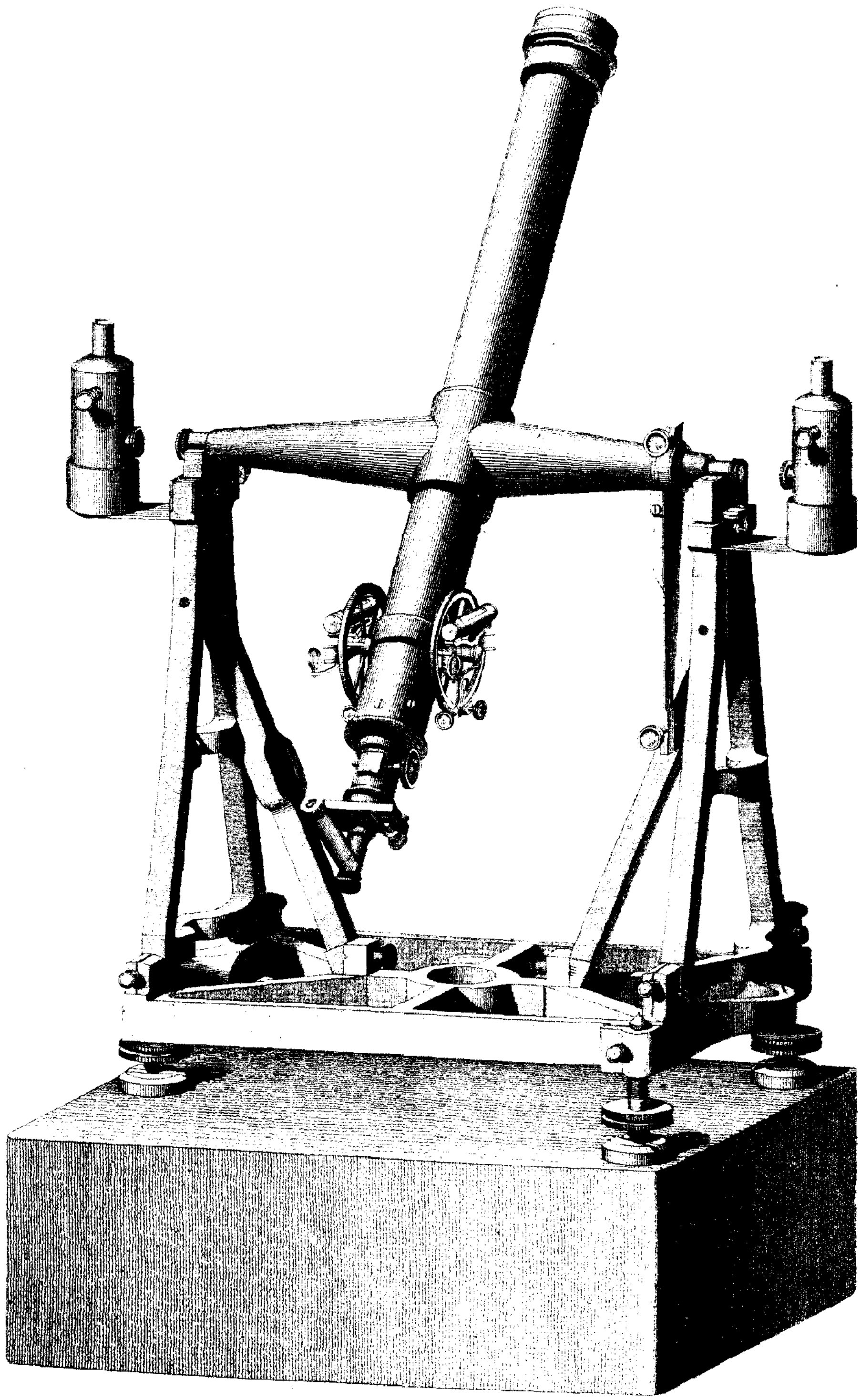
ζ	74½°	74¾°	75°	75¼°	75½°	75¾°	76°	76¼°	76½°	76¾°	77°	77¼°	77½°	77¾°	78°	78¼°	78½°	78¾°	79°	79¼°	79½°	79¾°	80°	ζ
46°	2.69	2.73	2.78	2.82	2.87	2.92	2.97	3.03	3.08	3.14	3.20	3.26	3.32	3.39	3.46	3.53	3.61	3.69	3.77	3.86	3.95	4.04	4.14	44°
47	2.74	2.78	2.83	2.87	2.92	2.97	3.02	3.08	3.13	3.19	3.25	3.31	3.38	3.45	3.52	3.59	3.67	3.75	3.83	3.92	4.01	4.11	4.21	43
48	2.78	2.82	2.87	2.92	2.97	3.02	3.07	3.13	3.18	3.24	3.30	3.37	3.43	3.50	3.57	3.65	3.73	3.81	3.89	3.98	4.08	4.18	4.28	42
49	2.82	2.87	2.92	2.96	3.01	3.07	3.12	3.18	3.23	3.29	3.35	3.42	3.49	3.56	3.63	3.71	3.79	3.87	3.96	4.05	4.14	4.24	4.35	41
50	2.87	2.91	2.96	3.01	3.06	3.11	3.17	3.22	3.28	3.34	3.41	3.47	3.54	3.61	3.68	3.76	3.84	3.93	4.02	4.11	4.20	4.30	4.41	**40**
51	2.91	2.95	3.00	3.05	3.10	3.16	3.21	3.27	3.33	3.39	3.45	3.52	3.59	3.66	3.74	3.82	3.90	3.98	4.07	4.17	4.26	4.37	4.48	39
52	2.95	3.00	3.04	3.09	3.15	3.20	3.26	3.31	3.38	3.44	3.50	3.57	3.64	3.71	3.79	3.87	3.95	4.04	4.13	4.22	4.32	4.43	4.54	38
53	2.99	3.04	3.09	3.14	3.19	3.24	3.30	3.36	3.42	3.48	3.55	3.62	3.69	3.77	3.84	3.92	4.01	4.09	4.19	4.28	4.38	4.49	4.60	37
54	3.03	3.08	3.13	3.18	3.23	3.29	3.34	3.40	3.47	3.53	3.60	3.67	3.74	3.81	3.89	3.97	4.06	4.15	4.24	4.34	4.44	4.55	4.66	36
55	3.07	3.11	3.16	3.22	3.27	3.33	3.39	3.45	3.51	3.57	3.64	3.71	3.78	3.86	3.94	4.02	4.11	4.20	4.29	4.39	4.50	4.60	4.72	35
56	3.10	3.15	3.20	3.26	3.31	3.37	3.43	3.49	3.55	3.62	3.68	3.76	3.83	3.91	3.99	4.07	4.16	4.25	4.34	4.44	4.55	4.66	4.77	34
57	3.14	3.19	3.24	3.29	3.35	3.41	3.47	3.53	3.59	3.66	3.73	3.80	3.88	3.95	4.04	4.12	4.21	4.30	4.39	4.50	4.60	4.72	4.83	33
58	3.17	3.22	3.28	3.33	3.39	3.45	3.51	3.57	3.63	3.70	3.77	3.84	3.92	4.00	4.08	4.16	4.25	4.35	4.44	4.55	4.65	4.77	4.88	32
59	3.21	3.26	3.31	3.37	3.42	3.48	3.54	3.61	3.67	3.74	3.81	3.88	3.96	4.04	4.12	4.21	4.30	4.39	4.49	4.60	4.70	4.82	4.94	31
60	3.24	3.29	3.35	3.40	3.46	3.52	3.58	3.64	3.71	3.78	3.85	3.92	4.00	4.08	4.17	4.25	4.34	4.44	4.54	4.64	4.75	4.87	4.99	**30**
61	3.27	3.33	3.38	3.44	3.49	3.55	3.62	3.68	3.75	3.82	3.89	3.96	4.04	4.12	4.21	4.29	4.39	4.48	4.58	4.69	4.80	4.92	5.04	29
62	3.30	3.36	3.41	3.47	3.53	3.59	3.65	3.72	3.78	3.85	3.92	4.00	4.08	4.16	4.25	4.34	4.43	4.53	4.63	4.73	4.85	4.96	5.08	28
63	3.33	3.39	3.44	3.50	3.56	3.62	3.68	3.75	3.82	3.89	3.96	4.04	4.12	4.20	4.29	4.38	4.47	4.57	4.67	4.78	4.89	5.01	5.13	27
64	3.36	3.42	3.47	3.53	3.59	3.65	3.72	3.78	3.85	3.92	4.00	4.07	4.15	4.24	4.32	4.41	4.51	4.61	4.71	4.82	4.93	5.05	5.18	26
65	3.39	3.45	3.50	3.56	3.62	3.68	3.75	3.81	3.88	3.95	4.03	4.11	4.19	4.27	4.36	4.45	4.55	4.65	4.75	4.86	4.97	5.09	5.22	25
66	3.42	3.47	3.53	3.59	3.65	3.71	3.78	3.84	3.91	3.99	4.06	4.14	4.22	4.31	4.40	4.49	4.58	4.68	4.79	4.90	5.01	5.14	5.26	24
67	3.44	3.50	3.56	3.62	3.68	3.74	3.81	3.87	3.94	4.02	4.09	4.17	4.26	4.34	4.43	4.52	4.62	4.72	4.82	4.94	5.05	5.18	5.30	23
68	3.47	3.53	3.58	3.64	3.70	3.77	3.83	3.90	3.97	4.05	4.12	4.20	4.28	4.37	4.46	4.55	4.65	4.75	4.86	4.97	5.09	5.21	5.34	22
69	3.49	3.55	3.61	3.67	3.73	3.79	3.86	3.93	4.00	4.07	4.15	4.23	4.32	4.40	4.49	4.58	4.68	4.79	4.89	5.00	5.12	5.25	5.38	21
70	3.52	3.57	3.63	3.69	3.75	3.82	3.89	3.95	4.03	4.10	4.18	4.25	4.34	4.43	4.52	4.61	4.71	4.82	4.93	5.04	5.16	5.28	5.41	**20**
71	3.54	3.60	3.65	3.71	3.78	3.84	3.91	3.98	4.05	4.13	4.20	4.28	4.37	4.46	4.55	4.64	4.74	4.85	4.96	5.07	5.19	5.32	5.45	19
72	3.56	3.62	3.67	3.74	3.80	3.86	3.93	4.00	4.07	4.15	4.23	4.31	4.39	4.48	4.57	4.67	4.77	4.88	4.98	5.10	5.22	5.34	5.48	18
73	3.58	3.64	3.69	3.76	3.82	3.89	3.95	4.02	4.10	4.17	4.25	4.33	4.42	4.51	4.60	4.70	4.80	4.90	5.01	5.13	5.25	5.37	5.51	17
74	3.60	3.65	3.71	3.78	3.84	3.91	3.97	4.04	4.12	4.19	4.27	4.36	4.44	4.53	4.62	4.72	4.82	4.93	5.04	5.15	5.27	5.40	5.53	16
75	3.61	3.67	3.73	3.79	3.86	3.92	3.99	4.06	4.14	4.21	4.29	4.38	4.46	4.55	4.65	4.74	4.84	4.95	5.06	5.18	5.30	5.43	5.56	15
76	3.64	3.69	3.75	3.82	3.88	3.94	4.01	4.08	4.16	4.23	4.31	4.40	4.48	4.57	4.67	4.76	4.87	4.97	5.09	5.20	5.32	5.45	5.59	14
77	3.65	3.70	3.76	3.83	3.89	3.96	4.03	4.10	4.17	4.25	4.33	4.41	4.50	4.59	4.68	4.78	4.89	4.99	5.11	5.22	5.35	5.47	5.61	13
78	3.66	3.72	3.78	3.84	3.91	3.97	4.04	4.11	4.19	4.27	4.35	4.43	4.52	4.61	4.70	4.80	4.91	5.01	5.13	5.24	5.37	5.50	5.63	12
79	3.67	3.73	3.79	3.86	3.92	3.99	4.06	4.13	4.21	4.28	4.36	4.45	4.54	4.63	4.72	4.82	4.92	5.03	5.14	5.26	5.39	5.52	5.65	11
80	3.68	3.74	3.81	3.87	3.93	4.00	4.07	4.14	4.22	4.30	4.38	4.46	4.55	4.64	4.74	4.84	4.94	5.05	5.16	5.28	5.40	5.54	5.67	**10**
81	3.70	3.75	3.82	3.88	3.94	4.01	4.08	4.16	4.23	4.31	4.39	4.48	4.56	4.65	4.75	4.85	4.95	5.06	5.18	5.30	5.42	5.55	5.69	9
82	3.71	3.76	3.83	3.89	3.96	4.02	4.09	4.17	4.24	4.32	4.40	4.49	4.57	4.67	4.76	4.86	4.97	5.08	5.19	5.31	5.43	5.56	5.70	8
83	3.72	3.77	3.84	3.90	3.96	4.03	4.10	4.18	4.25	4.33	4.41	4.50	4.59	4.68	4.78	4.87	4.98	5.09	5.20	5.32	5.45	5.58	5.72	7
84	3.72	3.78	3.84	3.91	3.97	4.04	4.11	4.18	4.26	4.34	4.42	4.51	4.60	4.69	4.79	4.88	4.99	5.10	5.21	5.33	5.46	5.59	5.73	6
85	3.73	3.79	3.85	3.91	3.98	4.05	4.12	4.19	4.27	4.35	4.43	4.51	4.60	4.69	4.79	4.89	5.00	5.11	5.22	5.34	5.47	5.60	5.74	5
86	3.73	3.79	3.85	3.92	3.98	4.05	4.12	4.20	4.27	4.35	4.43	4.52	4.61	4.70	4.80	4.90	5.00	5.11	5.23	5.35	5.47	5.61	5.74	4
87	3.74	3.79	3.86	3.92	3.99	4.06	4.13	4.20	4.28	4.36	4.44	4.52	4.62	4.71	4.81	4.90	5.01	5.12	5.23	5.35	5.48	5.61	5.75	3
88	3.74	3.80	3.86	3.92	3.99	4.06	4.13	4.20	4.28	4.36	4.44	4.53	4.62	4.71	4.81	4.91	5.01	5.12	5.24	5.36	5.48	5.61	5.75	2
89	3.74	3.80	3.86	3.93	3.99	4.06	4.13	4.21	4.28	4.36	4.44	4.53	4.62	4.71	4.81	4.91	5.01	5.12	5.24	5.36	5.49	5.62	5.76	1
90	3.74	3.80	3.86	3.93	3.99	4.06	4.13	4.21	4.28	4.36	4.44	4.53	4.62	4.71	4.81	4.91	5.02	5.13	5.24	5.36	5.49	5.62	5.76	**0**

For collimation factor $C = \sec. \delta$ see last or bottom line.

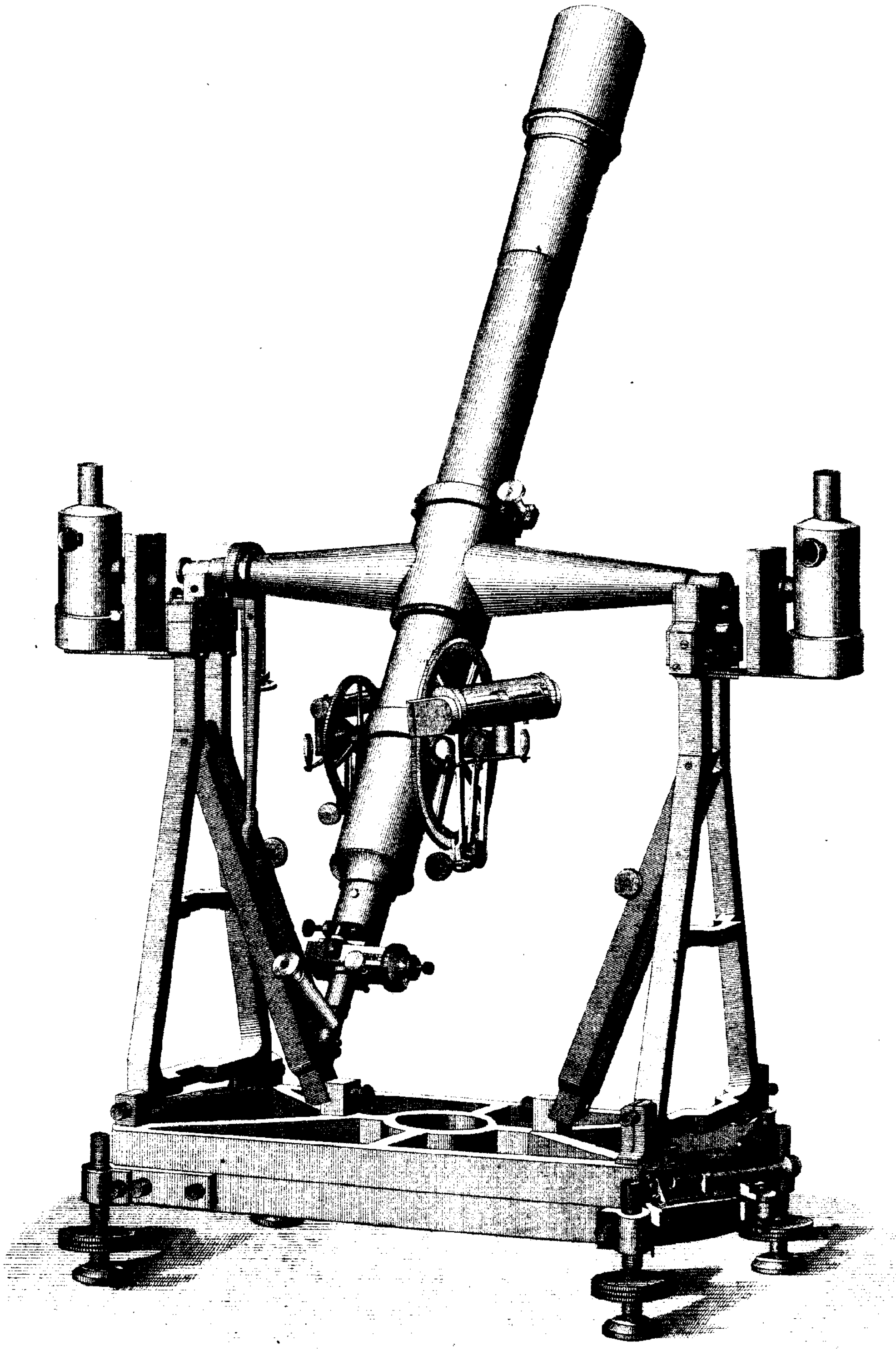


P.E. del.

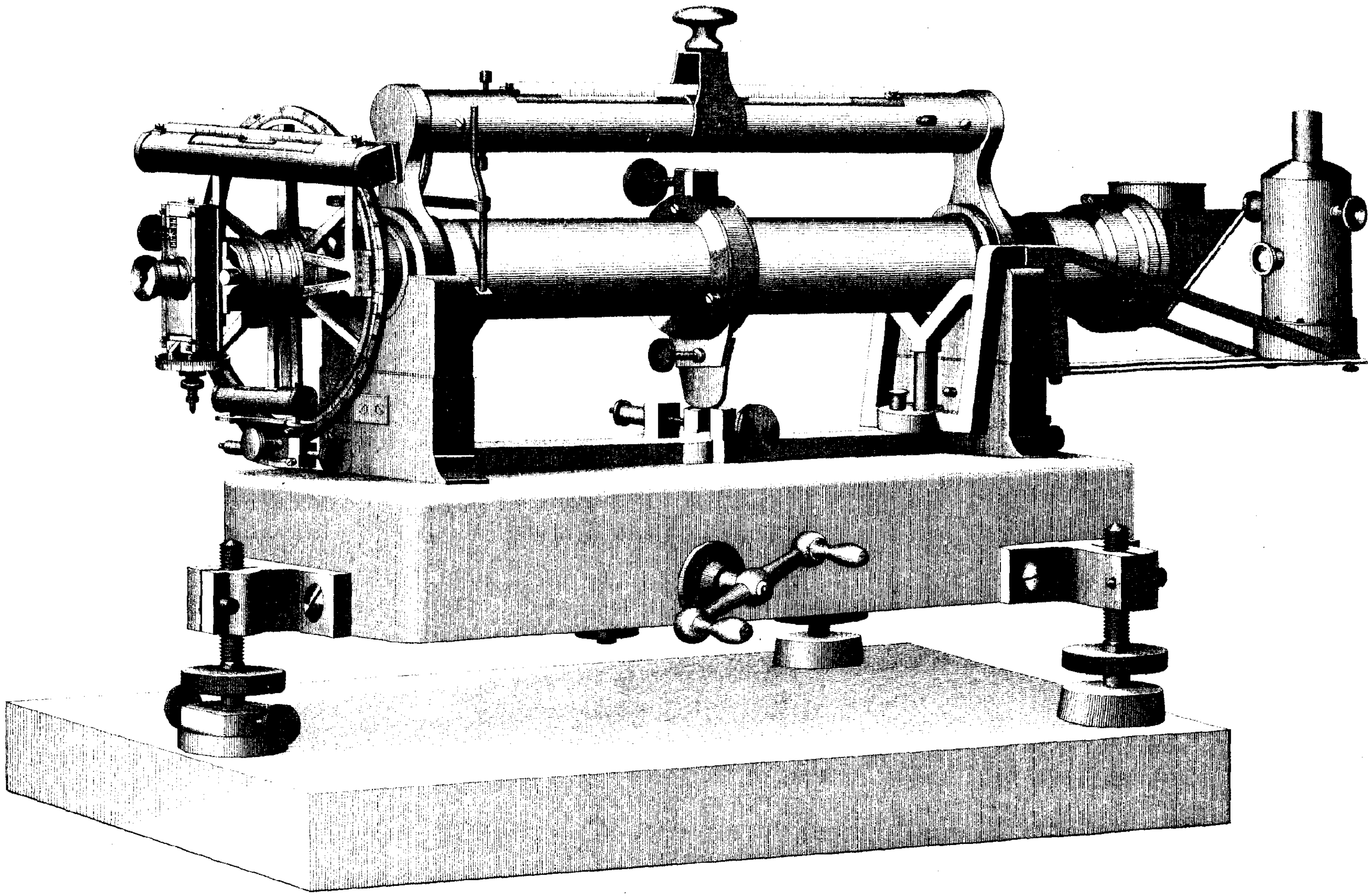
FORTY-SIX INCH. (117 CM) TRANSIT



PORTABLE TRANSIT.



MERIDIAN- OR TRANSIT AND EQUAL ALTITUDE INSTRUMENT.



PRISMATIC TRANSIT AND ZENITH TELESCOPE

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PART II.

DETERMINATION OF LONGITUDE

BY MEANS OF THE ELECTRIC TELEGRAPH.

WITH TWO PLATES.

ILLUSTRATING:

1. DISPOSITION OF TELEGRAPH INSTRUMENTS.
2. CHRONOGRAPH.

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PART II.

DETERMINATION OF LONGITUDE BY MEANS OF THE ELECTRIC TELEGRAPH.

(With two plates.)

In accordance with the design of this paper the only method here considered for the determination of longitude will be that using the electric telegraph, which is now exclusively employed, whenever the means exist, in geodetic operations and which affords an accuracy in a resulting longitude almost equal to that of a resulting latitude, both determinations being subject to local deflections of the vertical, which frequently exceed the probable error of a measure of either of these coördinates.

(1.) *Telegraphic determination of longitude.*—The determination of the longitude of a place or of its meridional distance from the first or initial meridian (for which that passing through Greenwich is generally taken), or the process for ascertaining the difference of longitude, or what is the same thing, the difference of time (expressed either in sidereal or mean solar) requires a most accurate determination of time at both places, combined with a direct comparison of these times through the medium of the electric telegraph. Respecting time determination but little needs to be added to what has been given; the instrumental constants are to be carefully determined, the transit instruments are to be kept in close adjustment, the stars are to be carefully selected with reference to position on the sphere as well as to accuracy of catalogue place, the transits are recorded automatically by the chronograph and *two* sets of time determinations are made, in the interval of which the *exchanges* of local times take place between the two localities. The latter operation is effected either automatically by break-circuit chronometers, or preferably by arbitrary signals, or breaks given by the observer. The parties are further provided with relays, switch-boards, galvanometer, rheostat, local battery and other minor requisites and they usually have the assistance of a telegraph operator.

Various methods have been employed; the first, simple and obvious one, of each observer regulating his clock or chronometer to local time and noting the time of any arbitrary break of the connecting circuit, each observer by tapping giving a number of such signals. As early as 1847 the principle of coincidence of beats between time keepers regulated to sidereal and mean time was used. In the following year the method of star signals* was introduced; it consists in observing and recording at both stations the transits of a star over every thread of the diaphragm of the telescope at the eastern station, and again recording at both stations the passage of the same star over the several threads of the instrument at the western station. For this work the clock which graduates the chronograph sheets may be located anywhere in the circuit, but the observers will determine their instrumental constants and deviations in the ordinary way. A number of such so-called time or zenith stars were thus observed and recorded. However perfect this method was theoretically, it nevertheless had soon to give way to a less cumbersome and less time-consuming and more practical method, one equally elegant in its conception, viz, that of the automatic transmission of clock beats first practiced in 1860. The connecting telegraph wire was now required each night only for as many minutes as hours had been consumed before; the observers put successively their clocks in the main circuit and allow them to graduate for a few minutes the chronograph registers at both stations. Two further improvements in the practical telegraphic work were

* A very full account of this method is given by W. Chauvenet in his Manual of Spherical and Practical Astronomy, vol. I, pp. 342–350, original edition of 1863. See also Coast Survey report of 1856, appendix No. 21. Details of telegraphic method for determining differences of longitude, with description of instruments. By Geo. W. Dean, Assistant, Coast Survey.

soon introduced—viz, the clock was placed in a local circuit, it having been found that the intensity of the current in the main line was too great for the satisfactory and permanent action of any mechanism employed to effect the break of the circuit by the motion of the clock's pendulum.

Next, the clock was superseded by the break-circuit chronometer, supplied with a condenser to prevent any injury through the passage of sparks. Of late, two excellent relays were introduced, known as the polarized and the Farmer relay, the latter proving slightly the superior one, but both reducing the armature time to a very small quantity. By means of the rheostat, and as measured by the galvanometer, the resistance of the line is kept about the average value and the same on each night of exchange of signals. Though various apparatus have been tried for the measure of absolute or relative personal equation, the exchange of place of the observers after one-half of the longitude work between two stations has been accomplished and its completion with the observers in their new places must be considered an essential condition of success for accurate work. This, of course, became impracticable in the case of crossing the Atlantic, and the observers had to compare for personal equation both before and after the completion of the exchanges. What now remains of differences in the values found each night as compared with the mean value would seem to depend mainly on *variations* in the personal equation of the observers, and they will therefore try to preserve their ordinary habits and conditions of body and mind. Variations in the rate of chronometers probably produce discrepancies in the results of a smaller magnitude. For stations lying approximately north and south of each other, the same stars may be used for determining the local times, and the resulting difference of longitude will be free from errors of catalogue star places; on the other hand, if the stations are approximately east and west of each other, the use of the same stars either becomes inconvenient (to the eastern observer) or otherwise impracticable, as in the case of crossing the Atlantic, and we must either trust to the chronometer keeping its rate uniformly during the interval of longitude or trust to the correctness of the right ascensions of another set of stars.*

For the computation of the difference of longitude we have the following simple formulæ:

Let t_e and Δt_e = the chronometer time and the chronometer correction at the *eastern* station when sending a signal,

t_w and Δt_w = the chronometer time and the chronometer correction at the *western* station when receiving this signal,

and t'_w and $\Delta t'_w$ = the chronometer time and its correction at the *western* station upon sending or returning a signal,

t'_e and $\Delta t'_e$ = the chronometer time and its correction at the *eastern* station when receiving this signal,

μ = transmission time of the electric effect, including retardation of current flowing through the wire, armature and induction time, and

λ = difference of longitude, west longitude being reckoned positive. Then supposing the chronometer times free from personal equations and the transmission time between the two stations the same both ways, we have from an *eastern* signal

$$\lambda - \mu = t_e + \Delta t_e - (t_w + \Delta t_w) = \lambda_e$$

and from a *western* signal

$$\lambda + \mu = t'_e + \Delta t'_e - (t'_w + \Delta t'_w) = \lambda_w$$

hence

$$\lambda = \frac{1}{2}(\lambda_e + \lambda_w) \text{ and } \mu = \frac{1}{2}(\lambda_w - \lambda_e)$$

If no correction were applied for personal equation and the observers have exchanged places in the middle of the work, then the mean values for λ, as found before and after the exchange, will differ by twice the amount of the personal equation, and if the observers have kept their steady habits during the longitude determination the mean of the two values or λ will be free from personal equation.

*See Coast Survey Report for 1867, Appendix No. 6. On the longitude between America and Europe from signals through the Atlantic cable. By Dr. B. A. Gould, jr., Assistant, pp. 57–133 and Coast Survey Report for 1874, Appendix No. 18. Transatlantic longitudes; final report on the United States Coast Survey determinations of 1872. By J. E. Hilgard, Assistant, pp. 163–242.

Ordinarily a set of time determinations consists of observations of a circumpolar and of four circumzenith stars (two north and two south of it); the transit axis is then reversed and four more time stars and one polar star are observed. In case of any defect additional stars are observed. Two such sets are taken each night with the telegraphic exchange of signals between them.

With respect to relative weights to be given to the individual results for longitude it will be observed that these must depend primarily on the probable errors of the local times as determined at the two stations, next on the interval elapsed between these epochs of transit observations and that of the exchange of the longitude signals—that is, on the performance of the chronometers by which the times are carried forward. The latter uncertainty may be greater than the former. If the exchange took place midway between the two local time determinations it will be most favorable; but if, as is sometimes the case, the exchange took place outside of this interval, the relative weight for that night would be very much weakened. Roughly we may give relative weights depending on the number of time-stars observed on any one night at the two stations: suppose there be n such stars at the first and n_1 at the second station, then the relative weight $w = \frac{2\,n\,n_1}{n + n_1}$. It will be much more accurate to make the relative weight w depend on the sum of the two weights of the time determination resulting from the normal equations of the sets, thus $P = p + p_1$ and similarly for the other station P_1, then the relative weight $= \frac{P\,P_1}{P + P_1}$. Special considerations, however, may be required in particular cases.

Generally exchanges for longitudes are effected on 10 nights, the observers exchanging places after 5 nights of successful observation. On any one working night two sets of transmissions of arbitrary signals or exchanges take place; the eastern station will transmit, say, 30 signals at *irregular* intervals of average duration of two seconds, and this is followed by an equal number and similar signals transmitted from the western station.

(2.) *Personal equation.*—As stated above, it is the practice of the Survey to try to eliminate the personal equation from the resulting longitude through the exchange of places of the observers, rather than use any of the many forms of personal equation apparatus.* Where the exchange is impracticable, perhaps the most satisfactory way of obtaining the personal equation is that of tapping transits of a star by the first observer over one-half of the lines of the diaphragm, and by the second observer over the remaining half, and to continue to observe a number of time stars (circumzenith stars), the observers *leading alternately*, in which case any error in the line intervals is eliminated. Such observations should be made before beginning the longitude work proper, and again after its completion. If we write down the personal equation between two observers, E and W, in the sense that $E - W = e$ indicates for a positive e that observer E is later than observer W—in other words, that E gives for his estimate of the happening of an event more chronometer time than observer W, and for a negative e that E gives less time or is earlier than W—we have stated the fact in its most simple form,† and we have a convenient rule to correct a resulting longitude for personal equation, viz: state the personal equation for eastern minus western observer and apply the corresponding value of e, with its algebraic sign to λ or the resulting difference of longitude, considered as essentially positive.

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* See, for instance, "Description of two forms of portable apparatus for the determination of personal equation, both relative and absolute, in observations of star transits, by J. E. Hilgard, assistant, Coast Survey. Appendix No. 17, Coast Survey Report of 1874.

† Sometimes the personal equation is stated in terms of difference in chronometer corrections, in which case the sign of e would be reversed.

The following table of results will serve as a specimen of presenting the separate results in a concise form, and of exhibiting the effect of personal equation:

Results for difference of longitude, Nashville, Tenn., and Atlanta, Ga.

Date.	Observer at— Nashville.	Atlanta.	Arbitrary signals through a Farmer relay. From west or Nashville signals. λ_w	From east or Atlanta signals. λ_e	2μ or $\lambda_w - \lambda_e$	Difference of longitude λ. Uncorrected for pers. equ'n.	Resulting values.	Rel. weight.
1879-'80.			*m. s.*	*m. s.*	*s.*	*m. s.*	*m. s.*	
Dec. 26	S.	D.	9 34.805	9 34.777	0.028	9 34.791	9 34.695	40
27	S.	D.	.905	.873	.032	.889	.793	30
Jan. 3	S.	D.	.950	.928	.022	.939	.843	14
13	S.	D.	.841	.822	.019	.831	.735	38
14	S.	D.	.815	.784	.031	.800	.704	37
Mean			9 34.863	9 34.837	.026	9 34.850		
Jan. 20	D.	S.	.664	.637	.027	.650	.746	36
22	D.	S.	.759	.738	.021	.748	.844	34
23	D.	S.	.696	.664	.032	.680	.776	37
24	D.	S.	.547	.521	.026	.534	.630	39
27	D.	S.	.693	.659	.034	.676	.772	38
Mean			9 34.672	9 34.644	.028	9 34.658	9 34.754	

Resulting longitude, weighted mean, $9^m\ 34^s.745$
$\pm\ 0.014$

Difference in values of λ before and after exchange of observers$=0^s.192$; hence the personal equation for the first position of observers $D-S=-0^s.096$, or for the second $S-D=+0.^s096$; applying these corrections we have the resulting values for longitude in the last column but one of the table. The relative weights given depend on the relative values of the transit observations at both stations.

The following table shows the variability of the personal equation between two experienced observers during a period of nearly three years, from which we may infer the amount of uncertainty in any of the subordinate longitude determinations made during this time, where it was thought to be a useless expense to have the observers exchange places, and where consequently an average value for the personal equation has to be applied.

Table showing variability in personal equation between two practiced observers.

	s.
December, 1877 and January, 1878	D−S=−.128*
November and December, 1878	−.088
January, February and March, 1879	−.040
March, 1879	−.056
November and December, 1879	−.084
December and January, 1879–'80	−.096
February and March, 1880	−.099
March and April, 1880	−.091
May, 1880	−.141
May, 1881	−.151
June, 1881	−.133
July and August, 1881	−.132
September and October, 1881	−.147
October and November, 1881	−.180
November, 1881	−.220

* The sign indicates that S is later, or gives more time for the happening of an event than D; in other words, D anticipates S.

(3.) *Determination of weights to be given to transit observations, recorded by the chronographic method.*—The introduction of the chronographic registration of transits of stars has considerably increased their precision and rendered it desirable to discuss the relative weights of the conditional equations resulting from the treatment by the method of least squares.

The general form of the probable error of a transit observation is the same for the chronographic as for the "eye and ear" method; which latter has been long since discussed by Bessel in the Berliner Jahrbuch for 1823 (see also Dr. Sawitsch's Practische Astronomie, vol. 1, pp. 128, 129, Hamburg, 1850). In general, there is a constant value related to the personality of the observer and a term variable with the star's declination, depending on the apparent motion of the star and affected by the condition of the atmosphere and by the magnifying power of the telescope.

The close circumpolar stars still continue to be observed by the eye and ear method; use being made, however, of the click of the armature of the recording magnet. Some observers prefer two taps, corresponding to the apparent bisection of the star by the preceding and following edges of the thread or lines.

The relative weights of incomplete transits are also slightly changed, since the determination of instrumental errors is but little improved, whereas the uncertainty in noting time on each thread has been considerably diminished by the chronographic method.

As already stated, in Coast Survey practice two classes of portable instruments are employed for the determination of longitudes by means of the electric telegraph: larger-sized transits of about twelve decimeters focal length, formerly fitted with reticules of twenty-five threads; and smaller-sized transits or combination instruments of about 6.6 decimeters focal length, generally provided with glass diaphragms of fifteen or less lines. The latter instruments are used in preference at stations of secondary importance.

RELATIVE WEIGHTS TO TRANSITS DEPENDING ON THE STAR'S DECLINATION.

The following tables of the probable error (ε) of an observation of a transit of a star over a *single* thread have been derived from a discussion of 1047 transits taken in February and March, 1869, at San Francisco, by Assistant G. Davidson, with the large transit C. S. No. 3 (aperture $2\frac{3}{4}$ inches, magnifying power 85); and 875 transits taken about the same time at Cambridge by Assistant A. T. Mosman, including some observations by Subassistant F. Blake, with the large transit C. S. No. 5 (aperture $2\frac{3}{4}$ inches, magnifying power 100). For the discussion of observations with a smaller instrument, 330 transits were used, taken in September, October and November, 1871, at Cleveland, Ohio; and 585 transits, taken in December and January, 1871–'72, at Falmouth, Ky., by Assistant E. Goodfellow, with a meridian telescope C. S. No. 13 (aperture $1\frac{3}{4}$ inches, magnifying power about 70).

Transit No. 3.		Transit No. 5.		Meridian telescope No. 13.		Meridian telescope No. 13.	
δ	ϵ	δ	ϵ	δ	ϵ	δ	ϵ
°	s.	°	s.	°	s.	°	s.
87.2	±0.74	86.9	±0.66	81.9	±0.62	76.3	±0.20
86.6	0.49	80.0	0.20	76.9	0.18	68.2	0.16
83.0	0.38	76.3	0.19	67.4	0.11	55.8	0.13
81.0	0.31	72.6	0.12	62.0	0.14	48.4	0.15
68.4	0.12	68.8	0.11	55.8	0.09	23.2	0.102
62.9	0.088	3.2	0.066	44.8	0.088	20.4	0.089
48.6	0.075	......	....	29.7	0.067	17.3	0.110
28.5	0.058	......	....	0.7	0.071	6.1	0.080
7.8	0.060	......	....	....	....	....	....

These tabular values are fairly represented by the expressions

Transit, No. 3, $\varepsilon = \sqrt{(0.060)^2 + (0.036)^2 \tan^2 \delta}$

Transit, No. 5, $\varepsilon = \sqrt{(0.066)^2 + (0.036)^2 \tan^2 \delta}$

Meridian telescope, No. 13, $\varepsilon = \sqrt{(0.069)^2 + (0.078)^2 \tan^2 \delta}$

Meridian telescope, No. 13, $\varepsilon = \sqrt{(0.087)^2 + (0.055)^2 \tan^2 \delta}$

Combining these expressions for the larger and smaller instruments we obtain

$$\varepsilon=\sqrt{(0.063)^2+(0.036)^2\tan^2\delta} \quad \text{and} \quad \varepsilon=\sqrt{(0.080)^2+(0.063)^2\tan^2\delta}$$

respectively,* from which the following tables of probable errors (ε) of relative weights (p), that of an equatorial star having the weight unity and of the multipliers $\sqrt{p}$ for the conditional equations, have been computed.

	δ	For large portable transits.			For small portable transits.		
		ε	p	$\sqrt{p}$	ε	p	$\sqrt{p}$
	° ′	s.			s.		
	0	±0.06	1	1	±0.08	1	1
	10	.06	1	1	.08	0.98	1
	20	.06	0.98	1	.08	.92	0.96
	30	.07	.91	0.95	.09	.83	.91
	40	.07	.82	.90	.10	.70	.83
	45	.07	.76	.87	.10	.62	.79
	50	.08	.69	.83	.11	.53	.73
	55	.08	.61	.78	.12	.44	.66
	60	.09	.51	.71	.14	.34	.59
	65	.10	.40	.63	.16	.26	.51
	70	.12	.29	.54	.19	.18	.42
	75	.15	.18	.43	.25	.10	.32
	80	.21	.09	.30	.37	.05	.22
	85	.42	.02	.15	.72	.01	.11
δ Ursæ Minoris..	86 36	0.61	0.011	0.103	1.1	0.006	0.075
51 Cephei........	87 14	0.75	0.007	0.084	1.3	0.004	0.061
α Ursæ Minoris .	88 39	1.5	0.002	0.041	2.7	0.001	0.030
λ Ursæ Minoris..	88 56	1.9	0.001	0.033	3.4	0.001	0.024

In the application of the multiplier $\sqrt{p}$ it generally suffices to employ but one significant figure.

RELATIVE WEIGHTS TO INCOMPLETE TRANSIT OBSERVATIONS.

Let ε=the probable error of a transit of an equatorial star over a *single* thread $=\pm0^s.063$ and $\pm0^s.080$ for our larger and smaller instruments, respectively; ε_1=the probable culmination-error, referred to the equator, mainly due to atmospheric displacement, to outstanding instrumental errors, irregularities in clock rate and changes in the personal equation; n=number of threads observed, then

$$r^2=\varepsilon_1{}^2+\frac{\varepsilon^2}{n}$$

will represent the square of the combined effect. To find r, individual determinations of right ascensions of stars, all referred to the same epoch (mean place), may be compared with their respective average values; thus, from 558 results of 36 stars observed at the United States Naval Observatory with the transit circle (using a magnifying power of 186) in 1870 and 1871, I find $r=\pm0^s.034$. To apply this value to our instruments, it must be somewhat increased, though not in proportion to the respective magnifying powers, since some of the errors involved approach the character of constants; multiplying it by 1.5 and 1.75, the equations

$$(0.051)^2=\varepsilon_1{}^2+\frac{(0.063)^2}{25} \quad \text{and} \quad (0.060)^2=\varepsilon_1{}^2+\frac{(0.080)^2}{15}$$

give

$$\varepsilon_1=\pm0^s.049 \text{ and } \varepsilon_1=\pm0^s.056$$

* The following formula has been published by Dr. Albrecht on p. 7 of his Formeln und Hülfstafeln, &c., Leipzig, 1873, viz:

$$\varepsilon=\sqrt{(0.05)^2+\left(\frac{3.18}{v}\right)^2\sec^2\delta}$$

Putting v=85 for the magnifying power and changing sec into tan, this expression is equivalent to

$$\varepsilon=\sqrt{(0.062)^2+(0.037)^2\tan^2\delta}$$

for the larger and smaller instruments respectively; and, consequently, the weights become

$$p=\frac{\varepsilon_1^2+\frac{\varepsilon^2}{N}}{\varepsilon_1^2+\frac{\varepsilon^2}{n}}$$

Hence for the larger instruments

$$p=\frac{1+\frac{1.6}{N}}{1+\frac{1.6}{n}}$$

and for the smaller instruments

$$p=\frac{1+\frac{2.0}{N}}{1+\frac{2.0}{n}}$$

very nearly. From these expressions, the relative weights have been computed for total number of threads N=25, 17, 13 and 11 for the larger instruments and for N=15, 13, 11 and 9 for the smaller ones.

Number of threads.	For large portable transits.								For small portable transits.							
	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$	p	$\sqrt{p}$
1	.41	.64	.42	.65	.43	.66	.44	.66	.38	.62	.38	.62	.39	.63	.41	.64
2	.59	.77	.61	.78	.62	.79	.64	.80	.56	.75	.58	.76	.59	.77	.61	.78
3	.69	.83	.71	.84	.73	.86	.75	.86	.68	.83	.69	.83	.71	.84	.73	.86
4	.76	.87	.78	.88	.80	.90	.82	.90	.75	.87	.77	.88	.79	.89	.82	.90
5	.81	.90	.83	.91	.85	.92	.87	.93	.81	.90	.82	.91	.84	.92	.87	.93
6	.84	.91	.86	.93	.89	.94	.90	.95	.85	.92	.87	.93	.89	.94	.92	.96
7	.87	.93	.89	.94	.91	.96	.93	.97	.88	.94	.90	.95	.92	.96	.95	.97
8	.89	.94	.91	.95	.94	.97	.96	.98	.91	.95	.92	.96	.95	.97	.98	.99
9	.90	.95	.93	.96	.95	.98	.97	.99	.92	.96	.94	.97	.97	.98	1.00	1.00
10	.92	.96	.94	.97	.97	.98	.99	.99	.94	.97	.96	.98	.99	.99		
11	.93	.96	.95	.98	.98	.99	1.00	1.00	.96	.98	.98	.99	1.00	1.00		
12	.94	.97	.96	.98	.99	1.00			.97	.99	.99	1.00				
13	.95	.97	.97	.99	1.00	1.00			.98	.99	1.00	1.00				
14	.96	.97	.98	.99					.99	1.00						
15	.96	.98	.99	1.00					1.00	1.00						
16	.97	.98	1.00	1.00												
17	.97	.98	1.00	1.00												
18	.98	.99														
19	.98	.99														
20	.98	.99														
21	.99	.99														
22	.99	1.00														
23	.99	1.00														
24	1.00	1.00														
25	1.00	1.00														

For the larger instruments, the gain in accuracy between 17 and 25 threads is very trifling and it is believed that the increased fatigue to the observer and consequent change in his personal equation will more than counterbalance it. Seventeen threads or lines were recommended in 1872, which may conveniently be disposed in three tallies; the middle one (especially for the observations of close circumpolars) of 7 equidistant, and the two outer tallies of 5 equidistant threads, about 2^s apart; and for the smaller instruments, 13 instead of 15 lines were recommended, with 7 lines in the middle and 3 lines each in the outer tallies. For occasional observations by the eye and the ear, two outer single threads may be added, forming, with the central ones of the tallies, 5 equidistant threads (about 12^s apart). If the observer prefers, he may have close double lines and tap when the star is exactly between them. Glass diaphragms came into regular use since 1871. In the glass diaphragm most in use we have 13 lines disposed in 5 tallies. The outer tallies consist of one line each, those next to them of 3 and the central one of 5 lines—equatorial distance of the middle lines of each tally about 15^s, or whole interval between first and last line 1^m; the interval of the lines constituting a tally is $2\frac{1}{2}$ seconds.

Respecting the probable error of the tabular right ascensions of clock stars, as given in the American Ephemeris, we may form some judgment from the table of corrections given in the Washington Observations for 1870 and 1871 (Table C, p. lxxxv). Taking the square root of the average square of corrections to these 119 clock stars, the mean correction, referred to the equator, becomes $\pm 0^s.041$

The probable error of a tabular right ascension of a fundamental star may be estimated at not less than $\pm 0^s.03$ and comparatively greater for other stars. To give weights for relative uncertainty in the tabular right ascensions is generally impracticable; but we may obtain as consistent and accurate a set of results as the nature of the observations admits of by first using the conditional equations with equal weights *with respect to tabular places* and deducing corrections to the assumed right ascensions for all stars not fundamental from the observations of the same star on different nights. A second formation of the numerical quantities of the conditional equations and solution of the normal equations will give the final results for instrumental deviations and for local time.

In this method, the apparent right ascensions of the stars are made to refer to the equinox belonging to the fundamental stars.

For the reduction of a set of transits by application of the method of least squares (for which see part I of this paper), it is recommended to introduce, in the conditional equations, two azimuthal deviations; one to apply to the state of the instrument before, the other after, reversal. It may also become desirable to introduce a correction to the assumed hourly rate of the time-keeper, especially if the observations in a set are greatly extended.

The following example, showing the arrangement of the reduction of transit observations when weights are applied, is given for the sake of completeness. The notation is the same as that previously used in part I.

It will generally be found preferable, on account of the laborious process of forming and solving four normal equations, determining the collimation, two azimuthal deviations and the clock correction, to divide the labor into two sets of two normal equations, one for clamp east and the other for clamp west, provided an independent azimuth can be found for each. This treatment is due to Mr. James Main, astronomical computer in the Coast Survey. The field computation, or a first rough reduction, will furnish an approximate value for the collimation and of the hourly rate of the clock for which the observed times of the transits are corrected, leaving the azimuthal deviation and the clock correction to be determined by two normal equations; for the second set, there result two similar normal equations, and the criterion for the correctness of the reduction will be the *equality of the clock corrections*, which apply to the *epoch of the reversal of the instrument*. Should the two values for δT differ by a few hundredths of a second, the process is easily gone over introducing an improved value of the collimation c. It will rarely be necessary to improve the correction for hourly rate; the latter being referred to the epoch of the reversal, the effect on δT becomes insignificant. It sometimes happens that the instrument is reversed twice in a night's work, in which case the reduction may be made as above, determining a third value for azimuthal deviation and demanding the identity of three values deduced for δT.

The example given below is drawn from the determination of the transatlantic longitude of 1872; being the observations at Paris, France, made August 16; instrument, C. S. transit No. 4; observer, F. Blake, jr.; latitude$=48° 50' 11''$; collimation$=-0^s.337$ for clamp west; epoch $T_0 = 18^h 46^m$; hourly rate of chronometer insignificant; transits complete; weights, p depending on δ and taken from the table prepared for large transit instruments. The last column, headed $p\Delta$, exhibits the differences, given by the individual stars on a uniform scale.

PARIS, AUGUST 16, 1872.

Reductions of observations for time.

Epoch, $18^h 46^m$. Collimation = $-0^s.337$ Clamp west.

Star.	Clamp.	Observed chronometer time—mean of threads.	Correction for rate.	Correction for inclination and pivot inequality.	Correction for collimation.	Correction for diurnal aberration.	Corrected time.	Adopted tabular right ascension. α	α—t=τ
		h. m. s.	s.	s.	s.	s.	s.	h. m. s.	s.
ψ¹ Draconis	W.	17 44 17.22	0.00	+0.23	—1.10	—0.05	16.30	17 44 15.13	—1.17
η Serpentis	W.	18 14 45.07	0.00	+0.08	—0.34	—0.02	44.79	18 14 43.09	1.70
1 Aquilæ	W.	28 18.48	0.00	+0.08	—0.34	—0.02	18.20	28 16.49	1.71
α Lyræ	W.	32 39.86	0.00	+0.21	—0.43	—0.02	39.62	32 38.13	1.49
β Lyræ	W.	45 24.98	0.00	+0.17	—0.41	—0.02	24.72	45 23.11	1.61
50 Draconis	W.	50 34 50	0.00	+0.47	—1.33	—0.06	33.58	50 32.61	0.97
ζ Aquilæ	E.	59 34.77	0.00	+0.10	+0.34	—0.02	35.19	59 33.56	1.63
δ Draconis	E.	19 12 34.02	0.00	+0.29	+0.88	—0.04	35.15	19 12 33.86	1.29
τ Draconis	E.	18 03.10	0.00	+0.38	+1.15	—0.05	04.58	18 03.31	1.27
κ Aquilæ	E.	30 03.81	0.00	+0.07	+0.34	—0.02	04.20	30 02.51	1.69
γ Aquilæ	E.	40 13.73	0.00	+0.08	+0.34	—0.02	14.13	40 12.55	1.58
α Aquilæ	E.	44 35.55	0.00	+0.08	+0.34	—0.02	35.95	44 34.40	1.55
ε Draconis	E.	48 38.87	0.00	+0.26	+0.99	—0.05	40.07	48 38.79	1.28

Clamp west. $\Delta T = -1^s.50$

Star.	τ	d	A	p	p A	p A²	p d	p A d	a A	Δ T₀	Δ	p Δ	p Δ²
	s.	s.					s.	s.	s.	s.	s.	s.	
ψ¹ Draconis	—1.17	+0.33	—1.30	0.25	—0.32	0.42	+0.08	—0.11	+0.36	—1.53	+0.05	+0.01	.0006
η Serpentis	1.70	—0.20	+0.79	1.00	+0.79	0.62	—0.20	—0.16	—0.22	1.48	0.00	0.00	.0000
1 Aquilæ	1.71	—0.21	+0.85	1.00	+0.85	0.72	—0.21	—0.18	—0.24	1.47	—0.01	—0.01	.0001
α Lyræ	1.49	+0.01	+0.23	0.85	+0.20	0.05	+0.01	0.00	—0.06	1.43	—0.05	—0.04	.0021
β Lyræ	1.61	—0.11	+0.32	0.90	+0.29	0.09	—0.10	—0.03	—0.09	1.52	+0.04	+0.04	.0014
50 Draconis	0.97	+0.53	—1.75	0.20	—0.35	0.61	+0.11	—0.19	+0.49	1.46	—0.02	0.00	.0001
				4.20	+1.46	2.51	—0.31	—0.67	Check, Σ	....	....	0.00	.0043

$$\left.\begin{array}{l}4.20\,\delta T+1.46\,a=-0.31\\ 1.46\,\delta T+2.51\,a=-0.67\end{array}\right\}\quad \text{hence } a=-0^s.280 \qquad \delta T=+0^s.02 \text{ and } \triangle T_0=-1^s.48$$

For the computation of the probable errors and weights, we have for the probable error of the unit of weights

$$\varepsilon_1=\sqrt{\frac{.455\,\Sigma\,p\triangle^2}{n_0-n_e}}=\pm 0.0221$$

where n_0=number of stars observed and n_e=number of unknown quantities or number of normal equations. Solving the weight equations

$$\left.\begin{array}{l}4.20\,Q+1.46\,q=1\\ 1.46\,Q+2.51\,q=0\end{array}\right\}\text{ and }\left\{\begin{array}{l}4.20\,q_1+1.46\,Q_1=0\\ 1.46\,q_1+2.51\,Q_1=1\end{array}\right.$$

we find $Q=.299$ $\qquad Q_1=.499$

hence the probable error of the time determination $\varepsilon_{\delta T}=\varepsilon_1\sqrt{Q}=\pm 0^s.012$

and the probable error of the azimuth determination $\varepsilon_a=\varepsilon_1\sqrt{Q_1}=\pm 0.016$

also the weights $P=\frac{1}{Q}=3.33$ for the time determination and $P_a=\frac{1}{Q_1}$ for the azimuth determination.

Reductions of observations for time—Continued.

Clamp east. $\Delta T = -1^s.50$

Star.	τ	d	A	p	p A	p A²	$p\,d$	p A d	a A	ΔT_0	Δ	$p\,\Delta$	$p\,\Delta^2$
	s.	*s.*					*s.*	*s.*	*s.*	*s.*	*s.*	*s.*	
ζ Aquilæ	−1.63	−0.13	+0.59	1.00	+0.59	0.35	−0.13	−0.08	−0.11	−1.52	+0.04	+0.04	.0016
δ Draconis	1.29	+0.21	−0.83	0.35	−0.29	0.24	+0.07	−0.06	+0.16	1.45	−0.03	−0.01	.0003
τ Draconis	1.27	+0.23	−1.42	0.25	−0.35	0.50	+0.06	−0.08	+0.27	1.54	+0.06	+0.01	.0009
κ Aquilæ	1.69	−0.19	+0.84	1.00	+0.84	0.71	−0.19	−0.16	−0.16	1.53	+0.05	+0.05	.0025
γ Aquilæ	1.58	−0.08	+0.63	1.00	+0.63	0.40	−0.08	−0.05	−0.12	1.46	−0.02	−0.02	.0004
α Aquilæ	1.55	−0.05	+0.65	1.00	+0.65	0.42	−0.05	−0.03	−0.12	1.43	−0.05	−0.05	.0025
ε Draconis	1.28	+0.22	−1.05	0.30	−0.32	0.33	+0.07	−0.07	+0.20	1.48	0.00	0.00	.0000
				4.90	+1.75	2.95	−0.25	−0.53					.0082

$$\left.\begin{array}{l}4.90\,\delta T+1.75\,a=-0.25\\ 1.75\,\delta T+2.95\,a=-0.53\end{array}\right\}\text{ hence } a=-0^s.190 \qquad \delta T=+0^s.02 \text{ and } \Delta T_0=-1^s.48$$

$$\varepsilon=\pm 0.273$$

$$\varepsilon_{\delta T}=\pm 0^s.011$$

$$P=3.86$$

hence the sum of the weights for August 16=7.19, a quantity which finds its application in the combination of the individual values for longitude referred to in § 2, example of results.

(4.) *Disposition in the observatory of telegraphic instruments and their electric connection.*—The arrangement and kind of instruments used by the observers were different at different times, and although the system adopted in 1879 was found to be most satisfactory, it is proposed to give here also a description of the disposition and use of the instruments during the period 1870 to 1878, inclusive, as illustrating the more simple arrangement still occasionally adopted when galvanometer and rheostat are dispensed with. For the following description of the use of the instruments and for the diagrams illustrating it, both before and after the rearrangement of the apparatus in 1879, the writer is indebted to Mr. Edwin Smith, assistant Coast and Geodetic Survey. Referring to the first appended plate, dispositions of instruments I, II, III relate to the period 1870–'78, and IV, V, VI to the present time. For the earlier period we have:

Arrangement I: *Circuits while observing transits.*—The chronometer breaks circuit B, causing pen on armature of chronograph magnet to record. The observer breaks circuit B with the observing key, also causing a record to be made.

Arrangements II and III: *Circuits while exchanging chronometer signals.*—At the *sending station* circuits are as in II, and at the *receiving* station as in III. When the chronometer at the sending station breaks circuit B, the armature of the chronograph magnet breaks the main circuit at x in II and the armature of the signal relay at receiving station breaks circuit B in III, causing the record to be made on chronograph.

Arrangement III: *Circuit while exchanging arbitrary signals.*—Circuits at both stations as in III. Arbitrary signals are made by breaking the main circuit with the signal key and the armature of the signal relays breaks circuits B, causing a record to be made at both stations.*

The present disposition and connection of instruments, as adopted in 1879, is due to Assistant Smith, who also arranged a suitable switch-board to effect readily the changes desired. See Appendix No. 7 of Coast and Geodetic Survey Report for 1880, "Explanation of Apparatus for observations of Telegraphic Longitudes, with directions for its use, 1881." For the period 1879–1880 we have—

Arrangement IV: *Circuits while observing transits.*—The chronometer breaks circuit A and the armature of the chronometer relay breaks circuit B, making the pen on the armature of the chronograph magnet record. The observer also breaks circuit B with observing key.†

*A sounder was also in circuit B, but when sending signals and observing it was cut out. This was a great inconvenience; when the sounder was in use the circuit B could not be used for observing.

†For *correspondence*, the talking relay and key only are connected with the main circuit. The batteries of the main circuit are always at the main office of the telegraph company.

Arrangement V: *Circuits while exchanging chronometer signals. Circuits the same at both stations.*—The chronometer breaks circuit A, the armature of the chronometer relay breaks the main circuit and the armatures of the polarized relays [now, in preference, the Farmer relays] break the circuits B at both stations; thus a record of chronometer signals sent and received is made on the chronographs at both stations. [Unless a break-circuit chronometer of a rate greatly differing from sidereal time, say gaining or losing one second in one minute, is provided, such ordinary chronometer signals are now little used for longitude work proper, as they repeat nearly the same fraction of a second. Still they are useful for identification of the minute of difference of longitude.]

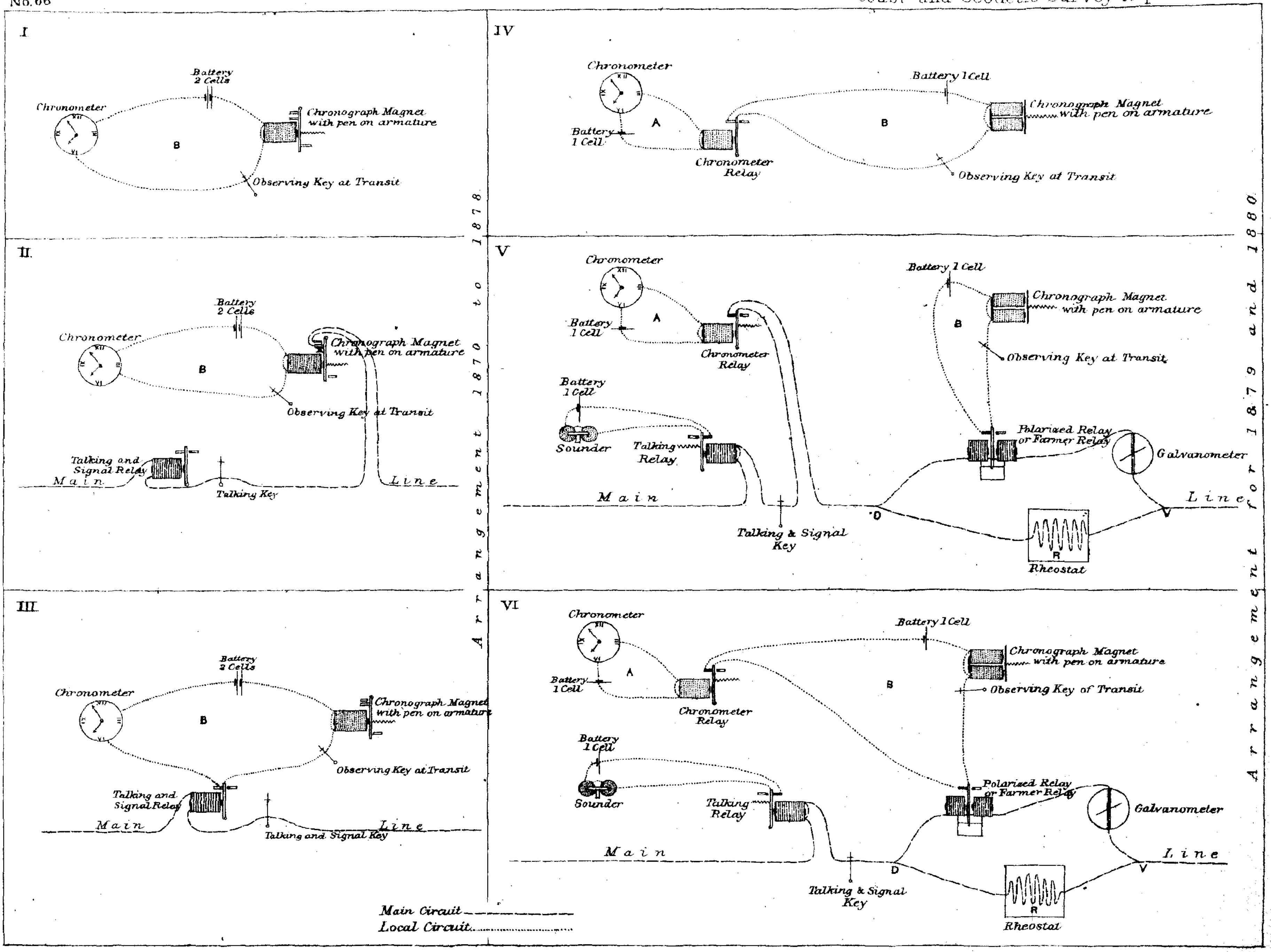
Arrangement VI: *Circuits while exchanging arbitrary signals. Circuits the same at both stations.*—The record of the chronometer is made as in figure IV, causing breaks in circuits A and B Arbitrary signals are made by breaking the main circuit with the signal or talking key and the armatures of the polarized [or of the Farmer] relays break circuits B at both stations.

NOTE.—The two polarized [or Farmer] relays are to be experimentally adjusted so as to record very nearly alike when the galvanometers have deflections of a certain number of divisions on the tangent scale. The galvanometers placed in branch circuits in cases V and VI are to be adjusted to this deflection by regulating the resistance in the branch D R V by means of the rheostat. It is proposed to use each set of instruments at each station during one-half the work [before exchange of observer and thus eliminate any constant difference in the records made by the two polarized [or Farmer] relays. In the extensive longitude work of 1881 a new signal relay was introduced, an instrument which proved superior to either the polarized* or the Farmer relays used in the preceding season. Its quickness of action depends mainly on the hollow and slit cylinders which form its core, on the shortness of the core and the distance of coils from the armature. With these signal relays the matter of equalizing the currents was found to be of less importance and the balancing of the currents was not always insisted on when the time during which the line wires were at the disposal of the party was short; it was however attended to when the galvanometer indications differed more from their normal indication than was desirable. The arrangement of the telegraphic apparatus in the observatories of 1881 is shown on the second plate accompanying this article, *vide* figures VII and VIII, which took the place of figures V and VI of the old arrangement.

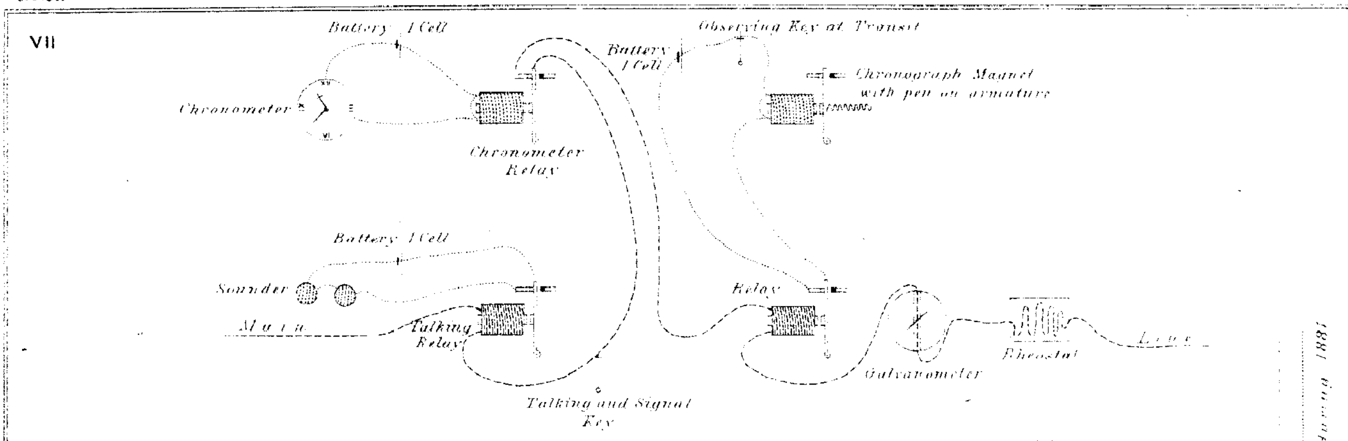
(5.) *Concluding remarks.*—The oldest chronograph, known as Bond's spring governor, though still of service, has been rivaled by the more portable Hipp fillet- or barrel-chronograph, regulated by a vibrating spring.† The noise made by these instruments is, however, very objectionable. The new cylinder chronograph of great accuracy, constructed by Fauth & Co., of Washington, supplied with a noiseless regulator, has proved of great efficiency; it can be adjusted for various speeds. Ordinarily, for records of transits a space of 9 millimeters ($\frac{1}{3}$ of an inch) represents one second of time, and during exchanges of signals, a double speed is given to the cylinder, making 18 millimeters to one second. These chronographs use but one pen; the marking fluid is the carmine ink manufactured by Thad. Davids & Co. of New York. This instrument is illustrated on the second plate. The chronograph sheet is read off to hundredths of a second.

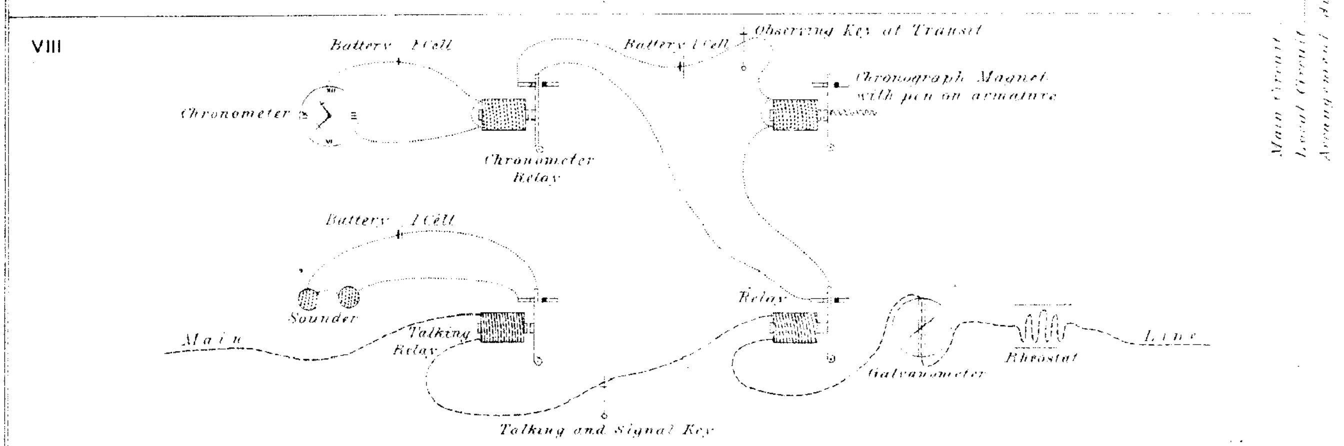
*This instrument required more attention than the other to put and keep it in proper adjustment and was less prompt in discharging.

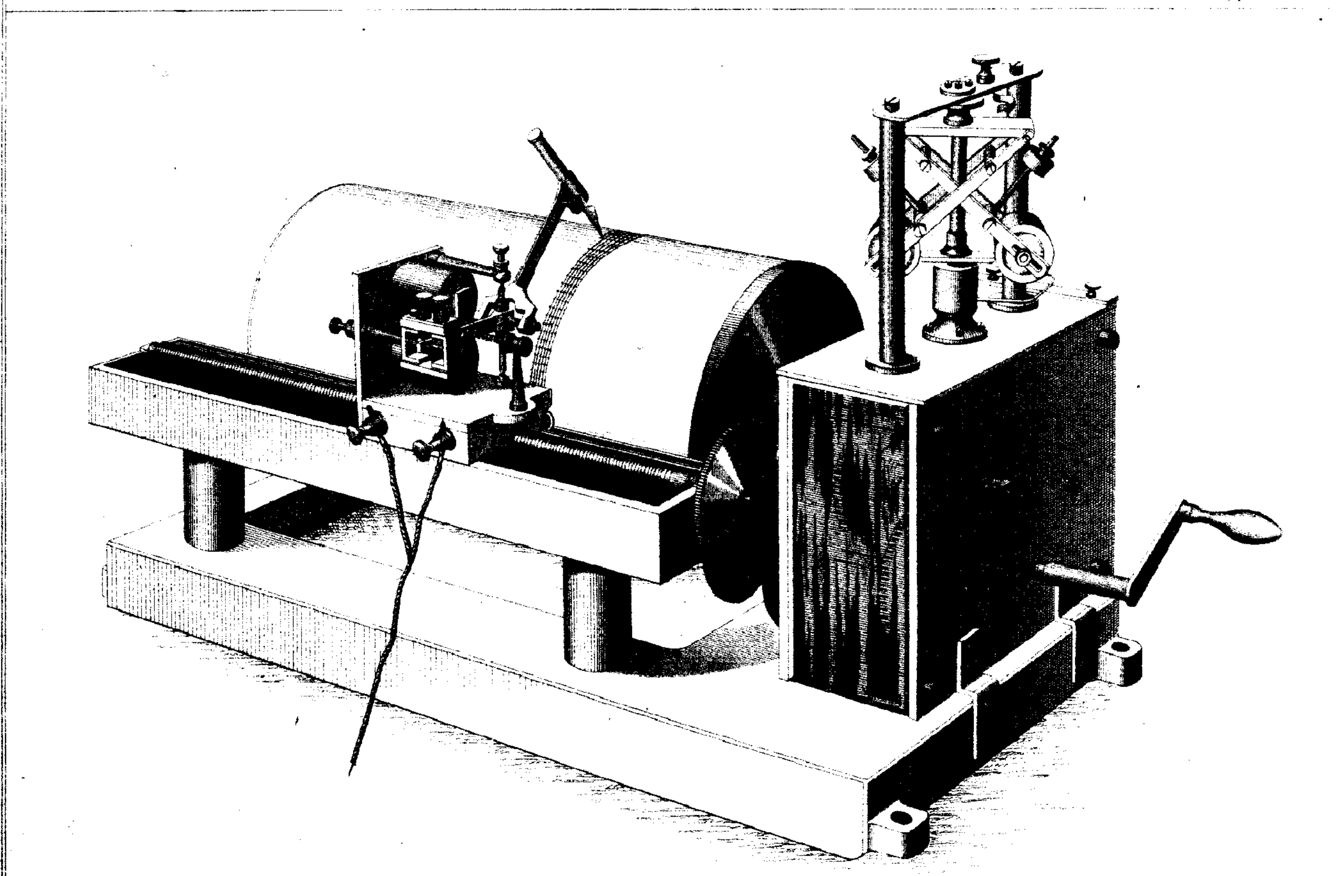
†See improvement of the Hipp chronograph, by W. Eimbeck; report of 1872, Appendix No. 18.



DISPOSITION AND CONNECTION OF TELEGRAPHIC INSTRUMENTS.







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CHRONOGRAPH

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PART III.

DETERMINATION OF LATITUDE

BY MEANS OF THE ZENITH TELESCOPE.

WITH ONE PLATE,

ILLUSTRATING

THE ZENITH TELESCOPE.

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PART III.

DETERMINATION OF LATITUDE BY MEANS OF THE ZENITH TELESCOPE.

(With one plate.)

(1.) *General remarks on Talcott's method.*—The method of determining the latitude or the declination of the zenith by means of the zenith telescope has been repeatedly described;* it was originally devised by Captain Andrew Talcott, late of the United States Corps of Engineers and was designed about the year 1834. It should however be mentioned that the instrument is figured on plates XII and XIII to the second volume of Pearson's "Introduction to Practical Astronomy," London, 1829 and its use as a latitude instrument is described on pp. 549–554 of Vol. II. The difference between this older method and Talcott's consists in the substitution by the latter of two stars of nearly equal and opposite zenith distance, for a single close zenith star. The range of applicability was thus greatly extended and the method soon became a favorite one with the practical astronomer. It substitutes micrometric measures of small differences of zenith distances in the place of measures of large arcs and it is to this improvement that the accuracy and facility of the method are chiefly due. In its application to latitudes, we measure the small difference of zenith distances of two stars culminating on opposite sides of the zenith, at nearly the same altitude and not far apart in time.

(2.) Since its introduction in the Coast Survey in 1846, the instrument has received some modifications to adapt it more fully to its use for latitude determinations, and it has now superseded all other instruments designed for the same purpose. The telescope turning freely through the zenith, and its horizontal axis being capable of accurate leveling, it was proposed by the late R. H. Fauntleroy, assistant in the United States Coast Survey, to determine also the local time by means of this instrument, and it has been so used, giving results of sufficient precision for the determination of the latitude. On the other hand, Assistant George Davidson,** in 1853 and, subsequently, Professor C. S. Lyman, of New Haven, suggested and practically illustrated† the temporary conversion of the ordinary transit instrument into a zenith telescope by attaching to the former the delicate level and micrometer; the great advantage of this combination, both in regard to economy and facility of transportation, need not here be pointed out. Professor Chauvenet also remarks that the instrument may be applied for finding the longitude from equal zenith distances of the moon's limb and a neighboring star.

As the time does not require to be known with great precision, the nearest second or two being ample, it may be obtained either by a sextant, using the method of equal altitudes, by a small portable transit, or by the zenith telescope itself;‡ in the latter case, a meridian mark, with two lamps,

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* See The Journal of the Franklin Institute (Philadelphia) of October, 1838. It contains remarks upon the method and an abstract of results, by Professor Courtenay;

A report by Major Emory, United States Topographical Engineers, in connection with the northeastern boundary survey of the United States;

A pamphlet by Captain T. J. Lee, United States Topographical Engineers, and assistant in the United States Coast Survey, dated April, 1848;

A pamphlet by the late A. D. Bache, Superintendent of the United States Coast Survey, New Haven, 1852, being extracted from the American Journal of Science and Arts, vol. xiv, second series. This paper was read before the American Association for the Advancement of Science, at their fifth meeting, in Cincinnati—*vide* vol. v, p. 151;

An article in the United States Coast Survey Report for 1857, pp. 324–334; and

An account in Chauvenet's Manual of Spherical and Practical Astronomy: Philadelphia. 1863, vol. ii, pp. 340–366.

** New Meridian Instrument for Time, Latitude, and Azimuth, by George Davidson, assistant, Coast Survey; Report of 1867, appendix No. 8. Also, Coast and Geodetic Survey Report of 1879, appendix No. 7.

† "On the transit instrument as a substitute for the zenith telescope in determining latitude, and on the latitude of New Haven." By Professor C. S. Lyman. American Journal of Science and Arts, vol. xxx, July, 1860.

‡ See Report of 1869, appendix No. 12. On the use of the zenith telescope for observations of time, by J. E. Hilgard, assistant.

differing from the middle line exactly by the distance of the vertical axis of the telescope from its line of collimation, will be found convenient.

(3.) *Description of the instrument.*—Referring to the accompanying plate, which exhibits the instrument as now constructed, a brief and general description of it will suffice. The telescope has an aperture of about 9^{cm} ($3\frac{1}{2}$ inches), and a focal length of about 114^{cm} (45 inches), and admits of observing with convenience stars as small as the $6\frac{1}{2}$th or 7th magnitude. The magnifying power used varies between 60 and 120. The telescope-tube turns about a horizontal axis nearly 18^{cm} (7 inches) in length, and is balanced by a weight in such manner as to prevent unequal pressure and flexure of the axis. This axis is supplied with a striding level and when horizontal the line of collimation of the telescope will move in a vertical plane; it is perforated and polished and the light of a lamp passes through it for the illumination of the micrometer and other threads. The vertical axis is supported by a column about 61^{cm} (24 inches) in height and at its lower end carries a clamp and vernier in connection with the azimuth circle. The horizontal circle is about 30^{cm} (12 inches) in diameter, and is graduated to read to half-minutes or less; two movable stops can be applied to it, defining on the instrument the position of the plane of the meridian and without interfering with the motion of the axis while reversing. The whole rests upon three foot-screws, by means of which the instrument can be leveled.

A delicate level (value of one division about $\frac{3}{4}$ of a second) at right angles to the horizontal axis is connected with the telescope, and revolves on a center so as to indicate the inclination of the telescope; concentric with the level-pivot and firmly connected with the tube is a graduated 30^{cm} (12-inch) semicircle, or a 15^{cm} (6-inch) full circle, on which zenith distances are read off to the nearest $30''$ by means of the arm and vernier attached to the movable level. The telescope can be set to any inclination and clamped; for accurate pointing, the bubble is brought into the middle by a fine-motion screw.

The micrometer screw carries a movable thread for the measure of the difference of zenith distances; its head is divided in 100 parts, of which tenths may be estimated; the whole number of turns are read off by means of a rack, shown on the side of the field of view. The value of one revolution of the micrometer is about $45''$. There are also two fixed threads parallel to the micrometer thread, about $15'$ or $20'$ apart, indicating the range between which the latter is ordinarily employed. To provide for the case of transit observations, there are also five equidistant vertical threads inserted symmetrically over the optical center of the field. For convenience of observing, the telescope is supplied with a prismatic eye-piece.

The instrument may be mounted on blocks of stone, brick, or wood. Other forms of the zenith telescope and adaptations thereto of transit instruments have already been mentioned in Part I.

(4.) *Adjustment of the instrument.*—When setting up, it will be found convenient to place two of the foot screws in an east and west line; the adjustments of the instrument may then be made as follows: The vertical axis to be made truly vertical by means of a striding level, which should not change when the instrument is made to describe a complete revolution in azimuth. The verticality should also be tested by the more sensitive level of the setting circle, in order to avoid large level corrections or a change in the position of the telescope. The horizontality of the transit axis is tested by the reversal of the striding level. The eye-piece is next adjusted to sidereal focus by means of the definition of a circumpolar star, and the threads of the diaphragm are properly focused. It is important that this adjustment should not be disturbed during the observations, and to make sure of it a leaden collar or a clamping screw is sometimes employed to keep the sliding tube in position. The horizontality of the micrometer thread is proved by an equatorial star running along the thread, or by the same appearance of a polar star, when the instrument is turned in azimuth, and the verticality of the system of transit threads may either be inferred from this last adjustment or may be tested by the bisection of a distant well-defined terrestrial object when the telescope is slightly elevated or depressed. The same terrestrial object may be used for the adjustment of the line of collimation, which may be effected by two positions of the instrument exactly 180° apart in the readings of the azimuth circle and making allowance for eccentricity; thus let d = distance of vertical axis from the line of collimation of the telescope, D = distance of object, and p = parallax, then

$$p = \frac{d}{\mathrm{D} \sin 1''}$$

A perfect adjustment, however, may be made by means of two collimating telescopes, or by the method employed when using a transit instrument in two positions of the clamp for the same purpose.

The reading, on the horizontal circle, of the plane of the meridian is ascertained by means of the known chronometer time of the culmination of a slow-moving star, which is bisected at that time by the middle thread and the corresponding reading of the circle noted; clamps are then applied to indicate the meridional position with the telescope pointing north or south of the zenith.

(5.) *Selection of stars for observation.*—The observer will next prepare an observing list of pairs of stars, containing the catalogue number of the star, its magnitude, the right ascension and declination, the zenith distance, north or south, and the middle zenith distance of the pair or the setting. The weak point of the method is want of sufficient accuracy in the catalogue star-places; they may deviate as often one way as the other without doing more than increasing the probable error of a resulting latitude, but when the errors are of a constant nature they seriously affect any deduced latitude which may depend upon them; hence too much care cannot be bestowed upon a proper selection of pairs from the catalogues and only those should be taken which have a satisfactory or, at least, more than one reliable authority. The catalogues usually employed formerly were those of the British Association and of the Greenwich Observatory;* they will furnish, generally, from one to three dozen of pairs in our latitudes for almost any night in the year. These catalogues are now in a great measure superseded by the Coast Survey catalogue of stars for observations of latitude. (Report of 1876, Appendix No. 7, Washington, 1879.) The programme should commence with stars of the earliest right ascensions permitting observation on account of daylight and be continued to as early a morning hour as the observer may find expedient. If there is an abundance of suitable pairs for the period, two lists may be made out covering the same time but observable on alternate nights. In selecting stars, suitable ones culminating *sub polo* should be included, and catalogues should be particularly examined for stars passing so near the zenith as to be within range of the micrometer with the instrument pointing north or south.

The latitude of the station requires to be known only within one or two minutes, which degree of approximation may be had either from a chart, sextant observations, or by means of the finding-circle of the transit instrument or of the zenith telescope itself.

The two stars forming a pair should culminate at nearly equal zenith distances, one north the other south of the zenith and their difference of zenith distance should, if possible, not much exceed one-half the breadth of the field of the telescope to avoid observing near its edge; about 15′ (or at most 20′) is the greatest range desirable for our instruments. The interval of time between the culmination of stars forming a pair should not be less than one minute, to give time to read deliberately the micrometer and to turn the instrument in azimuth for observing the second star and should not usually exceed 20 minutes, to guard against possible changes in the state of the instrument. The interval between any two pairs should afford time for reading the micrometer and level and for setting the instrument preparatory to the next pair; for this three minutes suffice for most observers. If the intervals between the pairs are unavoidably long, they may be filled up by observing transits for time. Stars as low as the 7th magnitude may be selected; their places are, however, generally not well determined; on the other hand, brighter stars are too few in number.

It is desirable to select the pairs with regard to their difference of zenith distances, making the

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* The catalogue of stars of the British Association, reduced in January 1, 1850, by the late Francis Baily. London, 1845.

Catalogue of 2156 stars formed from the observations made during 12 years, from 1836 to 1847, at the Royal Observatory, Greenwich. London, 1849.

Catalogue of 1576 stars formed from the observations made during six years, from 1848 to 1853, at the Royal Observatory, Greenwich, and reduced to the epoch 1850. London, 1856.

Seven-year catalogue of 2022 stars reduced from observations between 1854 and 1860, at the Royal Observatory Greenwich, and reduced to the epoch 1860. Volume for 1862.

New seven-year catalogue of 2760 stars for 1864 reduced from observations extending from 1861 to 1867, at the Royal Observatory, Greenwich. Appendix II to volume of Greenwich observations for 1868.

To these may now be added:

Nine-year catalogue of 2263 stars for epoch 1872 from observations extending from 1868 to 1876, forming Appendix I to the volume of Greenwich observations for the year 1876.

Catalogue of stars observed at the United States Naval Observatory during the years 1845 to 1877. Second edition, Washington, 1878.

sum of all the *positive* micrometer corrections equal to the sum of all the *negative* corrections, which condition leaves the final latitude free from any effect of error in the value of the micrometer screw.

From 15 to 20 pairs of stars, if well selected from a modern catalogue with reliable star-places and observed each on, say, 5 nights, will generally suffice to give a satisfactory value for the latitude of a place—that is the probable error of the latitude may be expected to be below 0″.1 To bring the probable error down to ±0″.05 or less, will require more pairs.

No precise limit can be given of the greatest zenith distance compatible with the requirements of the method, but it may be readily extended to 25° and beyond; however, the greater the inclination of the telescope the greater the flexure, any inequality of which in the two positions of the tube and which is not shown by the level, would affect the result. In Steinheil's prismatic transit and zenith telescope there is no such flexure, but the observer must assure himself of the fixity in the position of the prism. The following specimen of a list of selected pairs of stars will serve to show the usual arrangement:

Pairs of stars proposed for observation during August and September, 1856, with zenith telescope No. 5, for latitude of station Mount Desert, Maine.

Approximate $\phi = 44° 21'.1$

Star No.	Catalogue.	Mag.	α	δ	ζ	N. or S.	Setting.
			h. m. s.	° ′	° ′		° ′
6062	B. A. C.	5½	17 47 24	+ 40 01	4 20	S.	
6068	"	5½	48 36	40 02	4 19	S.	4 13
6129	"	5	59 23	48 28	4 07	N.	
6255	"	5	18 17 52	49 03	4 42	N.	
6268	"	5½	19 29	39 26	4 55	S.	4 46
6357	"	6	33 21	39 33	4 48	S.	
6395	"	5	39 50	55 24	11 03	N.	
6429	"	3	44 47	33 12	11 09	S.	11 07
6522	"	6	57 53	55 27	11 06	N.	
6553	"	6	19 01 59	32 17	12 04	S.	12 10
6583	"	5	08 57	56 37	12 16	N.	
6629	"	6½	15 28	62 57	18 36	N.	18 29
6637	"	6	16 58	25 59	18 22	S.	
etc.							

The columns headed α, δ, ζ, contain the approximate right ascension, declination, and zenith distance of each star.

(6.) *Directions for observing.*—The instrument being adjusted and the line of collimation of the telescope placed in the meridian, in which position the azimuthal motion is arrested by the stops, the index of the vertical circle is set to the mean zenith distance of the first pair taken from the list previously prepared, on which list the chronometer time of culmination of each star for the night is noted. The telescope is then directed to that side of the zenith where the first star will culminate and the bubble of the level is made to play very nearly in the middle. As soon as the star enters the field and when transiting on one of the vertical wires, or at any convenient number of seconds before the culmination, the observer will pick up the beat of the chronometer and bisect the star with the micrometer thread and keeping it bisected up to the instant of culmination; the level and micrometer are then read, the instrument is revolved 180° and the second star is observed in the same manner. During these observations, the tangent screw of the vertical circle must not be touched, though the tangent screw which gives a slow motion to the telescope (and consequently also to the level) may be used after the reversal of the instrument in the exceptional case when the vertical axis of the instrument is not well adjusted.

(7.) If for some reasons the meridian observation fails, the star may be bisected off the meridian and the time noted. This may be done in two ways, either by moving the telescope in azimuth and bisecting in the line of collimation, or by observing the star off the middle of the field, leaving the telescope undisturbed in the plane of the meridian. The latter method is generally the preferable one, particularly when the star culminates near the zenith. If, however, the meridional distance of the star be considerable, the first method had better be followed.

Though the star may be bisected several times while passing through the field, in our experience little is gained in multiplying observations upon the same star under *the same circumstances.* The relative accuracy of a single observation, and of the position of a star assigned by the catalogues, points to the multiplication of stars rather than to that of repeated pointings on the same star.

It is not advisable to combine more than one north star with more than one south star, for the reason that greater accuracy is gained by observing pairs on different nights and in case of an imperfection in the position assigned to any of the stars thus combined it would be difficult to detect the faulty one. It is preferable, therefore, to break up combinations into pairs. We have, however, many cases where one star enters as a component of a pair with different stars.

Each pair is generally observed on five or six nights; a greater number of observations would add but very little to the value of the mean result, as will be seen in the discussion of the relative weights.

(8.) *General expression for the latitude.*—Let ζ and ζ' equal the true meridional zenith distance of the southern and northern star and δ and δ' the declination of the same, respectively; then the expression for the latitude is

$$\varphi=\tfrac{1}{2}(\delta+\delta')+\tfrac{1}{2}(\zeta-\zeta')$$

Now, if z, z' denote the observed zenith distance of the south and the north star; n, s the north and the south reading of the level for the south star and n', s' the same for the north star; b the value of one division of level; r and r' the refraction correction and m and m' the reduction to the meridian for the south and the north star, respectively, then

$$\varphi=\tfrac{1}{2}(\delta+\delta')+\tfrac{1}{2}(z-z')+\frac{b}{4}\left\{(n+n')-(s+s')\right\}+\tfrac{1}{2}(r-r')+\tfrac{1}{2}(m'-m)$$

and if M and M′ be the micrometer readings of the south and the north star, the micrometer being supposed to read *from* the zenith and R the value of one division, then

$$\tfrac{1}{2}(z-z')=\tfrac{1}{2}(M-M')R$$

If the micrometer reads *toward* the zenith (the direction appears, of course, inverted in the astronomical telescope), change M−M′ into M′−M and it may be remarked here that during half of the observations at the station the instrument may be used in the reversed position of the telescope with regard to the vertical axis, thus varying the circumstances under which measures are taken.

(9.) *Determination of the value of a division of the micrometer.*—Different methods have been used for this purpose; the one formerly most frequently employed was by turning the micrometer at right angles to the position in which it is used for making latitude observations and noting the times of the passage of a close circumpolar star near culmination over the micrometer thread placed successively before the star for each turn or half-turn of the screw; now, let τ=interval (converted into seconds of arc) from culmination, and δ = the star's declination, then the sine of the angular distance from the meridian = $\sin\tau\cos\delta$ and the differences of quantities thus computed, divided by the corresponding differences in the screw-readings, give the value of one division. The treatment of a set of observations by application of the method of least squares is given by J. E. Hilgard, assistant in the United States Coast Survey, in Gould's Astronomical Journal, No. 36 (Cambridge, March 13, 1852). Another method, formerly employed, was to measure the angular space covered by a well-defined distant terrestrial object by means of a suitable theodolite and also by means of the micrometer-screw, from which the value of the latter will readily result. The method, however, introduced in 1847 by C. O. Boutelle, assistant in the United States Coast Survey, and now almost exclusively used, consists of observing a close circumpolar star near its elongation when rapidly rising or falling, accompanied with but a slight motion in azimuth; this method avoids the risk of a disturbance in the *focal adjustments;* it requires the reading of the level in order to allow for possible changes, and necessitates a correction for differential refraction.

By $\cos t_e=\cot\delta\tan\varphi$ and $\cos\zeta_e=\operatorname{cosec}\delta\sin\varphi$ we find the star's hour angle t_e and zenith distance ζ_e at elongation; and if α=star's right ascension and ΔT=chronometer correction, then

Chronometer time of elongation $=\alpha-\Delta T\pm t_e$ where $\left\{\begin{matrix}+\\-\end{matrix}\right\}$ for $\left\{\begin{matrix}\text{western}\\\text{eastern}\end{matrix}\right\}$ elongation.

About 40 or more minutes before the elongation, the telescope is directed to the star, and transits are noted, the micrometer thread being set in advance, consecutively, by whole, half, or quarter turns of the screw, throughout its length. A correction for rate of chronometer should be applied, if sensible. It is well to note the temperature, since the value of the screw may vary with a change of temperature.

Let t = difference of time of observation and elongation of the star, and z'' = number of seconds of arc in the direction of the vertical from elongation, then

$$z''=\frac{\cos\delta\sin t}{\sin 1''}$$

for which we can write

$$z''=15\cos\delta\left\{t-\tfrac{1}{6}(15\sin 1'')^2t^3\right\}$$

where t is expressed in seconds of time. It is convenient to apply the term $\frac{1}{6}(15\sin 1'')^2t^3$ to the observed time of noting, additive to the observed time before, and subtractive after, either elongation. The following table gives the value of $\frac{1}{6}(15\sin 1'')^2t^3$, also of the additional term $-\frac{1}{120}(15\sin 1'')^4t^5$ when sensible, for every minute of time from elongation to 65^m.

t	Term.	t	Term.	t	Term.	t	Term.	t	Term.	t	Term.
m.	*s.*	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*	*m.*	*s.*
6	0.0	16	0.8	26	3.3	36	8.9	46	18.5	56	33.3
7	0.1	17	0.9	27	3.7	37	9.6	47	19.7	57	35.1
8	0.1	18	1.1	28	4.2	38	10.4	48	21.0	58	37.0
9	0.1	19	1.3	29	4.6	39	11.3	49	22.3	59	39.0
10	0.2	20	1.5	30	5.1	40	12.2	50	23.7	60	41.0
11	0.2	21	1.8	31	5.7	41	13.1	51	25.2	61	43.1
12	0.3	22	2.0	32	6.2	42	14.1	52	26.7	62	45.2
13	0.4	23	2.3	33	6.8	43	15.1	53	28.3	63	47.4
14	0.5	24	2.6	34	7.5	44	16.2	54	29.9	64	49.7
15	0.6	25	3.0	35	8.2	45	17.3	55	31.6	65	52.1

The correction to be applied to the observed times of noting for change of level is given by the formula

$$\pm\left\{\tfrac{1}{2}(n-s)-\tfrac{1}{2}(n_0-s_0)\right\}\frac{b}{15\cos\delta}$$

where n_0, s_0 the north and the south readings for a selected state of level; n, s the north and the south readings for any other state and b the value of one division of level in seconds of arc. The upper sign is to be used for western, the lower sign for eastern elongation.

After these two corrections have been applied to the observed times of noting, we have in one column the readings of the micrometer and in another the corresponding times, such as would have been observed if the star had moved uniformly in a vertical line, leaving out of consideration, for the present, the change in refraction. Various methods of combination might be adopted for the determination of the turn of the screw; that followed in the example, where we subtract the values resulting from the first observation from those of the middle one, next those of the second from those of the middle one plus one, and so on, recommends itself for its simplicity and is probably only inferior to that which employs the method of least squares. We thus obtain a number of values for the time of a given number of turns, half, or quarter-turns, from which we deduce the value of one turn by the formula given above; the correction for refraction (in seconds of arc) is negative for either eastern or western elongation and equals the change of refraction for the space equal to one turn=value of one turn times difference of refraction for 1′ at star's altitude divided by 60. The probable error of the resulting value of one turn is readily found; see example appended to this paper. If we wish to proceed with the utmost rigor, the method of least squares should be applied, a development of which is given in Chauvenet's article on the zenith telescope, above cited, page 363. It is sufficiently explained by the following statement and the example. Let M_0=the unknown reading of micrometer for the time of elongation or for the middle time of any one set of observations near elongation, or for T_0; also, M_1 = an assumed approximate value for M_0 and μ its correction; also, R_1 = an assumed approximate value for R and ρ its correction; then

$$M_0 = M_1 + \mu \quad \text{and} \quad R = R_1 + \rho$$

If we now subtract each micrometer reading M from M_0 and each corresponding time from T_0 and also convert these intervals into differences of zenith distance, or into $z-z_0$ using the first term of our formula and put $n=z-z_0-(M_1-M)R_1$ we have for each observation the conditional equation $n=R_1\mu+(M_1-M)\rho$ from which we form the normal equations in the usual way and deduce the two quantities μ and ρ. The additional labor is considerable and since the result differs only from that found by the preceding method by a small fraction of the probable error of R, we may, in all ordinary cases, dispense with its application.*

It is hardly necessary to remark that a number of sets of observations, for value of one turn of screw, are usually taken and their results are combined to a mean.

(10.) *Determination of the value of one division of the level.*—The value of one division of the level may be found in different ways, according to the means available. The temperature should be noted, since the result may change with a change of temperature. The value may be found directly with a level-trier or by attaching the level to a well-divided vertical circle and measuring directly the angular value passed over by a change of inclination of a given number of divisions in the position of the bubble; a distant object may be sighted as a mark or, better, a second instrument may be used as a collimator and in connection with it; the angular space is measured with the micrometer screw, the value of which is already known. To employ a star for a mark renders the determination unnecessarily complex. In the example appended, the value of a division of level is found in terms of the micrometer screw, the bubble is made to traverse the whole length of graduation and the micrometer differences corresponding to the displacements of the bubble by a change of inclination are measured by pointing on a collimator; such observations, in particular, should include those divisions of the level which come most commonly into use during the observations for latitude.

(11.) *Correction for differential refraction.*—The difference of refraction for any pair of stars is so small that we can neglect the variation in the state of the atmosphere at the time of the observation from that mean state supposed in the refraction tables. The refraction being nearly proportional to the tangent of the zenith distance, the difference of refraction for the two stars will be given by

$$r - r' = 57''.7 \sin (z - z') \sec^2 z$$

and since the difference of zenith distances is measured by the micrometer, the following table of correction to the latitude for differential refraction has been prepared for the argument ½ difference of zenith distance or ½ difference of micrometer reading at the side and the argument "Zenith

* In case no special observations for value of micrometer have been made, we may still find it from the latitude observations themselves. Let R = approximate value of one turn of the micrometer as used in the computation and dR its correction; also, φ=the latitude resulting from all the pairs by the use of R, and $d\Phi$ its correction. Let $M_1, M_2, M_3 \ldots$ = half the mean difference of micrometer-readings of the south and the north stars of the several pairs, $\varphi_1, \varphi_2, \varphi_3 \ldots$ the results for latitude by the several pairs; we then have the conditional equations

$$M_1 dR - d\varphi = \varphi - \varphi_1$$
$$M_2 dR - d\varphi = \varphi - \varphi_2$$
$$\text{etc.}$$

which gives the normal equations for finding dR and $d\varphi$

$$\Sigma M\, dR - \Sigma d\varphi = \Sigma(\varphi - \varphi_0)$$
$$\Sigma M^2 dR - \Sigma M d\varphi = \Sigma M(\varphi - \varphi_0)$$

If weights are given to the several pairs depending upon the probable error of declination of stars and upon the number of observations on a pair, they may readily be introduced in the above normal equations. To find a reliable value, however, by this method, it is essential that the errors in the catalogue-places of stars should be as small as possible.

distance" on the top of the table. The sign of the correction is the same as that of the micrometer difference.

½ diff. in zenith distance.	Zenith distance.						½ diff. in zenith distance.	Zenith distance.					
	0°	10°	20°	25°	30°	35°		0°	10°	20°	25°	30°	35°
′	″	″	″	″	″	″	′	″	″	″	″	″	″
0	.00	.00	.00	.00	.00	.00	6.5	.11	.11	.12	.13	.14	.16
0.5	.01	.01	.01	.01	.01	.01	7	.12	.12	.13	.14	.15	.18
1	.02	.02	.02	.02	.02	.02	7.5	.13	.13	.14	.15	.16	.19
1.5	.02	.03	.03	.03	.03	.03	8	.13	.14	.15	.16	.18	.21
2	.03	.03	.04	.04	.04	.05	8.5	.14	.15	.16	.17	.19	.22
2.5	.04	.04	.05	.05	.05	.06	9	.15	.16	.17	.18	.20	.23
3	.05	.05	.06	.06	.07	.08	9.5	.16	.17	.18	.20	.21	.24
3.5	.06	.06	.07	.07	.08	.09	10	.17	.18	.19	.21	.23	.26
4	.07	.07	.08	.08	.09	.10	10.5	.18	.19	.20	.22	.24	.27
4.5	.08	.08	.09	.09	.10	.11	11	.18	.19	.21	.23	.25	.28
5	.08	.09	.10	.10	.11	.13	11.5	.19	.20	.22	.24	.26	.30
5.5	.09	.10	.10	.11	.12	.14	12	.20	.21	.23	.25	.27	.31
6	.10	.10	.11	.12	.13	.15	12.5	.21	.21	.24	.26	.28	.32

(12.) *Reduction to the meridian.*—First, when the line of collimation of the telescope is off the meridian, the instrument having been revolved in azimuth and the star observed at the hour-angle τ, near the middle thread, then

$$m=\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}\cdot\frac{\cos\varphi\cos\delta}{\sin\zeta}$$

and the correction to the latitude, if the two stars are observed off the meridian $=\frac{1}{2}(m'-m)$, as given in Art. (8.) The value of

$$\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}$$

for every second of time up to two minutes (a star being rarely observed at a greater distance than this from the meridian in zenith-telescope observations) is given in the following table:

τ	Term.	τ	Term.	τ	Term.	τ	Term.	τ	Term.	τ	Term.
s.	″	s.	″	s.	″	s.	″	s.	″	s.	″
1	0.00	21	0.24	41	0.91	61	2.03	81	3.58	101	5.56
2	0.00	22	0.26	42	0.96	62	2.10	82	3.67	102	5.67
3	0.00	23	0.28	43	1.01	63	2.16	83	3.76	103	5.78
4	0.01	24	0.31	44	1.06	64	2.23	84	3.85	104	5.90
5	0.01	25	0.34	45	1.10	65	2.31	85	3.94	105	6.01
6	0.02	26	0.37	46	1.15	66	2.38	86	4.03	106	6.13
7	0.02	27	0.40	47	1.20	67	2.45	87	4.12	107	6.24
8	0.03	28	0.43	48	1.26	68	2.52	88	4.22	108	6.36
9	0.04	29	0.46	49	1.31	69	2.60	89	4.32	109	6.48
10	0.05	30	0.49	50	1.36	70	2.67	90	4.42	110	6.60
11	0.06	31	0.52	51	1.42	71	2.75	91	4.52	111	6.72
12	0.08	32	0.56	52	1.48	72	2.83	92	4.62	112	6.84
13	0.09	33	0.59	53	1.53	73	2.91	93	4.72	113	6.96
14	0.11	34	0.63	54	1.59	74	2.99	94	4.82	114	7.09
15	0.12	35	0.67	55	1.65	75	3.07	95	4.92	115	7.21
16	0.14	36	0.71	56	1.71	76	3.15	96	5.03	116	7.34
17	0.16	37	0.75	57	1.77	77	3.23	97	5.13	117	7.46
18	0.18	38	0.80	58	1.83	78	3.32	98	5.24	118	7.60
19	0.20	39	0.83	59	1.89	79	3.40	99	5.34	119	7.72
20	0.22	40	0.87	60	1.96	80	3.49	100	5.45	120	7.85

Secondly, when the star is observed off the line of collimation, the instrument remaining in the plane of the meridian, then

$$m=\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}\sin\delta\cos\delta \qquad\text{or}\qquad m=\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}\cdot\frac{1}{2}\sin 2\delta$$

and the correction to the latitude is half of this quantity, whether the star be north or south and if the two stars forming a pair are observed off the line of collimation, two such corrections, separately computed, must be added to the latitude. If the stars should be south of the equator, the essential sign of the correction is negative. The value of m for every 5° of declination is given in the following table:

	10s.	15s.	20s.	25s.	30s.	35s.	40s.	45s.	50s.	55s.	60s.	
δ	"	"	"	"	"	"	"	"	"	"	"	δ
5°	.00	.01	.02	.03	.04	.06	.08	.10	.12	.14	.17	85°
10	.01	.02	.04	.06	.08	.11	.15	.19	.23	.28	.34	80
15	.01	.03	.05	.09	.12	.17	.22	.28	.34	.41	.49	75
20	.02	.04	.07	.11	.16	.22	.28	.36	.44	.53	.63	70
25	.02	.05	.08	.13	.19	.26	.34	.42	.52	.63	.75	65
30	.02	.05	.09	.15	.21	.29	.38	.48	.59	.71	.85	60
35	.03	.06	.10	.16	.23	.31	.41	.53	.64	.77	.92	55
40	.03	.06	.11	.17	.24	.33	.43	.54	.67	.81	.97	50
45	.03	.06	.11	.17	.25	.33	.44	.55	.68	.82	.98	45

(13.) *Record of the observations.*—The observations for latitude are recorded in a note-book, ruled to suit the convenience of the observer and of a form similar to the following:

Record Z. T. latitudes.

Station, ———. Date, ——— ———.
Instrument, ———. Observer, ——— ———.

No.	Catalogue star-number.	North or south.	Micrometer.		Level.		Chronometer time of observation.	Remarks.
			Turns.	Divisions.	North.	South.		

The first column shows the number of times each pair has been observed; the other columns explain themselves. (See example appended.)

(14.) *Reduction of the observations.*—The reduction will be facilitated by the use of any convenient printed form, of which the following may be taken as a specimen:

(Left-hand page.)

U. S. Coast and Geodetic Survey.
Section ———. Latitude-station ———. State ———.

Date.	Star.		Micrometer.		Level.			Meridian distance.	Declination.
	No.	N. S.	Reading.	Diff. Z. D.	N.	S.	Diff. N−S.		
			t. d.	t. d.				s.	° ′ ″

(Right-hand page.)

Latitude computation.

Instrument ———. Telescope No. ———.

Sum and half sum.	Corrections.				Latitude.	Remarks.
	Microm.	Level.	Refr.	Merid.		
° ′ ″	′ ″	″	″	″	° ′ ″	

For the mean places of stars to be used in the computation the computer consults all catalogues of precision and in addition to those already mentioned in § (5) the following: United States Northern Boundary Commission; Declination of Fixed Stars, by Assistant Lewis Boss, director of Dudley Observatory, 1877. Reale Accademia dei Lincei; Catalogo delle Declinazioni medie pel 1875; Roma, 1880. Catalogue of 618 stars observed at the astronomical observatory of Harvard College; Cambridge, 1880. Catalogue of 1098 standard clock and zodiacal stars; Simon Newcomb, Prof. U. S. N., Supt. Amer. Ephem. (published in 1881) and other catalogues. The values of a star's declination from all catalogues available are tabulated and the *most probable* value is selected according to the weight to be attached to each result. The question of the effect of proper motion enters conspicuously into the judgment for assigning relative weights.

(15.) *Discussion of the results.*—The weights of the results by each pair differ with the number of observations upon each pair, with the number of times a star enters into any such combinations and with the accuracy of the star's position as found from the catalogues.

To find the weight due to the number of observations or the probable error of observation, let n = number of observations upon a pair, p = number of pairs, Δ = difference of latitude between each observed result and the mean result deduced for the respective pair (see example to Art. 14), $[\Delta^2]$ = sum of all the Δ^2's for any one pair and $\Sigma[\Delta^2]$ the sum-total from all the pairs; then, if e = probable error of observation,

$$e^2 = \frac{0.455\ \Sigma[\Delta^2]}{n-p}$$

On the average, the value of e from many determinations is rather less than $\pm 0''.4$ and occasionally reaches $\pm 0''.3$ and even less; the corresponding probable error of an observed zenith distance equals $e\sqrt{2}$ or $\pm\ 0''.56$

To find the probable error e_ϕ of a resulting latitude by any one pair and the probable error e_δ of the mean of two declinations or of $\frac{1}{2}(\delta+\delta')$, or $e_{\frac{*+*}{2}}$, we must consider separately the errors of observation ε and the errors of declination; then

$$e_\delta^2 = e_\phi^2 - \varepsilon^2$$

The value of e_ϕ^2 is obtained by means of the difference $\triangle\varphi$ of the result for latitude by any one pair and by the mean of all the pairs; then

$$e_\phi^2 = \frac{0.455\ \Sigma\Delta\varphi^2}{p-1}$$

and the value of ε^2 is found by

$$\varepsilon^2 = \frac{e^2}{p-1}\left[\frac{1}{n}\right]$$

The value of e_δ being thus known, the probable error of a single declination becomes $\varepsilon_\delta = e_\delta\sqrt{2}$ and our weights will be found to differ for different catalogues. If but one catalogue is used, its declinations may be considered as affected with the same probable error, provided the authorities and number of observations from which the declinations were derived are the same; but if different catalogues are employed, the probable error and weight of any declination may be taken as found for the same authority by our previous experience. The average probable error of any single declination from the older catalogues may be taken as less than $\pm 0''.5$, but with the catalogues at present available (1881) it may be as low as $\pm 0''.4$

(16.) *Combination of the results by weights.*—If ε_δ and ε_{δ_1}=probable errors of the declinations of the stars of a pair, and n the number of observations on the pair, then

$$e_\delta = \tfrac{1}{2}\sqrt{(\varepsilon_\delta^2+\varepsilon_{\delta_1}^2)} \quad \text{and} \quad e_\phi = \sqrt{e_\delta^2 + \frac{e^2}{n}}$$

hence the weight of the result by a pair

$$\frac{n}{ne_\delta^2+e^2} = \frac{n}{\frac{n}{4}(\varepsilon_\delta^2+\varepsilon_{\delta_1}^2)+e^2}$$

and for an equal probable error of the declinations the weight

$$\frac{n}{\frac{n}{2}\varepsilon_\delta^2+e^2}$$

and since the weights need only be proportional numbers, we may divide by 4 and use the expressions for combination-weights

$$w=\frac{n}{n(\varepsilon_\delta^2+\varepsilon_{\delta_1}^2)+4e^2}$$

and for equal errors of declination

$$\frac{n}{2n\varepsilon_\delta^2+4e^2}$$

In order to show how little is gained in weight after a pair has been observed on five or six nights, the following table has been computed:

Suppose $e=\pm0''.50$ and $\varepsilon_\delta=\pm0''.40$, then $w=\frac{n}{1+0.32n}$

Suppose $e=\pm0''.40$ and $\varepsilon_\delta=\pm0''.50$, then $w\,1=\frac{1}{.50+\frac{.64}{n}}$ hence the following table:

$n=$	1	2	3	4	5	6	7	8	9	10
$w=$	0.75	1.22	1.53	1.76	1.92	2.05	2.16	2.25	2.32	2.38
$w_1=$	0.88	1.22	1.40	1.52	1.59	1.65	1.69	1.72	1.75	1.77

Not unfrequently a close zenith star may be observed transiting within the range of the micrometer, with instrument north and instrument south. In this case the pair is replaced by a single star and the weight formula $\frac{n}{ne^2_\delta+e^2}$ changes into $\frac{n}{n\varepsilon^2_\delta+e^2}$; also the combination weight w becomes for a zenith star $\frac{n}{4n\varepsilon^2_\delta+4e^2}$ Irrespective of error of observation the weight of a resulting latitude from a single zenith star necessarily observed in both positions of the instrument will be $\frac{1}{\sqrt{2}}$ that from a pair of stars being unity.

To obtain the latitude φ_0 from the separate results φ_1, φ_2, φ_3 . . . by each pair with their weights w_1, w_2, w_3 . . . we have

$$\varphi_0=\frac{[w\varphi]}{[w]} \text{ with the probable error } \varepsilon_{\phi_0}=\sqrt{\frac{0.455\,[w\Delta\varphi^2]}{(p-1)[w]}}$$

It sometimes happens that, instead of the ordinary combination, one or more south stars are combined with one or more north stars. In this case the mean of the declinations of the south stars may be combined with the mean of the declinations of the north stars, the corresponding mean of the micrometer and level readings being also used; or else we may combine each south star, for instance, with each of the north stars and the mean of these separate results of the latter method must equal the result by the entire combination. In general, the formation of stars into pairs is preferable, as defects of observation or of catalogue-place are more readily detected. Suppose the simple cases of one star entering into combination with two others, forming doublets or entering into combination with three others, forming triplets, etc., and supposing the weight of an ordinary pair $=1$ and *disregarding* the observing error, the weight of each doublet will be $\frac{2}{3}$, and of each triplet$=\frac{1}{2}$, etc., according to the form $\frac{2}{c+1}$, and our former weights w must first be multiplied by this fraction before using them in the combination for φ_0. Supposing N (north) combined with S (south) stars, then the weight (that of an ordinary pair being 1) of the single mean of this combination becomes $\frac{2NS}{N+S}$. In case there are many stars in combination, the computation by separate pairs may become troublesome, since the number of such combinations is NS. If all combinations are formed, the weight of any single one is $\frac{2}{N+S}$. If the declinations of stars entering in combination have different weights, the weights of the separate combination by pairs can readily be determined according to the above rules and their sum will determine the weight of the entire combination, in case the latter form of computation is preferred.

The method of observing several north with several south stars is not now practiced, as observation by pairs is far preferable and doublets or triplets generally enter now only in such cases where a south (or north) star is combined with a certain north (or south) star, say for a number of nights, but with another north (or south) star on some following nights and perhaps with still another star at a later period.

To ART. (9.)—*Example of observation and reduction of the value of one turn of the micrometer.*

STATION, HARRIS, *August* 24, 1855.—Observations on Polaris, near eastern elongation, for value of micrometer of zenith telescope No. 2. Elongation by chronometer, $19^h\ 15^m\ 02^s$. One division of level = 1″.16 Daily rate of chronometer, 6^s gaining. Temp. 64°.0 Fahr. Observer, G. W. D.

No.	Reading of micrometer turns.	Time by sid. chronometer.	Level readings.		Time from elongation.	Correction for *t*.	Reduction to mean state of level.	Correction for change of level.	Reduced time.
			North end.	South end.					
		h. m. s.	*d.*	*d.*	*m.*	*s.*	*d.*	*s.*	*h. m. s.*
1	5	18 36 11.5			38.8	+11.0		+3.0	18 36 25.5
2	5.5	37 09.7	24.9	12.2	37.8	10.2	+1.00	+3.0	37 22.9
3	6	38 10.0			36.8	9.4		+2.3	38 21.7
4	6.5	39 09.5	25.2	11.6	35.8	8.7	+0.55	+1.7	39 19.9
5	7	40 10.0			34.8	8.0		+2.0	40 20.0
6	7.5	41 10.0	25.1	11.7	33.8	7.3	+0.65	+2.3	41 19.6
7	8	42 11.0			32.8	6.7		+2.0	42 19.7
8	8.5	43 10.0	25.2	11.6	31.8	6.1	+0.55	+1.7	43 17.8
9	9	44 08.4			30.9	5.5		+1.5	44 15.4
10	9.5	45 07.2	25.3	11.5	29.9	5.0	+0.45	+1.2	45 13.4
11	10	46 08.0			28.9	4.5		+1.4	46 13.9
12	10.5	47 03.0	25.2	11.5	27.9	4.1	+0.50	+1.5	47 08.6
13	11	48 04.7			26.9	3.7		+1.1	48 09.5
14	11.5	49 03.0	25.4	11.2	25.9	3.3	+0.25	+0.8	49 07.1
15	12	50 02.4			25.0	2.9		+0.5	50 05.8
16	12.5	51 00.0	25.6	11.1	24.0	2.6	+0.10	+0.3	51 02.9
17	13	51 56.0			23.1	2.3		+0.1	51 58.4
18	13.5	52 57.2	25.7	11.0	22.1	2.0	0.00	0.0	52 59.2
19	14	53 52.4			21.1	1.8		0.0	53 54.2
20	14.5	54 53.0	25.7	11.0	20.1	1.6	0.00	0.0	54 54.6
21	15	55 54.1			19.1	1.3		0.0	55 55.4
22	15.5	56 50.9	25.7	11.0	18.2	1.1	0.00	0.0	56 52.0
23	16	57 48.0			17.2	1.0		0.0	57 49.0
24	16.5	58 48.4	25.7	11.0	16.2	0.8	0.00	0.0	58 49.2
25	17	59 47.0			15.2	0.7		0.0	59 47.7
26	17.5	19 00 44.4	25.7	11.0	14.3	0.6	0.00	0.0	19 00 45.0
27	18	01 44.4			13.3	0.5		−0.1	01 44.8
28	18.5	02 42.0	25.8	10.9	12.3	0.4	−0.10	−0.3	02 42.1
29	19	03 43.4			11.3	0.3		−0.2	03 43.5
30	19.5	04 39.9	25.8	11.0	10.4	0.2	−0.05	−0.1	04 40.0
31	20	05 39.8			9.4	0.2		−0.3	05 39.7
32	20.5	06 36.9	25.8	10.8	8.4	0.1	−0.15	−0.4	06 36.6
33	21	07 39.0			7.4	0.1		−0.4	07 38.7
34	21.5	08 34.5	25.9	10.9	6.4	0.1	−0.15	−0.4	08 34.2
35	22	09 33.0			5.4	0.0		−0.5	09 32.5
36	22.5	10 31.0	25.9	10.8	4.5	0.0	−0.20	−0.6	10 30.4
37	23	11 30.7			3.5	0.0		−0.6	11 30.1
38	23.5	12 25.2	25.9	10.8	2.6	0.0	−0.20	−0.6	12 24.6
39	24	13 27.0			1.6	0.0		−0.7	13 26.3
40	24.5	14 23.9	25.9	10.7	0.6	0.0	−0.25	−0.8	14 23.1
41	25	15 23.0			−0.6	0.0		−0.9	15 22.1

whence the following table:

No.	Time for 10 turns.	Δ	Δ^2	No.	Time for 10 turns.	Δ	Δ^2
	m. s.	*s.*			*m. s.*	*s.*	
1 to 21	19 29.9	2.2	4.8	11 to 31	19 25.8	1.0	3.6
2 22	29.1	1.4	2.0	12 32	28.0	0.3	0.1
3 23	27.3	0.4	0.2	13 33	29.2	1.5	2.2
4 24	29.3	1.6	2.6	14 34	27.1	0.6	0.4
5 25	27.7	0.0	0.0	15 35	26.7	1.0	1.0
6 26	25.4	2.3	5.3	16 36	27.5	0.2	0.0
7 27	25.1	2.6	6.8	17 37	31.7	4.0	16.0
8 28	24.3	3.4	11.6	18 38	25.4	2.3	5.3
9 29	28.1	0.4	0.2	19 39	32.1	4.4	19.4
10 30	26.6	1.1	1.2	20 40	28.5	0.8	0.6

	s.	*logs.*
Mean time for 1 turn - -	116.774	2.06735
	cos δ	8.40750
	15	1.17609
		1.65094

We have for 10 turns

$$\sqrt{\frac{0.455\times 83.3}{20\times 19}}=\pm 0^s.31$$

Probable error of 1 turn $=\pm 0''.012$

	″
One turn - - - - - -	=44.765
Correction for refraction -	— .025
Correction for rate - - -	— .003
Resulting value - -	44.737

N. B.—Another set of observations immediately follows the above.

For the application of the method of least squares to the above set, we prefer to take the 41 original measures of half-turns and find the mean reduced time $T_0=18^h\,55^m\,54^s.6$ and assuming $M_1=15$ and $\frac{1}{2}R_1=22''.4$, the first conditional equation results as follows: $M_1-M=+20$; corresponding difference in reduced time taken from last column of example above and converted into seconds, $1169^s.1$; which multiplied by 15 cos δ corresponds to $z-z_0=+448''.17$; also $(M_1-M)\,R_1=448''.00$; hence $n=+0.17$ and the conditional equation becomes $+0.17=22.4\mu+20\rho$. Forming in this manner the 41 equations, we find the normal equations much simplified in consequence of the symmetry of the observations, and they give the unknown quantities directly. The result in the present case is $R=44''.768$, irrespective of refraction and rate. To find the probable error of the determination, we must substitute the resulting values μ and ρ in the conditional equations, and proceed by the usual method.

TO ART. (10).—*Example of the determination of the value of one division of the level.*

STATION, HARRIS, *August* 23, 1855.—*Observations for value of one division of level B of zenith telescope No.* 2. Collimator eight feet from object glass. Value of one division of micrometer screw (mean of 4 sets) = 0''.448 Observer, G. W. D.

NOTE.—Only a part of the observations made are here given.

No.	Temp.	Micr. turns.	Level reading.		Difference of reading.		Value of 1 div. of level.	Δ	Δ²
			North.	South.	In micr.	In level.			
	° *Fahr.*		*d.*	*d.*	*d.*	*d.*	*d.*		
1	66.2	18.94	34.2	1.8	64	25.2	2.54	0.01	.000
		18.30	9.0	27.0					
2	....	18.26	34.7	1.4	61	24.55	2.48	0.07	.005
		17.65	10.0	25.8					
3	....	17.64	36.0	0.0	66	27.1	2.44	0.11	.012
		16.98	8.8	27.0					
4	....	16.95	35.5	0.0	73	30.0	2.43	0.12	.014
		16.22	5.5	30.0					
5	66.5	16.22	34.0	1.5	74	28.45	2.60	0.05	.002
		15.48	5.6	30.0					
6	....	15.43	34.3	1.2	76	30.85	2.46	0.09	.008
		14.67	3.5	32.1					
7	....	14.62	31.0	4.8	81	32.35	2.50	0.05	.003
		13.81	− 1.5	37.0					
8	....	13.77	33.4	2.2	67	25.0	2.68	0.13	.017
		13.10	8.2	27.0					
9	....	13.07	35.0	0.2	71	27.55	2.58	0.03	.001
		12.36	7.5	27.8					
10	67.0	12.33	35.0	0.6	67	25.3	2.65	0.10	.010
		11.66	9.5	25.7					
11	....	11.65	30.5	4.8	60	22.35	2.68	0.13	.017
		11.05	8.0	27.0					
12	....	11.00	33.0	1.9	68	26.25	2.59	0.04	.002
		10.32	6.8	28.2					
Mean							2.55	Sum	0.091

One division of level B = 2.55×0''.448 = 1''.14 at temperature 66°.6 Fahr., with a probable error of $\sqrt{\frac{0.455\times0.091}{12\times11}} = \pm0^{d}.018 = \pm0''.01$

TO ART. (13).—*Example of record.*

Station, Mount Desert.—Date, September 4, 1856. Instrument, zenith telescope No. 5. Observer, S. H.

No.	Star-number.	Catalogue.	N. or S.	Micrometer.		Level.		Chronometer time of observation.			Remarks.
				Turns.	Divisions.	North.	South.	*h.*	*m.*	*s.*	
4	7220	B. A. C.	N.	30	85.0	31.3	34.8	20	41	51	Weather fair; clouds flying;
	7256	"	S.	39	22.0	34.9	30.5		47	56	wind moderately fresh from SW.
	7721	"	S.	22	25.0	38.7	30.0	22	02	22	
6	7731	"	S.	22	52.0	38.5	30.0		03	06	Bar., 28.65 in.
7	7754	"	N.	31	16.0	28.8	39.8		06	07	Ther., 65°.2 Fahr.
	7778	"	N.	13	54.5	29.0	39.6		09	14	
	7800	"	N.	14	73.0	25.4	43.8	22	14	36	
	7803	"	S.	......	......	......	......	...	...	...	Too faint to observe.
5	7855	"	N.	16	62.0	37.1	33.4	22	24	52	
	7858	"	S.	6	75.0	28.2	42.0		25	35	
7	7862	"	N.	35	39.5	43.3	27.2		29	26	
5	8141	"	S.	23	13.0	20.5	52.0	23	14	23	Observed off line of collimation.
	8188	"	N.	15	88.0	51.9	21.3		22	55	
	etc.										

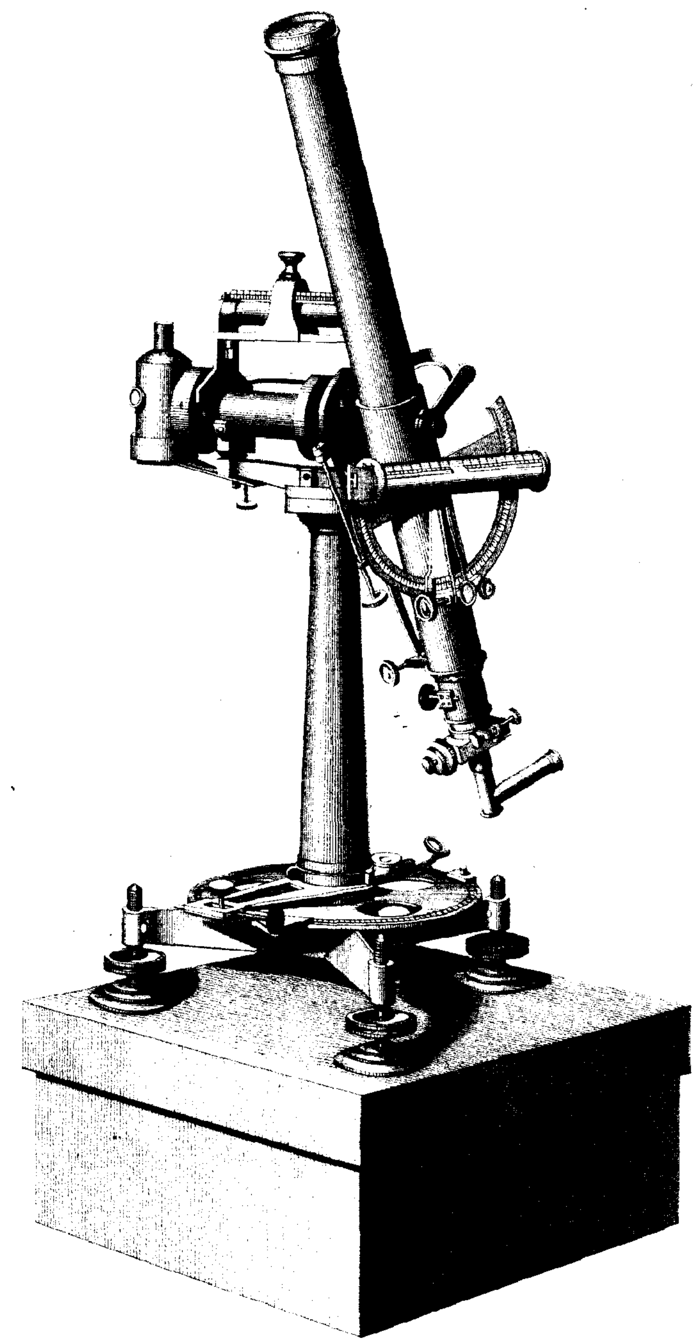
N. B.—Value of one turn of micro. screws 41''.42 and value of 1 div. of level, 0''.731 Chronometer slow 30s.2]

TO ART. (14).—*Example of reduction.*

(Reduction of Z. T. lat'n.)
STATION, MOUNT DESERT, MAINE.

Pair { 8141 B. A. C. or 5161 Armagh catalogue (Dublin, 1859). S. of zenith.
Pair { 8188 B. A. C. or 1968 G. 7-year catalogue. N. "

Date.	Microm'r. Diff. in reading.	Level. Sum N. Sum S.	Diff. of sums.	Mer. dist.	Declination.	Sum and half-sum.	Corrections. Micr.	Corrections. Level.	Corrections. Refr.	Corrections. Mer.	Latitude.	Δ	$Δ^2$	Remarks.
1856.	*t.* *d.*			*s.*	° ′ ″	° ′ ″	′ ″	″	″	″	° ′ ″	″		
Aug. 26	−7 19.0	68.8	......	......	31 01 41.13	88 47 08.41								
			+6.6											
		62.2	......	......	57 45 27.28	44 23 34.21	−2 29.00	+1.21	−0.05	......	44 21 06.37	0.43	0.185	
27	−7 04.0	92.7	......	......	41.40	09.03								
			−9.0											
		101.7	......	......	27.63	34.51	−2 25.80	−1.64	−0.05	......	07.02	0.22	0.048	
Sept. 2	−7 17.0	87.9	......	......	42.97	12.73								
			−4.9											
		92.8	......	......	29.76	36.36	−2 28.49	−0.90	−0.05	......	06.92	0.12	0.014	
3	−7 26.5	92.0	......	......	43.22	13.34								
			+4.4											
		87.6	......	......	30.12	36.67	−2 30.46	+0.80	−0.05	......	06.96	0.16	0.026	
4	−7 25.0	72.4	......	33	43.47	13.95	......	......	......	......	......	......	......	8141 observed off middle thread.
			−0.9											
		73.3	......	......	30.48	36.97	−2 30.15	−0.16	−0.05	+0.13	06.74	0.06	0.004	
										Mean	44 21 06.80	Sum	0.277	



ZENITH TELESCOPE.

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PART IV.

DETERMINATION

OF THE

ASTRONOMICAL AZIMUTH OF A DIRECTION.

WITH FOUR PLATES.

ILLUSTRATING:

1. THIRTY-INCH (76^{cm}) THEODOLITE.
2. TWENTY-INCH (50^{cm}) THEODOLITE.
3. TWELVE-INCH (30^{cm}) THEODOLITE.
4. AZIMUTH MARK, FOUR-INCH (10^{cm}) ALT-AZIMUTH INSTRUMENT AND HELIOTROPE.

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PART IV.

DETERMINATION OF THE ASTRONOMICAL AZIMUTH OF A DIRECTION.

(With four plates.)

(1.) *General remarks.*—The methods employed in the Coast and Geodetic Survey for determining astronomically, the azimuth of a triangulation-line or what is the same thing, the direction of a line with respect to the meridian of the place, are very various and there are, perhaps, no other geodetic operations in which the choice of the method, the perfection of the instrument and the skill of the observer enter so directly into the value of the result. It is intended to give here in a concise form an account of the several methods in use, to present the formulæ as well as specimens of record and examples of computation. If it is proposed to measure a primary or subordinate azimuth, the observer will generally have the choice of the method most suitable and adequate for the purpose and accordingly provide himself with the proper instrument, yet not unfrequently he may find himself already provided with an instrument, in which case that method will have to be selected which is compatible with the mechanical means on hand and at the same time insures the greatest accuracy.

The astronomical azimuth or the angle which the plane of the meridian makes with the vertical plane passing through the object whose direction is to be determined, is generally reckoned from the south and in the direction southwest, etc.; however, when circumpolar stars are observed, it will be found more convenient to reckon from the *north* meridian and eastward—that is, in the same direction as before.

The geodetic azimuth differs from the astronomical azimuth. The former is supposed free from local deflections of the plumb-line or vertical, it being the mean of several astronomical azimuths, all referred geodetically to one station and it may be supposed that in this normal azimuth the several local deflections will have neutralized each other. The astronomical azimuth is, of course, subject to any displacement of the zenith due to local attraction or deflection.

We may distinguish between primary and secondary azimuths—the one fixing the direction of a side in the primary triangulation, the other having reference to sides of secondary or tertiary triangulations or to directions in connection with the measure of the magnetic declination. For the determination of a primary azimuth the local time (sidereal) must either be known, as for instance, when a telegraphic longitude was at the same time determined or special observations must be made for it. For subordinate azimuths time and azimuth observations may sometimes be made together, as with the alt-azimuth instrument for magnetic purposes, in which case the sun's limbs are usually observed. In refined work and for certain methods we need the transit instrument to furnish the chronometer correction; in other cases or for second-class azimuths, local time may be found by means of vertical circles, sextants or alt-azimuth instruments.*

(2.) *Instruments.*—First-class azimuths are generally observed with an astronomical theodolite of the best workmanship and of the largest portable size. In the practice of the Coast and Geodetic Survey theodolites having circles of 76 and of 50^{cm} diameter (or of 30 and 20 inches respectively), also repeating circles of 46^{cm} (or 18 inches), and others of smaller size, are employed, and in cases where no greater accuracy than a quarter of a minute is needed, as in magnetic work, even a 10^{cm}

* That very handy little instrument known as the chronodeik (S. C. Chandler in Science Observer, Vol. III, No. 3: Boston, Sept. 1880) may be of service in azimuth work as well as in latitude work with zenith telescope. In principle it is an equal altitude instrument. With it the nearest whole second may be secured.

(or 4 inch) theodolite or alt-azimuth instrument will answer the purpose. The first plate appended to this part exhibits the largest and oldest theodolite much used on the survey during the period from 1844 to 1873; the second plate shows one of the later* theodolites of the largest size now considered desirable and of the best pattern; it has been frequently in use since 1874. The aperture of these telescopes is $7\frac{1}{2}^{cm}$ (nearly 3 inches), their focal length about 104^{cm} (or 41 inches) and they bear a magnifying power of 95. A 30^{cm} (or 12-inch) astronomical theodolite is illustrated on the third plate. These instruments carry either 2 or 3 micrometer microscopes; their aperture is between 6 and $7\frac{1}{2}^{cm}$ (or $2\frac{1}{4}$ and 3 inches), with a focal distance of 61 and 71^{cm} (or 24 and 28 inches) and they carry a magnifying power of 50 (or more). The telescope can be turned through the vertical without taking its axis off the V's. In this as well as in the preceding instrument the horizontal or azimuth circles are full plates (*i. e.*, they have no spokes), supported by ribs underneath and they may be freely placed in any position with regard to the zero of the graduation. Their circles are free from any clamping and slow-motion screw, in fact they are only to be looked at through the reading microscopes, but may be set to any position and then tightened. These instruments may carry a vertical circle or a finder. The last plate (fourth) exhibits the small alt-azimuth, so useful in a variety of ways. Its dimensions are, horizontal and vertical circles 10^{cm} (or 4 inches) with two verniers each, reading to single minutes, aperture of telescope 3^{cm} nearly ($1\frac{1}{8}$ inch), focal length 18^{cm} nearly (or 7 inches), prismatic eye-piece with magnifying power 20. The telescope can be swung through the vertical when reversing position. When the axis is not perforated the focal illumination can readily be effected by a perforated ring reflector placed over the objective. This plate shows also a convenient form of an azimuth mark and a simple heliotrope. Transit instruments and meridian telescopes are used less frequently for azimuth. Transits are mounted either in the plane of the meridian or in the vertical plane of a circumpolar star when at or near elongation. Stability of the instruments being of great importance, they should be mounted on stone or masonry and in all cases when they must be mounted at a considerable elevation above the surface of the ground it is best to build a stone or brick tower, double walls and hollow and surmounted by a stone slab to receive the instruments. Heavy poles and wooden tripods, though the observer's support be a separate structure, should be avoided. For the purpose of reference to the triangulation an azimuth mark is established as near as may be in the same horizontal level as the observing station, but if elevated above or depressed below the horizon the angular amount must be measured. The distance of the mark is generally determined by the configuration of the ground surrounding the station, but on no account should it be placed any nearer than about $1\frac{1}{2}^{km}$ or say a statute mile, in order that the sidereal focus of the telescope may not require changing when pointing from the mark to the star or *vice versa*, since any such change is likely to disturb the line of collimation. When the transit is employed the mark must, of course, be placed in the vertical plane in which the telescope moves or if this be impracticable, a collimator may be resorted to. When using a theodolite the magnitude of the angle between the planes of the mark and star is of little consequence. The azimuth mark is usually a square box about 30^{cm} cube (about $\frac{3}{4}$ cubic foot), having in its front face a round hole or aperture of suitable and adjustable size, through which the light of a bull's-eye lantern can be shown at night and can be made to appear of about the apparent brilliancy and size of the star observed upon for azimuth. For day observations a narrow vertical black stripe is painted on the white wand centrally below the aperture and above it two black stripes on both sides of it. These stripes are of the same width but wider than the aperture. An aperture the diameter of which subtends an angle of 1″ is considered rather large and near the superior limit, an aperture subtending an angle of 0.″5 is rather small and in practice is near the inferior limit. The distance to the mark being measured or known the observer may readily compute the size of the aperture† required,

* For our purpose these instruments admit of an inclination of the telescope sufficient for observing Polaris at upper culmination at any place south of latitude 50°. See "Examination of three of the new 20-inch theodolites," in Report of 1877, appendix No. 11.

† For conversion of measures we have $\begin{cases} 1 \text{ inch} = 25.4^{mm} \text{ and } 1^{km} = 0.621 \text{ statute mile.} \\ 1^{mm} = 0.0394 \text{ inch.} \end{cases}$

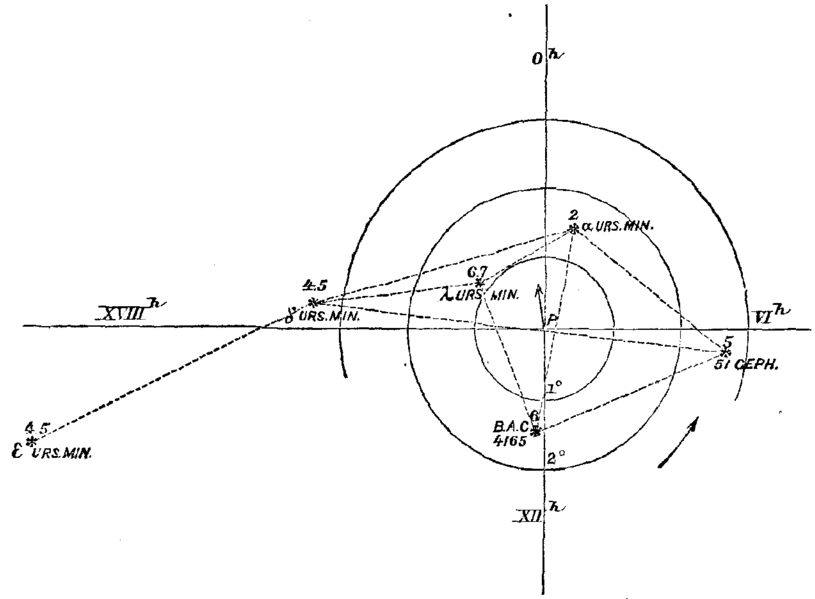
or he may take it from the following table, in which the last column but one answers for the case of ordinary light and low power of telescope and the last column for a brilliant illumination and high telescopic power:

Distance of mark.		Diameter of aperture.	
km.	st. miles.	Max.	Min.
1.5	0.9	7mm	4mm
2.0	1.2	10	5
2.5	1.6	12	6
3	1.9	15	8
4	2.5	19	10
6	3.7	29	14
10	6.2	48	24

Collimators in the place of marks are rarely used, but where no suitable place for a mark can be found, as, for instance, on some of the isolated peaks of the Sierra Nevada in California, they cannot well be dispensed with. Their aperture should be as large as that of the collimating telescope and the greatest precaution should be used to give them the firmest ground connection and shelter them from changes of temperature. Marks or collimators should be connected with points of the triangulations by horizontal angles. Respecting reflex observations the reader may be referred to the end of Part I, art. 2. A glass roof over the mercury should never be employed, since reversal of it does not sufficiently correct for error by refraction.

(3.) *General considerations.*—Let the time (t), declination (δ), and latitude (φ) be slightly in error by the quantities dt, $d\delta$ and $d\varphi$ and let dA equal their effect upon the azimuth (A); then, in general, it will be seen that, all other circumstances being equal, dA increases as the zenith distance (ζ) decreases; for a star near the pole and for a latitude not too high a small error in time and in latitude has but a slight effect upon the azimuth, and in the case of a circumpolar star at the elongation (when the parallactic angle is 90°) a small error in time, dt, will not affect the azimuth; but small errors in declination, $d\delta$ and in latitude, $d\varphi$, then attain nearly their maximum effect upon the azimuth. If observations are made upon a circumpolar star ($\delta > \varphi$) at the eastern and at the western elongation, effects of $d\delta$ and $d\varphi$ will disappear in the combination of the two results; this, therefore, is the most favorable condition for observing. In general, effects of $d\delta$ and $d\varphi$ disappear in mean results of observations of equal and opposite azimuths. In observations of a circumpolar star in the meridian, the effect of a small error in time and in right ascension may be eliminated by a combination of results from upper and lower culminations; for a star in the meridian the quantities $d\delta$ and $d\varphi$ do not enter in the azimuth. If the object to be observed, star (or sun), is of great polar distance (also $\delta < \varphi$), and if δ is positive, the best time for observing is before the eastern transit, or, after the western transit over the prime vertical, when the change in azimuth with respect to time is a maximum; but the altitude of the star (or sun) should not approach too near the zenith nor be so low as to be affected by changes of refraction; if δ is negative, the star (or sun) should be observed some distance from the meridian.

The circumpolar stars α, δ, λ Ursæ Minoris and 51 Cephei are those almost exclusively used; their position is most accurately given in the second edition of Dr. Gould's Standard Places of Fundamental Stars (Washington, 1866), specially prepared for the use of the Survey, and still adhered to; the apparent places may be taken from the American Ephemeris. The diagram on page 266 will assist in readily finding the two fainter stars λ U. M. and 51 C., which barely become visible to the naked eye under the most favorable circumstances; it also shows that when δ Ursæ Minoris and 51 Cephei culminate on either side of the pole, Polaris is not yet far from its elongation; and, on the contrary, if the pole-star culminates, the other two are on either side of the meridian, not far from their elongations. A similar approximate relation exists between α and λ Ursæ Minoris. Polaris offers the advantage of being observable in day-time with portable instruments; hence it may be observed at eastern and western elongations, or at upper and lower culminations, provided the sun be not too high; λ, from its greater proximity to the pole and its smaller size, presents to the larger instruments a finer and steadier object for bisection than Polaris*; 51 Cephei is also advantageously used on account of its small size. The star B. A. C. No. 4165 shown on the diagram was



proposed and used for azimuth work by Assistant G. Davidson. The apparent precessional motion of the pole in 100 years is indicated by the direction and length of the arrow. The sun is employed only to determine azimuths of inferior accuracy, generally in connection with the determination of the magnetic declination.

For a satisfactory determination of the azimuth from a high star, it is essential that the horizontal axis of the instrument be long and its inclination be accurately measurable by a delicate level; a determination of the inequality of the pivots is essential. This inclination of the transit-axis should be measured in the position when the telescope is pointed to the star and again when pointed to the mark, unless the latter be in the horizon; the best results, however, are obtained by observing the star direct and also its image reflected from the surface of still mercury; the mean result is free from the effect of any inclination of the transit axis. The collimation error is eliminated from the mean result by combining observations with telescope direct and with telescope reversed, the horizontal axis having been turned 180° in azimuth and the telescope again pointed to the star (during this process the pivots of the transit axis remain otherwise undisturbed in their Y's). If the Y's are too short to permit the telescope to be turned through the vertical, it may be carefully lifted out, swung through twice the zenith or nadir distance, and let down again, the pivots resting on the *same* Y's as before; the azimuth circle is then turned through 180°. The collimation may be adjusted in the first place by reversal of the axis in the Y's as in the transit instrument. Errors of graduation are sought to be eliminated by observing in different positions of the instrument, the circle being shifted after each set of observations an equal amount of angular space, depending upon the number of positions intended to cover 360°, and upon the number of equidistant microscopes or verniers, so that no one shall occupy a position previously occupied by another. With the large theodolites, supplied with three reading microscopes, the number of positions adopted may be one of the smaller prime numbers 7, 11, 13, 17, 19, 23 and for less perfect graduation one of the larger numbers should be taken.

Observations for azimuth are generally made in sets, commencing, after the instrument is leveled, with a number of readings on the mark (about six for primary and from three to one for secondary azimuths), followed by about an equal number of readings on the star, also preceded and

*If the image of Polaris is too bright or diffused the placing of a cap with a central hole over the object glass is recommended.

followed by level readings (unless reflections in mercury are taken, when no level readings in connection with the star are required). The instrument is then reversed and the preceding operations are repeated in the inverse order, the number of observations upon the star and the mark being as before. Some observers reverse the instrument also upon the mark, before and after the reversal upon the star; but as every reversal renders the instrument liable to disturbance, their number might be reduced to three, or even to a single one, in the middle of each set; the number of pointings on mark and star necessarily varies with different observers and instruments. If the mark is not in the horizon, its zenith distance must be measured and level readings must be given also when pointing to it. Precautions should be taken to prevent the pivot or level from becoming heated by the lamp, the body, or hand of the observer. The level value may be ascertained by a level trier, or by means of a vertical circle, or by a micrometer of known value. With smaller instruments, the principle of repetition has been tried, though not always with satisfactory results; whether repetitions should be employed or not depends upon the relative value of definition of telescope and of accuracy of graduation; the clamping apparatus, however, must have no tendency to disturb the relative position of the circles, and the motion of the instrument must be free. When repetitions are used, not only the direct angle between the mark and star, but also its explement or 360° *minus* this angle, should be measured, and the two results combined to one.

(4.) *Methods for determining azimuths.*—The methods of recording and reducing the different kinds of azimuth observations will next be stated in detail, and specimens of record and of computation will be given at the end of this paper. The formulæ and method of reduction in each case are as follows:

(5.) *Observations of a close circumpolar star near its elongation.*—A table of chronometer corrections and rates, covering the period during which azimuthal observations are to be made, is prepared; the readings of the horizontal circle on the mark and star are corrected for over- or under-run of micrometer of reading microscopes, if required. The mean places of stars and their constants are taken from the American Ephemeris, as well as the apparent right ascensions (α) and declinations (δ), or they are computed by either of the two methods given in the American Ephemeris and Nautical Almanac, and the results are tabulated.

Apparent $\left\{ \begin{matrix} \alpha \\ \delta \end{matrix} \right.$ at time and place of observation=apparent $\left\{ \begin{matrix} \alpha \\ \delta \end{matrix} \right.$ at upper culmination at Washington (or Greenwich)+(difference of longitude [in hours] $\pm$ hour-angle of ✳) $\frac{\text{daily difference}}{24}$+correction for terms of nutation involving 2 ☾.

The hour angle, t_e and the azimuth A_e at elongation, for the latitude φ, are computed by the formulæ

$$\cos t_e = \tan \varphi \cot \delta \qquad \text{and} \qquad \sin A_e = \sec \varphi \cos \delta$$

Also, sidereal time of $\left\{ \begin{matrix} \text{W.} \\ \text{E.} \end{matrix} \right.$ elongation$=\alpha \pm t_e$ and chronometer time of $\left\{ \begin{matrix} \text{W.} \\ \text{E.} \end{matrix} \right.$ elongation$=\alpha \pm t_e +$correction of chronometer. $\left\{ \begin{matrix} + \\ - \end{matrix} \right.$ when chronometer is $\left\{ \begin{matrix} \text{fast} \\ \text{slow} \end{matrix} \right.$ of sidereal time.

Let τ=interval of times of elongation by chronometer and by observation, then reduction to azimuth, for α and λ Ursæ Minoris, within 25 minutes of the time of elongation, with sufficient accuracy

$$112.5\tau^2 \sin 1'' \tan A_e \qquad \text{or} \qquad \frac{2 \sin^2 \frac{1}{2}\tau}{\sin 1''} \tan A_e$$

in which formulæ tan A_e may be exchanged for sin A_e. Supposing the circle to read in the direction N., E., S., W. the reduction to elongation is applied to the reading of the star with the sign $\left\{ \begin{matrix} + \\ - \end{matrix} \right.$ when ✳ is $\left\{ \begin{matrix} \text{E.} \\ \text{W.} \end{matrix} \right.$ of the meridian. The means of all the readings of the star, reduced to elongation, for telescope "D" and for telescope "R", are corrected for error of inclination of axis by the formula

$$\frac{d}{4} \left\{ (w+w') - (e+e') \right\} \left\{ \begin{matrix} \sin h \\ \cos \varphi \end{matrix} \right.$$

where d=value of one division of level scale in seconds of arc, w, e and w', e' the west and east readings of the level before and after reversal and h the *'s altitude. For $\frac{\sin h}{\cos \varphi}$, $\tan \varphi$ may be substituted without sensible error. The mean of the corrected readings for telescopes D and R is then taken for the reading of the star at elongation; hence, reading of meridian=reading of * at elongation $\pm A_e$, where $\left\{ \begin{smallmatrix} + \\ - \end{smallmatrix} \right.$ for $\left\{ \begin{smallmatrix} \text{W.} \\ \text{E.} \end{smallmatrix} \right.$ elongation. The mean of D and R readings of the mark,* before and after the observations upon the star, is taken for the reading of the mark; and, finally, the azimuth of mark=difference of readings of meridian and mark. This result is yet to be corrected for effect of diurnal aberration.

Let ζ=zenith distance and A=azimuth of star; then

$$dA = \frac{0''.308 \cos A \cos \varphi}{\sin \zeta}$$

where $\sin \zeta = \frac{\sin p \sin t}{\sin A}$ and p the polar distance, t the hour angle. For elongation, the formula becomes simply $dA = 0''.31 \cos A$ with sufficient accuracy. This correction is $\left\{ \begin{smallmatrix} - \\ + \end{smallmatrix} \right.$ when mark is $\left\{ \begin{smallmatrix} \text{W.} \\ \text{E.} \end{smallmatrix} \right.$ of north and is always positive when applied directly to the azimuth, which, geodetically, is counted in the Survey from south towards west to 360°. The final result for azimuth and its probable error is obtained by the combination of the separate results by each star, with application of the method of least squares.

(5b.) *Observations with a transit instrument in the vertical of a close circumpolar star, near its elongation.*—If a transit instrument only is available and a mark can be placed in the vertical of the elongation, the method (see Coast Survey Report of 1856, Appendix No. 27) of measuring the azimuthal angle between the mark and a close circumpolar star at elongation by means of the micrometer screw which moves one of the V-bearings in azimuth may be applied with results possessing a considerable degree of accuracy. To secure this, it is, however, essential that the sum of the positive and negative micrometer measures balance (the mark being placed, for this reason, a little inside the vertical of the elongation), in which case an inequality in the value of a division at different parts of the screw will not affect the result; further, the measures should be small, since the V-supports of the axis are not pivoted and any considerable motion must to some extent roll and elevate the axis, changing its bearings. The collimation is eliminated by reversals. The level correction may be found with sufficient precision by $\frac{d}{4}[(w+w')-(e+e')] \tan \varphi$ (see Art. 5); and the value of a division of the pivot micrometer is found by means of successive transits of the star near culmination over the same thread, for equidistant micrometer divisions, by the formula

$$A = \frac{\sin p \sec (\varphi \pm p)}{\sin 1''} \sin t$$

where the sign $\pm$ is to be used for upper and lower culmination; but generally the azimuthal value, expressed in seconds of arc, may be found with sufficient precision by the formula

$$15 \sin p \sec h \,.\, t$$

where p=the polar distance, h the altitude and t the hour angle in seconds of time. The reduction to elongation and the correction for diurnal aberration are the same as in Art. 5.

(6.) *Observations of a close circumpolar star at any hour angle.*—The chronometer correction and rate are tabulated, the corrections for run of reading-microscopes of azimuth circle are applied and the right ascension and declination of the star are computed for the various dates, as in the preceding case. We may employ three different methods for the computation of the azimuth, viz: by the use of the fundamental trigonometrical formula, of Napier's analogies, and of a development in series.

(7.) By means of the fundamental formula, and counting the azimuth from the *north*

$$\tan A = \frac{\sin t}{\cos \varphi \tan \delta - \sin \varphi \cos t}$$

The first term of the denominator may be tabulated for slightly different values of δ during the

* If the mark is not in the horizon, its readings must be corrected for inclination of axis, if sensible.

period of observation; the second term, for a close circumpolar star, may be computed by five-figure logarithms. A plus sign of A thus indicates star *west* and a minus sign *east* of the meridian. The formula may be separately applied to each observation, if we desire individual results; but this work may be much shortened by computing only the azimuth corresponding to the *mean* hour angle, and applying to it the correction to *mean* azimuth. Let n be the number of observations on the star, A the azimuth, corresponding to the mean hour angle and, consequently, $\frac{\Sigma A}{n}$ the mean azimuth; let also τ=the difference* between the time of any observation and the mean of the times; then for a circumpolar star

$$\frac{\Sigma A}{n} = A - \tan A \cdot \frac{1}{n}\Sigma \frac{2\sin^2 \frac{1}{2}\tau}{\sin 1''}$$

The reading of the meridian = reading of $* \pm \frac{\Sigma A}{n}$, where $\left\{\begin{matrix}+\\-\end{matrix}\right.$ for star $\left\{\begin{matrix}\text{W.}\\\text{E.}\end{matrix}\right.$ of meridian, the circle being supposed to read as stated above.

The correction for level for a circumpolar star may be applied as in the preceding method, or by means of the general formula, which also includes the collimation, $\pm b \cot \zeta \pm c \operatorname{cosec} \zeta$, where b the inclination of the transit axis and c the collimation, both expressed in arc; the two signs refer to the position of the axis. The sign of the level correction in any case can readily be found from a special consideration. The application of the correction for diurnal aberration and the manner of obtaining the resulting azimuth have already been explained. In the prime vertical, the diurnal aberration vanishes.

(8.) By Napier's analogies: Let q = parallactic angle, or the angle at the star; then

$$\tan \tfrac{1}{2}(q+A) = \frac{\cos \frac{1}{2}(\delta-\varphi)}{\sin \frac{1}{2}(\delta+\varphi)} \cot \tfrac{1}{2}t = m \cot \tfrac{1}{2}t$$

$$\tan \tfrac{1}{2}(q-A) = \frac{\sin \frac{1}{2}(\delta-\varphi)}{\cos \frac{1}{2}(\delta+\varphi)} \cot \tfrac{1}{2}t = m' \cot \tfrac{1}{2}t$$

hence, $A = \frac{1}{2}(q+A) - \frac{1}{2}(q-A)$, where A counts from the *north*. m and m' vary but slowly with a change in δ. If the hour angle is reckoned from the lower culmination, we must employ the formulæ

$$\tan \tfrac{1}{2}(q+A) = m \tan \tfrac{1}{2}t$$
$$\tan \tfrac{1}{2}(q-A) = m' \tan \tfrac{1}{2}t$$

The successive azimuths of the star at the times of observation are applied to the corresponding readings of the star, thus giving, after being corrected for level, as in the preceding case, a series of readings of the meridian, the mean of which is combined with the mean reading of the mark in order to obtain the azimuth of the mark. The latter is then to be corrected for diurnal aberration, unless the star be in the prime vertical.

(9.) By means of a development in series: We have with sufficient precision

$$A = \frac{\sin t}{\cos \varphi}\left\{p + p^2 \sin 1'' \tan \varphi \cos t + \tfrac{1}{3}p^3 \sin^2 1'' \left[(1+4\tan^2\varphi)\cos^2 t - \tan^2\varphi\right]\right\}$$

where the azimuth may be reckoned either way from the *north* and is expressed in seconds of arc; if the hour angle be reckoned from the lower culmination, the term $p^2 \sin 1'' \tan \varphi \cos t$ must be taken with the opposite sign. The third term $\frac{1}{3}p^3 \sin^2 1'' [(1+4\tan^2\varphi)\cos^2 t - \tan^2\varphi]$, may be tabulated for each polar star for every 10^m of hour angle, and for every degree of latitude, within a certain range. Since p varies slightly (for a given star) in time, the tabular quantities must be corrected accordingly; thus, in the case of Polaris, an increase or diminution of 1′ in p demands an increase or diminution of the tabular value nearly of its $\frac{1}{29}$th part. The remaining reduction is as above.

For the case of a close circumpolar star observed *near the culmination*, the general formula reduces to

$$A = \frac{\sin t}{\cos \varphi}\left\{p + p^2 \sin 1'' \tan \varphi \cos t + \tfrac{1}{3}p^3 \sin^2 1'' (1+3\tan^2\varphi)\right\}$$

* If a mean-time chronometer is used, the value $\Sigma \frac{2\sin^2 \frac{1}{2}\tau}{\sin 1''}$ should be increased by its $\frac{1}{180}$ part.

If the hour angle is counted from the lower culmination, change the sign of the second term; we may use this formulæ for Polaris to within one hour of culmination. For a given star, time and latitude, the expression reduces to

$$A = [c] \sin t \left\{ p + c' - [c''] \cos t \right\}$$

where c, c', c'' are constants; the rectangular brackets include logarithms. For a very small hour angle, the expression becomes [C] sin t, where C may be taken as constant. The mean azimuth of the polar star is obtained from its azimuth computed from the mean hour angle by the formula

$$A_m = A - \tan A \,.\, \frac{1}{n} \, \Sigma \frac{2 \sin^2 \frac{1}{2}\tau}{\sin 1''}$$

(10.) *Observations of a close circumpolar star at equal intervals before and after culmination.*—For chronometer correction and rate and correction of run of reading microscopes, see first method.

Apparent α at time and place = apparent α at upper culmination at Washington (or Greenwich) + [difference of longitude (in hours)] $\frac{\text{daily difference}}{24}$ + correction for nutation involving 2 ☾.

Chronometer time of $\left\{ \begin{array}{l} \text{upper} \\ \text{lower} \end{array} \right.$ culmination = $\left\{ \begin{array}{l} \alpha \\ \alpha + 12^h \end{array} \right.$ + correction for chronometer error.

Reading of approximate meridian = mean of corresponding readings on the star before and after culmination. The means of these readings for telescopes D and R are separately taken, the instrument having been reversed at culmination.

$$\text{Correction for inclination} = \frac{d}{4} \left\{ (w + w') - (e + e') \right\} \tan h.$$

The means require a further correction for error of assumed time of culmination by chronometer. Let τ = correct chronometer time of culmination, τ' = assumed chronometer time for observations, dA = motion of the star in azimuth in one second of time, which quantity is readily found from the observations themselves, then correction = $\mp (\tau - \tau')\, d\text{A}$ for $\left\{ \begin{array}{l} \text{upper} \\ \text{lower} \end{array} \right.$ culmination; the circle being supposed to read in the direction from N. to E.

$$\text{Correction for diurnal aberration} = \frac{0''.31 \cos A \cos \varphi}{\sin \zeta}$$

where $\sin \zeta = \sin \left\{ \begin{array}{l} \delta - \varphi \\ \delta + \varphi \end{array} \right.$ for $\left\{ \begin{array}{l} \text{upper} \\ \text{lower} \end{array} \right.$ culmination. The sign of this correction to the azimuth is as explained above. For interpolation, in case of accidental omissions, or a non-correspondence in time before and after culmination, or where the star is observed only *on one side* of the meridian, the reading may be referred to the meridian by means of any of the three methods given for the case of observations at various hour angles. The same formulæ apply in the case of one star observed on one side of the meridian and another star on the other side and when the results of the two are proposed for combination.

The effect upon the azimuth for a small difference in time, near lower culmination, may be computed by the formula $d\text{A} = \frac{1}{2}(m - m') \cos t\, dt$, where m and m' are the factors developed by the use of Napier's analogies; or it may be derived from the observations themselves. Observations of a polar star within about 20^m of culmination may be reduced by the formulæ

$$A = \frac{\cos \delta \sin t}{\sin (\delta \mp \varphi) \sin 1''} \qquad \text{or} \qquad A = \frac{\sin p \sin t}{\cos (\varphi \pm p) \sin 1''}$$

where in the latter formula the sign $\left\{ \begin{array}{l} + \\ - \end{array} \right.$ refers to $\left\{ \begin{array}{l} \text{upper} \\ \text{lower} \end{array} \right.$ culmination. We have also $d\text{A} = \frac{\sin p}{\cos (\varphi \pm p)} \cos t\, dt$, where $\cos t$ may be omitted as insignificant.

(10*b*.) *Observations with a transit instrument of a close circumpolar star, near culmination.*—If a transit instrument is fitted with an eye-piece micrometer (with movable vertical thread), and if a meridian mark can be established, its azimuth may be determined with great precision by micrometric measures of the mark and the star when culminating. In this case, the *instrumental constants* and the time must be determined with precision and, as the method admits of stars being observed above and below the pole, the effect of a small error in time or in the star's right ascension may be eliminated or greatly reduced. The mark should be at a distance sufficient to require no change in the sidereal focus of the telescope. The chronometer-correction is found by the ordinary transit observations; in those for azimuth proper, the vertical thread of the micrometer is set in advance of the star successively by equal divisions or turns of the screw, and the transits are recorded by the eye and ear or by the use of a chronograph.* The value of a division of the micrometer is found from the azimuth observations themselves.

Let t = time of transit of a culminating polar star, corresponding to one turn of micrometer converted into arc, then 1 turn $= \frac{\cos \delta \sin t}{\sin 1''}$. The level correction (in time) is found by the formula bB, where $b = \frac{1}{15} \cdot \frac{d}{4} [(w+w')-(e+e')]$ and $B = \cos(\varphi - \delta) \sec \delta$. For lower culmination take $180° - \delta$, instead of δ, or else reverse the sign of δ; if the level correction, however, is not applied to the times prior to computing the azimuthal deviation, it may be applied after it, using the formula $i \cot \zeta$, where i = the inclination of the axis in seconds of arc $\left\{ \begin{matrix} + \\ - \end{matrix} \right\}$ for $\left\{ \begin{matrix} \text{east} \\ \text{west} \end{matrix} \right\}$ end high.

If there is a sensible inequality in the pivots a correction for it must be applied.

The collimation correction is found by subtracting the mean reading of micrometer, for lamp west and east, on the mark, from the mean micrometer reading on the star and by converting this difference into seconds of time. (See determination of the value of micrometer.) The sign of the correction follows from the appearance of the record.

To obtain the hour angle of the star, let

T = observed chronometer time + $\triangle$ T + level correction + collimation correction

then the hour angle t is found by

$$t = a - T$$

hence, the azimuthal effect—

$$A = \frac{\sin p \sec(\varphi \pm p) \sin t}{\sin 1''} \quad \left\{ \begin{matrix} + \\ - \end{matrix} \right\} \text{ for } \left\{ \begin{matrix} \text{upper} \\ \text{lower} \end{matrix} \right\} \text{ culmination.}$$

To the azimuth of the star thus referred to the line of collimation of the instrument, we add algebraically the difference of the micrometer readings of star and mark, and convert the same into seconds of arc. The signs are readily found from the positions in each particular case.

The method is much simplified by observing each star with lamp east and lamp west, reversing at the middle of the pointings; hence the collimation may be deduced from the observations of the star instead of from reversal on the mark. In the case of irregular figure of the pivots the former method may be preferable. To find the effect of a small error in time (t) on the resulting azimuth (A) we differentiate the preceding expression, and find

$$\frac{dA}{dt} = \frac{\sin p \sec(\varphi \pm p) \cos t}{\sin 1''} = A \cot(t)$$

or expressing both A and t in seconds of arc,

$$\frac{dA}{dt} = A \cot. t. \sin 1''$$

(10*c*.) *Observations with a transit instrument of a close circumpolar star, near culmination.*—If the transit has no eye-piece micrometer (as is usually the case with the smaller instruments), we may still accurately observe an azimuth by means of the pivot (or V) micrometer, as in the preceding case of Art. 10*b*, but without moving the instrument much from its meridional position. When thus observing culminations, the same precautions respecting the use of the pivot-micrometer are necessary, as already mentioned.

It is desirable for these observations that a scale be applied to the micrometer to facilitate the counting of the whole turns. In connection with this method, and considering the special appliances when the instrument is known as the meridian telescope, the transit thus becomes of great

*Observations have also been made at convenient *equal* intervals of time, the star being followed with the micrometer bisecting it and read off at the proper moment. The practice indicated in the text seems to be the better of the two.

importance in geodesy, as this single instrument permits most accurate observations for time, latitude, longitude, and azimuth. Should, for the latter purpose, the ground not admit of the location of a distant meridian mark, a collimator is recommended, consisting of any *firmly* mounted (and collimated) telescope, of about equal object lens and optical power with the transit telescope.

The value of one turn of the pivot micrometer is either found from the azimuth record or from special observations of a close circumpolar star near culmination, as in preceding Art. 10*b*, by the formula—

$$A = \frac{\sin p \sec (\varphi \pm p) \sin t}{\sin 1''}$$

or by 15 sin p sec $h \,.\, t$ and, in case of t being too great to admit of the direct substitution of the arc for the sine, we can apply the correction to the observed times by means of the following table:

t	$\frac{1}{6}(15 \sin 1'')^2 t^3$	t	$\frac{1}{6}(15 \sin 1'')^2 t^3$
m.	*s.*	*m.*	*s.*
5	0.02	20	1.52
6	0.04	21	1.76
7	0.07	22	2.03
8	0.10	23	2.32
9	0.14	24	2.63
10	0.19	25	2.97
11	0.25	26	3.34
12	0.33	27	3.74
13	0.42	28	4.18
14	0.52	29	4.64
15	0.64	30	5.14
16	0.78	31	5.67
17	0.93	32	6.24
18	1.11	33	6.84
19	1.30	34	7.48

The correction for level is found, as in the preceding article, $= b$ B and the azimuth of the star is computed by the formula given in the same article, viz:

$$A = \frac{\sin p \sec (\varphi \pm p) \sin t}{\sin 1''}, \qquad \left\{ \begin{matrix} + \\ - \end{matrix} \right\} \text{ for } \left\{ \begin{matrix} \text{upper} \\ \text{lower} \end{matrix} \right\} \text{ culmination.}$$

(11.) **Azimuths for tertiary triangulation, or azimuths in connection with the magnetic declination**, where an accuracy of a fraction of a minute suffices, may conveniently be obtained from observations of the sun with a small altazimuth instrument (say of five or even three inches diameter). Supposing the latitude given, but the time only approximately known, the sun's zenith distance and azimuth may be observed, as follows: reading of mark, three readings, noting the chronometer time at contacts of the sun's upper and first limb; instrument reversed, three readings of the sun's lower and second limb, reading of mark.

Let $h =$ altitude, corrected for refraction, parallax (semi-diameter and dip, if necessary) and $p =$ the sun's or star's polar distance, then counting the azimuth A from the *north*

$$\tan^2 \tfrac{1}{2} A = \frac{\sin (s - \varphi) \sin (s - h)}{\cos s \cos (s - p)}$$

in which expression $s = \frac{1}{2}(\varphi + h + p)$. If the time should also be desired, it may be computed by

$$\tan^2 \tfrac{1}{2} t = \frac{\cos s \sin (s - h)}{\sin (s - \varphi) \cos (s - p)}$$

or by the formula:

$$\tan \tfrac{1}{2} t = \cot \tfrac{1}{2} A \frac{\sin (s-h)}{\cos (s-p)}$$

If the sun's limb is observed, the correction to the azimuth for reduction to center is $\pm \frac{r}{\sin \zeta}$, where r = sun's radius; whether + or — is to be used can readily be found in each particular case.

(12.) Examples of record and reduction for the various methods employed in determining astronomical azimuths and specified above are herewith appended.

TO ART. (5.)—*Example of record.*

STATION, AGAMENTICUS, YORK COUNTY, ME.

Polaris near western elongation. October 17, 1847.

Observer, A. D. B. Instrument, 30-inch theodolite C. S. No. 1. Index of graduation, 0 upon 140°.

Weather, light fog. Wind, S. W., moderate. Temp., 48° Fahr.

No.	Object.	Appear.	Tel.	Time by sid. chron.	Azimuth circle.								Level.
						A		B		C			
				h. m. s	° ′	d.	d.	d.	d.	d.	d.		1 div. = 0″.97
1	Mark.	m-d. st.	R	6 30	63 55	39.7	39.0	27.5	27.0	27.7	26.5	Correction for run +0.1	
2				33	63 55	41.0	39.7	27.0	28.0	26.0	24.3		
3				34	63 55	41.0	41.0	20.8	29.0	26.4	26.3		
4			D	37	243 55	26.2	28.2	16.8	17.0	16.8	13.3		
5				39	243 55	25.5	28.0	17.0	17.0	16.4	15.2		
6				42	243 55	27.0	29.0	19.0	19.0	16.2	14.0		Level C.
													E. W.
1	Star.	m-l. m-st.	D	6 47 12	127 42	68.0	67.0	61.5	63.0	64.5	64.3	Correction for run 0.0	
2				49 06	127 42	65.0	65.0	63.5	63.2	63.1	60.5		44 63
3				51 38	127 42	62.8	62.8	57.0	59.8	60.0	58.2		63 44
4				52 12.5	127 42	58.0	58.0	54.0	52.5	55.3	53.5		43 63
5				55 55.5	127 42	56.0	57.0	51.1	52.0	53.0	52.0		64 43
6			R	7 00 54	307 42	48.2	48.7	45.2	45.0	47.7	45.8		
7				2 25.5	307 42	48.0	49.2	43.2	44.2	45.0	44.8		46 62
8				4 01.5	307 42	48.0	48.7	42.0	44.7	46.8	45.0		62 46
9				5 51	307 42	49.0	49.0	44.7	45.0	47.9	46.9		43 63
10				7 14.5	307 42	49.2	50.5	44.8	44.8	47.2	46.2		63 43
7	Mark.	m-d. m-st.	R	7 16	63 55	40.0	40.0	23.0	25.0	26.8	25.2	Correction for run +0.1	
8				17	63 55	39.7	39.7	23.0	23.0	25.7	24.8		
9				18	63 55	38.0	39.0	21.5	22.7	25.0	23.8		
10			D	23	243 55	26.0	26.5	13.7	14.0	15.0	14.6		
11				24	243 55	26.8	26.8	14.5	14.8	15.2	14.0		
12				26	243 55	26.7	27.3	14.0	13.0	14.5	13.9		

TO ART. (5.)—*Example of reduction.*

STATION, AGAMENTICUS. 1847.

$\phi = 43° 13' 25''.0$; $\lambda = 4^h 42^m 44^s.8$ west of Greenwich.

Specimen of ephemeris and of time and azimuth at elongation.

Date.	Elongation.	α	δ	A_e	t_e	Sid. time of elongation. $\alpha \pm t_e$	Chron. fast.	Chron. time of elongation.
		h. m. s.	° ′ ″	° ′ ″	h. m. s.	h. m. s.	m. s.	h. m. s.
Sept. 17, 1847	E	1 05 28.14	88 29 42.80	2 03 54.95	5 54 20.5	19 11 07.6	12.2	19 11 19.8
Sept. 21, 1847	W	29.30	44.54	52.56	20.6	6 59 49.9	31.4	7 00 21.3
Sept. 22, 1847	E	29.40	44.73	52.31	20.6	19 11 08.8	33.3	19 11 42.1
Sept. 22, 1847	W	29.50	44.91	52.06	20.6	6 59 50.1	35.0	7 00 25.1
Oct. 17, 1847	W	1 05 32.96	88 29 54.27	2 03 39.21	5 54 21.2	6 59 54.2	1 51.8	7 01 46.0

Polaris near western elongation, October 17.

No.	Tel.	Time from elong'n.	Reduc'n to elong'n.	Corr'd mean reading.	Reading reduced to elong'n.
		m. s.	″	° ′ ″	° ′ ″
1	R			63 55 31.3	
2				31.3	
3				32.3	
4	D			243 55 19.8	
5				19.9	
6				20.8	
1	D	14 34.0	15.0	127 42 64.7	127 42 49.7
2		12 40.0	11.3	63.2	51.9
3		10 08.0	7.3	60.1	52.8
4		9 33.5	6.5	55.2	48.7
5		7 50.5	4.3	53.5	49.2
6	R	52.0	0.1	307 42 46.7	307 42 46.6
7		39.5	0.0	45.7	45.7
8		2 15.5	0.3	46.0	45.7
9		4 05.0	1.2	47.1	45.9
10		5 28.5	— 2.1	47.1	45.0
7	R			63 55 30.1	
8				29.4	
9				28.5	
10	D			243 55 18.4	
11				18.8	
12				18.3	

Chronometer time of elongation $7^h\ 1^m\ 46^s.0$

Reading of star reduced to elongation.

Tel.	Mean reading.	Level corr'n.	Corr'd mean.
	° ′ ″	″	° ′ ″
D	127 42 50.46	—0.23	127 42 50.23
R	307 42 45.78	0.00	307 42 45.78

	° ′ ″
Reading of * at elongation	127 42 48.00
Azimuth of *	2 03 39.21
Reading of meridian	129 46 27.21
Reading of mark	243 55 24.89
Mark east of north	114 08 57.68
Corr'n for diur'l aber'n	+0.31
Mark E. of N	114 08 57.99

TO ART. (5.)—*Example of record and reduction.*

STATION, POINT AVISADERA, SAN FRANCISCO BAY, CAL.

Polaris near eastern elongation, September 9, 1851.

Observer, R. D. C.—Instrument, 10-inch Gambey theodolite, C. S. No. 20 (graduation from right to left).

No.	Tel.	Star.	Chron. time, Dent, 1838.	Reading of horiz'l circle, mark, and *.
			h. m. s.	° ′ ″
				254 45 50.0
				45.0
				50.0
				62.5
1		Dir.	3 42 30.5	
2		Ref.	44 08.0	
3		Dir.	45 52.0	
4		Ref.	47 15.0	
5	R	Dir.	48 50.0	
6		Ref.	50 34.0	
7		Dir.	52 28.0	
8		Ref.	53 31.5	
				149 15 25.0
				15.0
				25.0
				22.5

N. B.—Several such sets are taken in succession.
Dent, 1838, is a mean-time chronometer.

$\phi = 37° 43' 31''$; $\lambda = 8^h\ 9^m\ 23^s$ west of Greenwich,

Sept. 9, at time of east elongation.

Polaris $\alpha = 1^h\ 6^m\ 15^s.33$

Polaris $\delta = 88° 30' 51''.26$

$t_e = 5^h\ 55^m\ 24^s.10$

$A_e = 1° 52' 42''.84$.

	h. m. s.
Sid. time, mean noon	11 13 05.49
Sid. time, east elongation	19 10 51.23
Mean time, east elongation	7 56 27.47
Chronometer, Dent, 1838, correction	+ 3 50 06.93
Chronometer time, east elongation	4 06 20.50
Mean chronometer time of observation	3 48 12.30
Time from elongation	18 08.20
Time from elongation, sid. interval	18 11.20

	Tab. quan.		
m. s.	″		
5 41.8	63.7		
4 04.3	32.5		
2 20.3	10.7	log 27.4	1.4380
57.3	1.8	log (ratio)	0.0024
46.7	1.2	log tan A	8.5140
2 21.7	11.0		
4 15.7	35.7		9.954
5 39.2	62.8	Correction	—0″.90
$\frac{1}{n}\Sigma$ tab. quan.	27.4		

	° ′ ″
Mean angle between * and mark	13 11 18.7
Reduction to elongation	— 21.3
Reduction to mean azimuth	— 0.9
Corrected angle, elongation and mark	13 10 56.5
Azimuth of * at elongation	1 52 42.8
Mark east of north	15 03 39.3

To which result the correction for diurnal aberration is yet to be applied.

TO ART. (5) *b.—Example of record and reduction.*

STATION, CAT ISLAND, MISSISSIPPI.

Polaris near western elongation, December 5, 1855. Observer, J. E. H. Instrument, 26-inch transit, by Würdemann, C. S. No. 9.

SET NO. 4.

Object.	Lamp.	Chro. time.	Microm.	Level. W.	Level. E.	Remarks.
		h. m. s.	*t. d.*	W.	E.	
Mark	E.	7 16	1 86.0			Chr. time of elongation, 7*h.* 06*m.* 00*s.*2
			85.1			Rate of chro. small. Chro. 220 fast at
			86.8	× 30.5	30.5	time of W. elong'n, 2*m.* 30*s.*0
Polaris ...	....	7 18 59.5	1 77.8	30.5	30.5 ×	
		19 21.5	77.2	....	....	
		19 47.0	77.2	....	....	
	W.	7 21 55.5	1 75.3	....	....	
		22 16.5	75.9	....	....	
		22 45.5	75.0	30.0	31.0 ×	
Mark	....	....	1 87.0	× 31.5	29.5	
		....	86.0	....	....	
		7 25	87.0	....	....	

Increase of micrometer readings corresponds to a movement of telescope from north to west 1 div. of level=2″.0 The value of 1 div. of micrometer is found from the following record:

Micr.	Chro. time.	Diff. from mean.	Polaris near U. C. $\phi = 30^\circ\ 14'\ 22''$
t. d.	*h.m. s.*	*h.m. s.*	$p = 1^\circ\ 27'\ 15''$
1 50	1 04 52.0	0 02 00.7	90 div's correspond to 439*s.* 0 1 div'n corresponds to 4*s.* 8778
60	05 39.0	01 13.7	
70	06 27.5	00 25.2	log *t* 0.68822
80	07 16.5	00 23.8	log 15 .... 1.17609
90	08 07.5	01 14.8	log sin *p* .... 8.40444 log sec. 31° 41′........ 0.07009
2 00	08 53.5	02 00.8	0.33884
Mean 1 75	1 06 52.7	Sum 07 19.0	Value of 1 div. of pivot-micr. = 2″.182

The azimuth is deduced as follows:

Time from elong'n.	Red'n to elong'n.	Mean readings.
m. s.	″	*t. d.* *mean.*
12 59.3	— 9.7	Mark { Lamp E. 1 85.97 / Lamp W. 1 86.67 } 1 86.32
13 21.3	10.3	
13 46.8	11.0	
15 55.3	14.6	Star { Lamp E. 1 77.40 / Lamp W. 1 75.40 } 1 76.40
16 16.3	15.3	
16 45.3	— 16.2	
Mean	— 12.85	Difference 9.92=21″.65

Mark west of star - - - - - - - - - - -	+ 21″.65
Correction for level - - - - - - - - - - -	— 0″.15
Reduction to elongation - - - - - - - - - -	— 12″.85
Mark west of star at elongation - - - - - - -	+ 8″.6
Azimuth of Polaris at west elongation - - - - - -	1° 41′ 00″.2
Mark west of apparent north - - - - - - - -	1° 41′ 08″.8
Correction for diurnal aberration - - - - - - -	— 00″.3
Mark west of north - - - - - - - - - - -	1° 41′ 08″.5

To Arts. (6) and (7).—*Example of record.*

Station, Dollar Point, Galveston Bay, Texas.

Polaris at various hour angles. April 5, 1848.

Observer, J. E. H. Instrument, 18-inch Troughton and Simms theodolite, C. S. No. 4.

Pos. II, set 2.

Object.	Tel.	Time by chronometer Hardy, 50.	Level.		Azimuth circle.			
			E.	W.	A	B	C	
		h. m. s.			° ′ ″	″	″	1 div. of level = 0″.82
Mark.	D	8 56			158 50 55	65	50	
	R				51 20	20	00	
			129	71.5				
			84	119				
			126	74				
			83	117				
Star.	D	9 03 33.5			337 18 40	35	20	
		4 47.5			18 55	55	35	
		6 07.0			18 75	70	55	
"	R	9 08 06.5			19 45	55	40	
		9 24.0			19 65	75	55	
		10 23.5			20 20	30	10	
			121.5	79				
			80	120				
			121.5	78				
			77.5	122				
Mark.	D				158 50 55	65	50	
	R	9 19			51 20	15	00	

To Arts. (6) and (7).—*Example of reduction.*

Station, Dollar Point, 1848.

Specimen of ephemeris: Polaris, at Dollar Point, mean midnight and table of chronometer correction and rate.

$\phi = 29° 26' 02''.6$ $\lambda = 6^h 19^m 32^s.0$ west of Greenwich.

Date.	α	δ	At sidereal time.	Chronometer fast.	Daily rate, gaining.
1848.	h. m. s.	° ′ ″	h.	m. s.	
March 23	1 04 05.51	88 30 01.88			
etc.					
April 2	1 04 04.46	88 29 58.80	12.0	0 11.4	Stopped.
5	04.70	57.77	10.5	02.0	2s.8
6	04.85	57.46	10.4	04.8	
etc.					

Polaris at various hour angles, April 5.

	h. m. s.	
Mean of times	9 07 03.7	
Correction to chronometer	— 01.8	
Sidereal time of observation	9 07 01.9	
α of *	1 04 04.7	
Hour angle	8 02 57.2	120° 44′ 18″.0

Time from mean.	Tabular quantity.
m. s.	″
3 30.2	24.1
2 16.2	10.1
0 56.7	1.7
1 02.8	2.2
2 20.3	10.7
3 16.8	21.8
Mean.	11.8
Reduction.	—0″.30

	° ′ ″
Mean reading of *	337 19 26.40
Level correction	—01.12
Reduction to mean azimuth	—00.30
Corrected reading of *	337 19 24.98
Azimuth of *	1 28 11.45
Reading of meridian	338 47 36.43
Reading of mark	158 51 04.60
Mark west of south	0 03 28.17

(To which result the correction for diurnal aberration is yet to be applied.)

TO ART. (9).—*Example of record and reduction.*

STATION, SANTA CRUZ, CALIFORNIA.

Polaris before upper culmination, October 30, 1854. Observer, R. D. C. Instrument, 12-inch Gambey theodolite, C. S. No, 30 (graduation from right to left).

Number.	Telescope.	Star.	Chronometer time.	Reading of horizontal circle, mark, and star.
			h. m. s.	° ′ ″
	D			37 21 21
				33
				27
				21
1		Dir.	9 51 08.0	
2		Ref.	52 19.5	
3		Dir.	53 35.0	
4		Ref.	54 44.0	
5		Dir.	56 55.0	
6		Ref.	58 44.0	
7	R	Dir.	10 00 35.5	
8		Ref.	01 54.5	
9		Dir.	03 07.0	
10		Ref.	04 21.5	
11		Dir.	05 29.0	
12		Ref.	06 46.5	
				216 16 15
				12
				24
				12

N. B.—Several such sets are taken in succession.
The chronometer used is regulated to mean time.

= 36° 58′ 32″   λ = $8^h\ 08^m\ 09^s$ west of Greenwich.

October 30. Polaris $\alpha = 1^h\ 06^m\ 54^s.38$

" $p = 1^\circ\ 27'\ 48''.35$

	h. m. s.
Santa Cruz, sidereal time at mean noon	14 35 14.31
Sidereal interval of upper culmination after mean noon	10 31 40.07
Chronometer time of observation	9 59 08.29
Chronometer slow	12 46.11
Mean time of observation	10 11 54.40
Sidereal interval of observation after mean noon	10 13 34.92
Sidereal interval of upper culmination after mean noon	10 31 40.07
Hour angle, + east, — west	— 18 05.15

We have

$p = 5268''.4$

second term = $101''.0$

third term = $3''.1$

hence—

$t = 4^\circ 31' 17'$,

$A = 530''.14$

τ	In sidereal time.	Tabular quantity.
m. s.	m. s.	″
8 00	8 01	126
6 49	6 50	92
5 33	5 34	61
4 24	4 25	38
2 13	2 13	10
0 24	0 24	0
1 27	1 27	4
2 46	2 46	15
3 59	4 00	31
5 13	5 14	54
6 21	6 22	80
7 38	7 39	115
Mean		52.2
Reduction to mean azimuth		−0″.13

	° ′ ″
Angle, mark and star	14 54 34.19
Azimuth of star corrected	−8 50.01
Mark west of north	14 45 44.18

(To which a correction for diurnal aberration is yet to be applied.)

TO ART. (10.)—*Example of record.*

STATION, SEBATTIS, KENNEBEC COUNTY, MAINE.

Polaris near upper culmination, July 13, 1853. Observer, A. D. B. Instrument, 30-inch theodolite, C. S. No. 1. Position of index and limb, No. V. Weather, clear. Wind, northeast, light. Temperature, 59° Fahrenheit. *Assumed time of culmination,* $1^h\ 05^m\ 57^s$. *Assumed chronometer error,* $+17^s$. Approximate chronometer time of culmination, $1^h\ 06^m\ 14^s$.

Number.	Object.	Appearance.	Telescope.	Time by sidereal chronometer.			Azimuth circle.								Level.
									A		B		C		
				h.	*m.*	*s.*	°	′	*d*	*d*	*d*	*d*	*d*	*d*	
1	Mark.	m-d. st.	R	0	5		202	04	32	30	30	28.5	34.5	32	1 division of level=1″.53
2				0	8		202	04	32.5	34.5	31	31	35	34.5	
3				0	11		202	04	32	34	31.5	30.5	35.5	34	
4			D	0	16		22	04	26	28	31.5	31	31	31	
5				0	18	30	22	04	26	27.5	29	27	30	28	
6				0	22		22	04	27	27.5	25.5	25.5	28	27	E. W.
1	Star.	m-d. s. r.	D	0	46	14	22	09	04.5	03	02	03.5	06	06	×72 75 75 72×
2				0	49	14	22	07	27	26	28	30	28.5	27	
3				0	52	14	22	05	44	42	45	46.5	48	49	71 72.5×
4				0	55	14	22	04	05	05	06	07	08.5	07	×69 74 ×72 70
5				0	58	14	22	02	25.5	24.5	26.5	27	29	29	67 74×
6		tr.	R	1	14	14	201	53	47.5	47.5	49.5	49.5	51.5	50	×69 68
7				1	17	14	201	52	07	08	09	09	10	10.5	74 62
8				1	20	14	201	50	33	33	34	34	33.5	35	74 61
9				1	23	14	201	48	49	49	51	49	52	51	×72 64 ×72 63
10		m-b. s. t.		1	26	14	201	47	10	12.5	10.5	12	12.5	12	73 61×
7	Mark.	ft. m-st.	R	1	30		202	04	31.5	31	32.5	32.5	36	34	
8				1	37		202	04	30	29	31	30	34.5	33	
9				1	39		202	04	31	30	32	30	34	33	
10				1	41		22	04	26.5	27	30.5	30.5	32	31	
11				1	43		22	04	26	27	30.5	30	32	31	No correction for run of
12				1	45		22	04	28.5	29.5	31	31	32.5	33	microscopes.

TO ART. (10.)—*Example of reduction.*

STATION, SEBATTIS, 1853.

$\phi=44^\circ\ 08'\ 37''.7$ $\lambda=4^h\ 40^m\ 17^s.5$ west of Greenwich.

Specimen of table of sidereal time and of chronometer time of culminations.

Date.	Culmination.	Sidereal time.	Chronometer fast.	Chronometer time of culmination.
1853.		*h. m. s.*	*s.*	*h. m. s.*
July 13	Lower	13 05 57.3	15.7	13 06 13.0
July 13	Upper	1 05 57.7	17.9	1 06 15.6
July 14	Lower	13 05 58.2	20.2	13 06 18.2
July 14	Upper	1 05 58.7	22.5	1 06 21.2
etc.				

Before upper culmination of Polaris.				After upper culmination of Polaris.				Reading of meridian.
Number.	Telescope.	Time from upper culmination.	Corrected mean reading	Number.	Telescope.	Time from upper culmination.	Corrected mean reading.	
		m.	° ′ ″			*m.*	° ′ ″	° ′ ″
1	R	....	202 04 31.2	12	D	....	22 04 30.9	
2	"	....	33.1	11	"	....	29.4	
3	"	....	32.9	10	"	....	29.5	
4	D	....	22 04 29.7	9	R	....	202 04 31.6	
5	"	....	27.9	8	"	....	31.3	
6	"	....	26.8	7	"	....	32.0	
1	D	20	22 09 04.2	10	R	20	201 47 11.6	21 58 07.9
2	"	17	07 27.7	9	"	17	48 50.2	08.9
3	"	14	05 45.7	8	"	14	50 33.7	09.7
4	"	11	04 66.4	7	"	11	52 08.9	07.7
5	"	8	02 26.9	6	"	8	53 49.2	08.0

Chronometer time of upper culmination....... $1^h\ 06^m\ 15^s.6$
Assumed time of upper culmination........... $14^s.0$

Mean reading of meridian.	Level correction.	Reduction to meridian.	Corrected mean.
° ′ ″	″	″	° ′ ″
21 58 08.44	−2.82	−0.85	21 58 04.77
	Reading of mark		22 04 30.60
	Mark east of north		0 06 25.83

(To which result the correction for diurnal aberration is yet to be applied.)

TO ART. (10) *b.—Example of record and computation.*

STATION, DEPOT KEY, FLA.

March 20, 1852. δ Ursæ Min. at L. C., and 51 Cephei at U. C.

Observer, J. E. H. Instrument, the Simms Transit, C. S. No. 8.

Time by chro. 202.	Mark.		Time by chro. 202.	Chro. time by 202.	δ Ursæ Min.	Chro. time by 202.	51 Cephei.
	Lamp E.	Lamp W.					
h. m.	*t. d.*	*t. d.*	*h. m.*	*h. m. s.*	*t d.*	*h. m. s.*	*t. d.*
5 20	18 76.0	12 67.0	5 40	6 18 44	18 22	6 27 34	13 22
	76.0	66.5		19 11	17 72	28 08	13 72
	75.0	67.0		19 37.5	17 22	28 40.5	14 22
	76.0	66.5		20 04.5	16 72	29 15	14 72
	75.0	67.5		20 31.5	16 22	29 48	15 22
	75.0	67.5		20 59	15 72	30 22	15 72
	75.1	67.0		21 25.5	15 22	30 54	16 22
	75.1	67.2		21 52	14 72	31 29	16 72
	75.8	67.0		22 19	14 22	32 01.5	17 22
5 30	75.0	66.5	5 50	22 46	13 72	32 36	17 72
				23 13	13 22	33 10	18 22

Level.			Level.	
W.	E.		W.	E.
48.1	49.8	1 div. of level = 1″	63.0	38.0
63.0	35.0		49.0	53.5
48.2	50.8		63.5	39.0
63.0	36.3		49.0	53.5

Determination of the value of one division of the micrometer:
Mean of times, $6^h\ 20^m\ 58^s.5$ for δ Ursæ Minoris and $6^h\ 30^m\ 21^s.6$ for 51 Cephei.

Corresponding micrometer readings, 15ᵗ 72ᵈ for δ Ursæ Minoris and 15ᵗ 72ᵈ for 51 Cephei. Hence the following differences from the mean:

δ Urs. Min.			51 Cephei.		
m. s.	*t. d.*		*m. s.*	*t. d.*	
2 14.5	2 50		2 47.6	2 50	
1 47.5	2 00	From obs. of δ Urs. Min.:	2 13.6	2 00	From obs. of 51 Cephei:
1 21.0	1 50	1 div. corresponds to 0s.5383	1 41.1	1 50	1 div. corresponds to 0s.6703
0 54.0	1 00	log 15 .... 1.17609	1 06.6	1 00	log 15 .... 1.17609
0 27.0	0 50	log *t* 9.73102	0 33.6	0 50	log *t* 9.82627
0 00.5	0 00	log cos δ .. 8.77395	0 00.4	0 00	log cos δ .. 8.67961
0 27.0	0 50		0 32.4	0 50	
0 53.5	1 00	9.68106	1 07.4	1 00	9.68197
1 20.5	1 50		1 39.9	1 50	
1 47.5	2 00	1 div. = 0″.4798	2 14.4	2 00	1 div. = 0″.4808
2 14.5	2 50		2 48.4	2 50	
Sum 807ˢ.5	1500 div's.		1005ˢ.4	1500 div's.	

Mean of all measures—1 division of micrometer = 0″.4800

φ=29° 07′ 30″ Mark, mean reading.		B=−7.30 δ Ursæ Minoris, L. C.		B=+11.04 51 Cephei, U. C.	
	t. d.		*h. m. s.*		*h. m. s.*
Lamp E	18 75.4	Chronometer time	6 20 58.46		6 30 21.64
Lamp W	12 67.0	Δ T	−51.30		−51.30
Line of collimation	15 71.2	Sidereal time of obs	6 20 07.16		6 29 30.34
Star, lamp W	15 72.0	Corr'n for level 0.42 × 7.30=	− 3.07	0.337 × 11.04=	+ 3.72
Difference	0.8	Corr'n for coll. 0.8 × 0.538=	+ 0.42	−0.8 × 0.670=	− 0.54
		T	6 20 04.51	T	6 29 33.52
		α	6 20 05.61	α	6 29 33.15
		α−T	+ 1.10	α−T	− 0.37
Star E. of N		A	−1″.09	A	−0″.31
Mark E. of star		3t. 4d.2=	2′ 26″.02		2′ 26″.02
Mark E. of N			0° 02′ 24″.93		0° 02′ 25″.71

To which the correction for diurnal aberration is yet to be applied.

If we were to use the second formula for level correction, as directly applied to the azimuth, the computation would stand as follows:

	h. m. s.	*h. m. s.*		
Sidereal time of observation.	6 20 07.16	6 29 30.34	For δ Urs. Min.,	i= − 6″.30; ζ=64° 16′ 54″
Correction for collimation...	+ 0.42	− 0.54		
T′	6 20 07.58	6 29 29.80	For 51 Cephei,	i= − 5″.06; ζ=58° 08′ 02″
α	6 20 05.61	0 29 33.15		
α—T′	− 1.97	+ 3.35		
A	+1″.95	+2″.83		
Level correction i cot ζ	−3″.04	−3″.14		
Mark E. of star	2′ 26″.02	2′ 26″.02		
Mark E. of N	0° 02′ 24″.93	0° 02′ 25″.71		

NOTE.—At this station, also, observations were made on δ Ursæ Minoris at upper culmination and on 51 Cephei at lower culmination, and the results were combined with those from the stars in the opposite position.

For a second illustration of the method the following example of the determination of the line of collimation by *reversal on the star* has been selected.

STATION, EL PASO, EAST BASE, COLO.

October 6, 1879. λ Ursæ Min. at U. C. Observer, O. H. T. Instrument, meridian telescope No. 3.
One division = 0.01 turn of eye-piece micrometer = 0″.6369 ± 0.0008 One division of level = 0″.705
Pivot inequality −0s.04 for Clamp W. or clamp pivot the larger.

$\phi = 38^\circ\ 57'\ 17''$ $\delta = 88^\circ\ 56'\ 51''.8$

Mark.		λ Ursæ Minoris.				Mark.	
Level.	Clamp W.	Clamp W.	Sid. chronometer.	Clamp E.	Sid. chronometer.	Clamp E.	Level.
	t.	t.	h. m. s.	t.	h. m. s.	t.	
	21.535	24.120	19 39 50	22.705	19 51 50	22.225	
	.500	23.837	40 50	.945	52 50	.220	
E. W.	.525	.580	41 50	23.212	53 50	.216	E. W.
26.5 25.5	.515	.355	42 50	.457	54 50	.218	27.0 28.0
22.5 30.0	.535	.120	43 50	.725	55 50	.218	26.5 29.0
25.5 27.0	.510	22.842	44 50	24.005	56 50	.210	27.5 27.5
23.5 29.0	.510	.580	45 50	.265	57 50	.195	27.5 28.0
	.520	.320	46 50	.504	58 50	.220	
At 19*h*. 30*m*.	.545	.072	47 50	.782	59 50	.235	at 20*h*. 04*m*.
	.540					.230	
Means	21.523	23.092	19 43 50	23.733	19 55 50	22.219	

	E. W.	E. W.	
Level	23.5 31.0	27.5 27.5	Level
	24.5 29.5	27.0 27.8	
	23.5 31.0	27.0 28.0	
	24.5 29.5	27.5 28.0	

Determination of line of collimation by reversal on star.

	Clamp W.	Clamp E.		Log's.
	h. m. s.	h. m. s.		
Mean chromometer time of observation .	19 43 50	19 55 50	Elapsed time.......	4.03232
Correction for level inequality	+ 3.70	+ 1.88	cos δ	8.26398
Corrected chronometer time	19 43 53.70	19 55 51.88	co. 1 turn of mic ...	8.19593
	Elapsed time	11 58.18	motion of * in turns of mic. = 3t.106	0.49223

Elapsed time corrected for rate .... 10772″.55 = 11 58.17

Line of collimation reads ½ (23t.092 + 23t.733 − 3t.106) = 21t.860
and for comparison, same from observation on mark, 21t.871

The computation for azimuth of mark, adopting the latter value, stands as follows:

	h. m. s.					
Mean chronometer time	19 49 50.00	Mark W...	21t.523			A = +26″.47
△T or correction	− 5 38.07	E...	22t.219	Mark W ...	21t.523	
Sid. time of obser'n....	19 44 11.93	Coll'n line.	21t.871	Coll'n line ..	21t.871	
Corr'n for level ineq....	+ 2.80	Star W ...	23t.092	diff=	− 0t.348	= −22″.16
Corr'n for collimation ..	− 1 14.10	E....	23t.733	Mark east of north		+ 4″.31
T..................	19 43 00.63	diff W ...	1t.221	to which add the corr'n for aberration		
α..........	19 44 14.22	diff E....	1t.862			
α−T....	1 13.59	diff ..	0t.641			
		half diff ..	0t.3205			

To Art. (10) c. *Example of record and reduction.*

Station, West Gulf Shore, Ala. (second-order station).

51 Cephei near upper culmination and Polaris near lower culmination, January 29, 1869. Observer, J. G. O. Instrument, the Würdemann transit C. S. No. 10.

Set 2.

Lamp.	Micrometer. Mark.		Micrometer. 51 Cephei.		Time by sid. chronometer Dent 2126.			Level.	
	t.	*d.*	*t.*	*d.*	*h.*	*m.*	*s.*	*E.*	*W.*
E.	15	95							
		96						54	53
		95						53	54
			19	42	6	53	05		
				60		53	47		
				73		54	17		
				84		54	47		
				95		55	17		
W.			20	34	6	56	40		
				49		57	15		
				63.5		57	47		
				80		58	20.5		
				91		58	48		
	15	95							
		96						57	54
		96						56	55

Further observing prevented by clouds.

Set 1.

Lamp.	Micrometer. Mark.		Micrometer. α Ursæ Min.		Time by sid. chronometer Dent 2126.			Level.	
	t.	*d.*	*t.*	*d.*	*h.*	*m.*	*s.*	*E.*	*W.*
W.	15	94							
		94						61	58.5
		93						63	56
			18	15.0	12	55	26		
			18	07.4		56	02.5		
			17	98.0		56	45		
			17	89.0		57	26		
			17	80.0		58	02		
E.			17	59.0	12	59	49.5		
			17	51.0	13	00	26.0		
			17	42.0		01	03.5		
			17	33.5		01	35.0		
			17	26.5		02	11.5		
	15	92.5							
		94						61	56.5
		92						59	58.5

After this four more sets were taken.

Determination of the value of one turn of the micrometer.

The following record is a part of a set, the whole covering more than is here needed for illustration

δ Ursæ Minoris near lower culmination, February 5, 1869.

Chronometer time of lower culmination, 6*h*. 15*m*. 8*s*.

Micr.	Chro. time.			Time from culmination.	Red'n.	Red'd time.			Time of 3 turns.			
t.	*h.*	*m.*	*s.*	*m.*	*s.*	*h.*	*m*	*s.*	*t.*	*t.*	*m.*	*s.*
21.0	5	55	57	19.9	+1.5	5	55	58.5	21	to 18	9	62.7
20.5		57	40	18.1	1.1		57	41.1	20.5	17.5	9	59.5
20.0		59	23.5	16.4	0.8		59	24.3	20	17	9	55.7
19.5	6	01	02.5	14.8	0.6	6	01	03.1	19.5	16.5	9	56.9
19.0		02	41.5	13.1	0.4		02	41.9	19	16	9	57.1
18.5		04	21.0	11.5	0.3		04	21.3	18.5	15.5	9	51.7
18.0		06	01.0	9.8	0.2		06	01.2	18	15	9	55.8
17.5		07	40.5	8.1	0.1		07	40.6	Mean		9	57.0
17.0		09	20.0	6.5	0.0		09	20.0				
16.5		11	00.0	4.8	0.0		11	00.0				
16.0		12	39.0	3.2	0.0		12	39.0				
15.5		14	13.0	1.6	0.0		14	13.0				
15.0		15	57.0	0.1	0.0		15	57.0				

The last column serves to indicate the probable uncertainty in the value. Subtracting the mean of the times and the mean of the micrometer readings from each separate measure, we obtain the following table:

t.	*m.*	*s.*
+3.0	+10	01.6
2.5	8	19.0
2.0	6	35.8
1.5	4	57.0
1.0	3	18.2
0.5	1	38.8
0.0	−0	01.1
−0.5	−1	40.5
1.0	3	19.9
1.5	4	59.9
2.0	6	38.9
2.5	8	12.9
−3.0	−9	56.9

Hence, 21 turns correspond to $4179^s.4$; 1 turn corresponds to $199^s.0$

Time of 1 turn $=199^s.0$	$\log t$	$= 2.29885$
$\delta=86° 36' 12''$	$\log \cos \delta$	$= 8.77267$
	$\log 15$	$= 1.17609$
1 turn $=176''.85$	log one turn	$= 2.24761$
$h=26° 50' 06''$	$\log \sec (\varphi-p)$	$= 0.04948$
1 turn, in azimuth $=198''.2$		2.29709
$\varphi=30° 13' 54''$		

Increase of micrometer reading corresponds to a westerly motion of the north end of the telescope.

One division of level $=0''.75$, B $=+11.3$ for 51 Cephei and B $=-20.0$ for Polaris; hence, level corrections $-0^s.28$ and $+1^s.81$ respectively.

SET 2. 51 Cephei. $p=2° 45' 32''$

	t.	*d.*		*h.*	*m.*	*s.*		″
Mean reading of mark ...	15	95.5	Mean of chro. times ..	6	56	00.35	Star W. of mer'dn..	824.1
Mean reading of star.....	20	17.15	Correction for level...			−00.28	Mark E. of star	835.7
Difference	4	21.65	Chro'r correction		−1	30.48	Mark E. of mer'dn .	11.6
	=835″.7							
			Sidereal time	6	54	29.59		
			α	6	38	31.40		
			t		15	58.19		

SET. 1. Polaris.

	t.	*d.*		*h.*	*m.*	*s.*		″
Mean reading of mark ...	15	92.75	Mean of chro. times ..	12	58	52.70	Star W. of mer.....	335.1
Mean reading of star.....	17	70.14	Correction for level...			+1.81	Mark E. of star	351.6
Difference	1	77.39	Chro'r correction		−1	30.48	Mark E. of mer'dn .	16.5
	=351″.6							
			Sidereal time	12	57	24.03		
			$\alpha+12^h$	13	10	53.85		
			t		3	29.82		

To connect the direction of a side of the triangulation with that of the meridian, the theodolite employed for the measure of the horizontal angle subtended between the mark and signal must be exactly centered over the intersection of the vertical planes passing through the optical and the horizontal axes of the transit. This may be effected in several ways, to suit the peculiarities of the station mark, the instruments and the ground. To fix this place of intersection, the telescope may be pointed vertical by means of its finder and level, after having a cylindrical piece of cork with a pin in its axis substituted for the eye-piece; the vertical, through this pin, will thus mark the point. Four stakes may be driven into the ground a few feet from the station, to admit of two silk threads being stretched across and to intersect, nearly at right angles, exactly on the point of the pin; the transit may then be removed and the theodolite mounted over the vertical of the thread intersection.

To Art. (11.)—*Example of record and reduction.*

Station, Capitol East Park, Washington, D. C.

Sun near prime vertical, August 15, a. m., 1856. Observer, C. A. S. Instrument, 5-inch magnetic theodolite. Sidereal chronometer.

Chronometer time.	Horizontal circle.		Vertical circle.		Temperature.
	A	B	A	B	
Set I.	⊙'s upper and first limb. Telescope D.				73° Fahr.
h. m. s.	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
5 02 53.0	25 24 30	205 24 30	61 56 00	61 56 00	(Bar. 30 in., assumed.)
05 34.0	25 50 45	205 51 30	61 24 30	61 25 00	
06 55.5	26 04 30	206 05 15	61 08 45	61 09 30	
	⊙'s lower and second limb. Telescope R.				
5 09 12.0	205 54 15	25 54 00	61 19 30	61 18 30	
10 32.0	206 07 15	26 06 45	61 04 00	61 03 00	
11 42.0	206 18 30	26 18 15	60 50 00	60 49 45	
Set II.	⊙'s lower and second limb. Telescope R.				
5 13 22.0	206 35 30	26 35 30	60 30 45	60 30 15	
14 32.0	206 47 30	26 47 30	60 17 30	60 17 00	
15 36.5	206 58 30	26 58 00	60 05 15	60 04 30	
	⊙'s upper and first limb. Telescope D.				
5 17 07.0	27 47 30	207 48 15	59 11 45	59 12 00	
18 16.5	28 00 00	208 00 30	58 57 45	58 58 00	
19 19.0	28 10 15	208 10 30	58 45 30	58 45 13	
Set III.	⊙'s upper and first limb. Telescope D.				
5 20 44.0	28 25 00	208 25 00	58 29 00	58 29 30	
22 01.5	28 37 45	208 38 15	58 14 45	58 14 30	
25 26.5	29 13 30	209 14 00	57 36 00	57 35 45	
	⊙'s lower and second limb. Telescope R.				
5 27 32.5	209 01 30	29 00 30	57 48 00	57 47 30	
28 39.5	209 12 45	29 12 15	57 34 30	57 34 15	
30 01.0	209 27 00	29 26 30	57 19 15	57 18 30	78° Fahr.

$\phi = 38° 53' 18''$ $\lambda = 5^h 08^m 01^s.0$ west of Greenwich.

	Mean chronometer time.	Mean reading horizontal circle.	Mean reading vertical circle.	Correct'n for parallax in altitude and refraction.	Corrected ζ.
	h. m. s.	° ′ ″	° ′ ″	′ ″	° ′ ″
Set I.........	5 07 48.1	25 56 40	61 17 02	+ 1 34	61 18 36
Set II........	5 16 22.2	27 23 17	59 38 00	+ 1 27	59 39 27
Set III.......	5 25 44.1	28 59 30	57 50 07	+ 1 21	57 51 28

	Set I.	Set II.	Set III.
	° ′ ″	° ′ ″	° ′ ″
ϕ	38 53 18	38 53 18	38 53 18
h	28 41 24	30 20 33	32 08 32
p	76 04 27	76 04 37	76 04 44
A (from north).........	95 06 06	96 32 34	98 08 54
Circle reads	25 56 40	27 23 17	28 59 30
South meridian reads ..	110 50 34	110 50 43	110 50 36

(13.) In planning work for observing an azimuth according to the requirements of the case and the construction and power of the instrument and the convenience of the observer, the following tables of the times of the culminations and elongations of four circumpolar stars will be found a useful auxiliary. These tables will give the times to the nearest minute for the first day of each month and for the year 1885, supposing the observer's position in latitude 40° N. and in west longitude 6^h from Greenwich and by an easy interpolation they will give the times for any day of the year, for any year (within this century), and for any north latitude between 30° and 50°. The times given are astronomical, counting from noon of the civil day.

Mean local time (astronomical) of the elongations and culminations of four circumpolar stars, for 1885, and lat. 40°, long. 6^h west of Greenwich.

1st of—	α Ursæ Minoris.				δ Ursæ Minoris.			
	E. E.	U. C.	W. E.	L. C.	E. E.	U. C.	W. E.	L. C.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Jan'y.	0 35.3	6 29.9	12 24.6	18 28.0	17 31.3	23 19.0	5 10.6	11 21.0
Feb'y.	22 29.0	4 27.6	10 22.2	16 25.6	15 29.5	21 17.2	3 08.8	9 19.1
March.	20 38.5	2 37.1	8 31.8	14 35.1	13 39.6	19 27.2	1 18.8	7 29.2
April.	18 36.4	0 35.0	6 29.7	12 33.1	11 37.9	17 25.5	23 13.2	5 27.5
May.	16 38.6	22 33.3	4 31.8	10 35.2	9 40.1	15 27.7	21 15.4	3 29.7
June.	14 37.0	20 31.7	2 30.3	8 33.7	7 38.3	13 25.9	19 13.6	1 27.9
July.	12 39.5	18 34.2	0 32.8	6 36.2	5 40.3	11 28.0	17 15.6	23 26.0
Aug't.	10 38.1	16 32.8	22 27.5	4 34.8	3 38.3	9 26.0	15 13.6	21 24.0
Sept'r.	8 36.6	14 31.3	20 26.0	2 33.3	1 36.2	7 23.9	13 11.6	19 21.9
Oct'r.	6 38.9	12 33.6	18 28.2	0 35.5	23 34.2	5 25.7	11 13.4	17 23.8
Nov'r.	4 37.0	10 31.7	16 26.4	22 29.7	21 32.1	3 23.7	9 11.3	15 21.7
Dec'r.	2 38.9	8 33.5	14 28.2	20 31.6	19 34.0	1 25.6	7 13.2	13 23.6

1st of—	51 H. Cephei.				λ Ursæ Minoris.			
	E. E.	U. C.	W. E.	L. C.	E. E.	U. C.	W. E.	L. C.
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Jan'y.	6 08.9	11 58.6	17 48.3	23 56.6	18 52.1	0 51.6	6 47.1	12 49.6
Feb'y.	4 07.0	9 56.7	15 46.4	21 54.7	16 50.2	22 45.7	4 45.1	10 47.6
March.	2 16.7	8 06.4	13 56.1	20 04.5	15 00.3	20 55.9	2 55.3	8 57.8
April.	0 14.6	6 04.3	11 54.0	18 02.3	12 59.0	18 54.5	0 54.0	6 56.5
May.	22 12.5	4 06.2	9 55.9	16 04.2	11 01.6	16 57.1	22 52.7	4 59.1
June.	20 10.5	2 04.2	7 53.9	14 02.2	9 00.2	14 55.7	20 51.2	2 57.6
July.	18 12.6	0 06.2	5 55.9	12 04.2	7 02.4	12 57.9	18 53.4	0 59.9
Aug't.	16 10.8	22 00.5	3 54.7	10 02.4	5 00.4	10 55.9	16 51.4	22 53.9
Sept'r.	14 09.1	19 58.8	1 52.4	8 00.8	2 58.0	8 53.6	14 49.1	20 51.6
Oct'r.	12 11.4	18 01.1	23 50.8	6 03.1	0 59.5	6 55.0	12 50.6	18 53.1
Nov'r.	10 09.8	15 59.5	21 49.2	4 01.5	22 53.0	4 52.4	10 48.0	16 50.5
Dec'r.	8 12.0	14 01.8	19 51.5	2 03.7	20 54.4	2 53.9	8 49.4	14 51.9

1. To correct the tabular times so as to apply to any year subsequent to 1885 (or for a year prior to 1885 by reversing sign):

Add, in the case of Polaris - - - - - - -	$0^m.35$ for every year.
Subtract, in the case of λ Ursæ Minoris - - - - -	$1^m.1$ for every year.
Add, in the case of 51 Cephei - - - - - . -	$0^m.5$ for every year.
Subtract, in the case of δ Ursæ Minoris - - - - -	$0^m.35$ for every year.

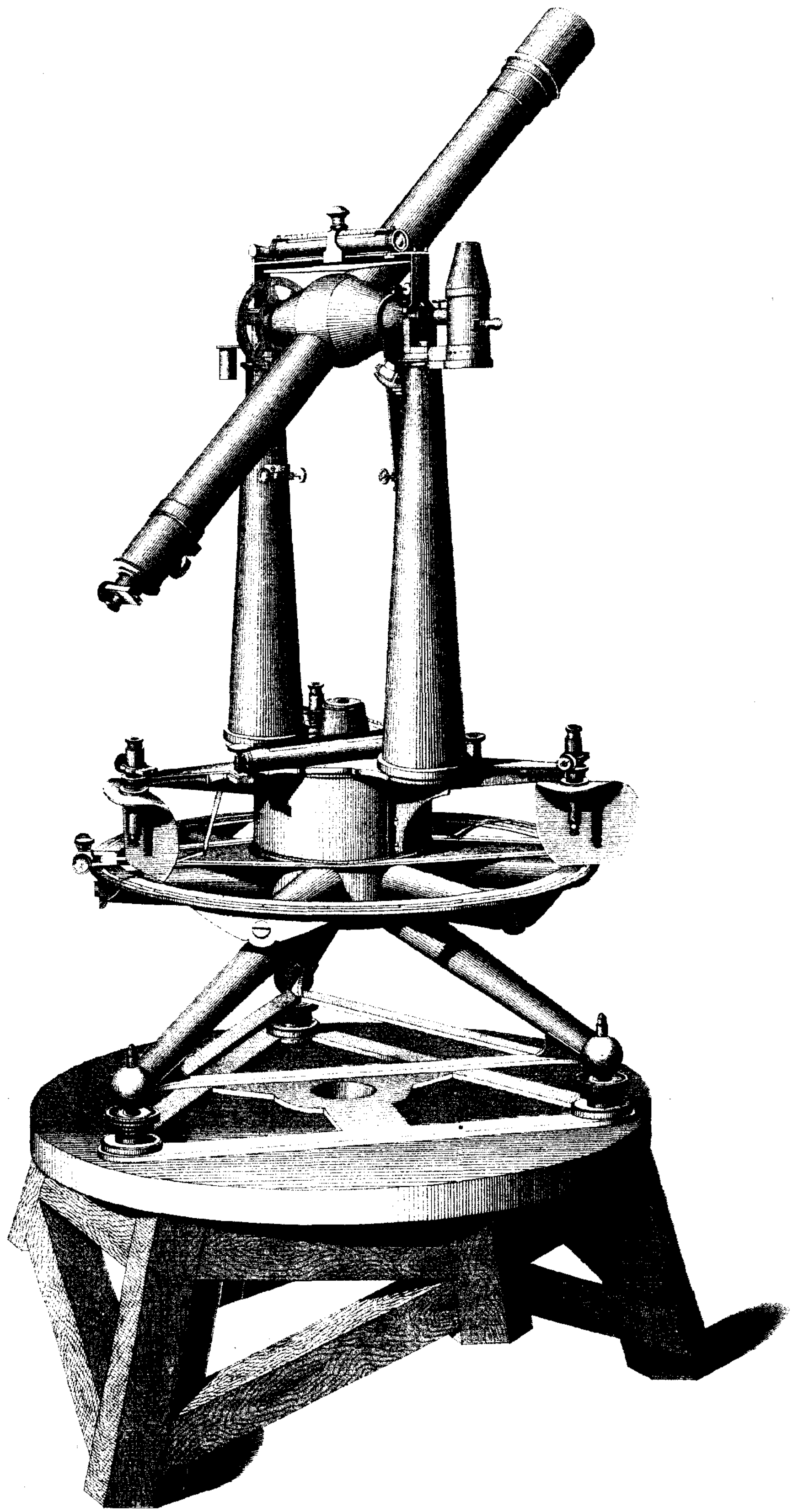
2. To correct the times for any year in a quadriennium:

For first year after a leap-year the table is perfect.

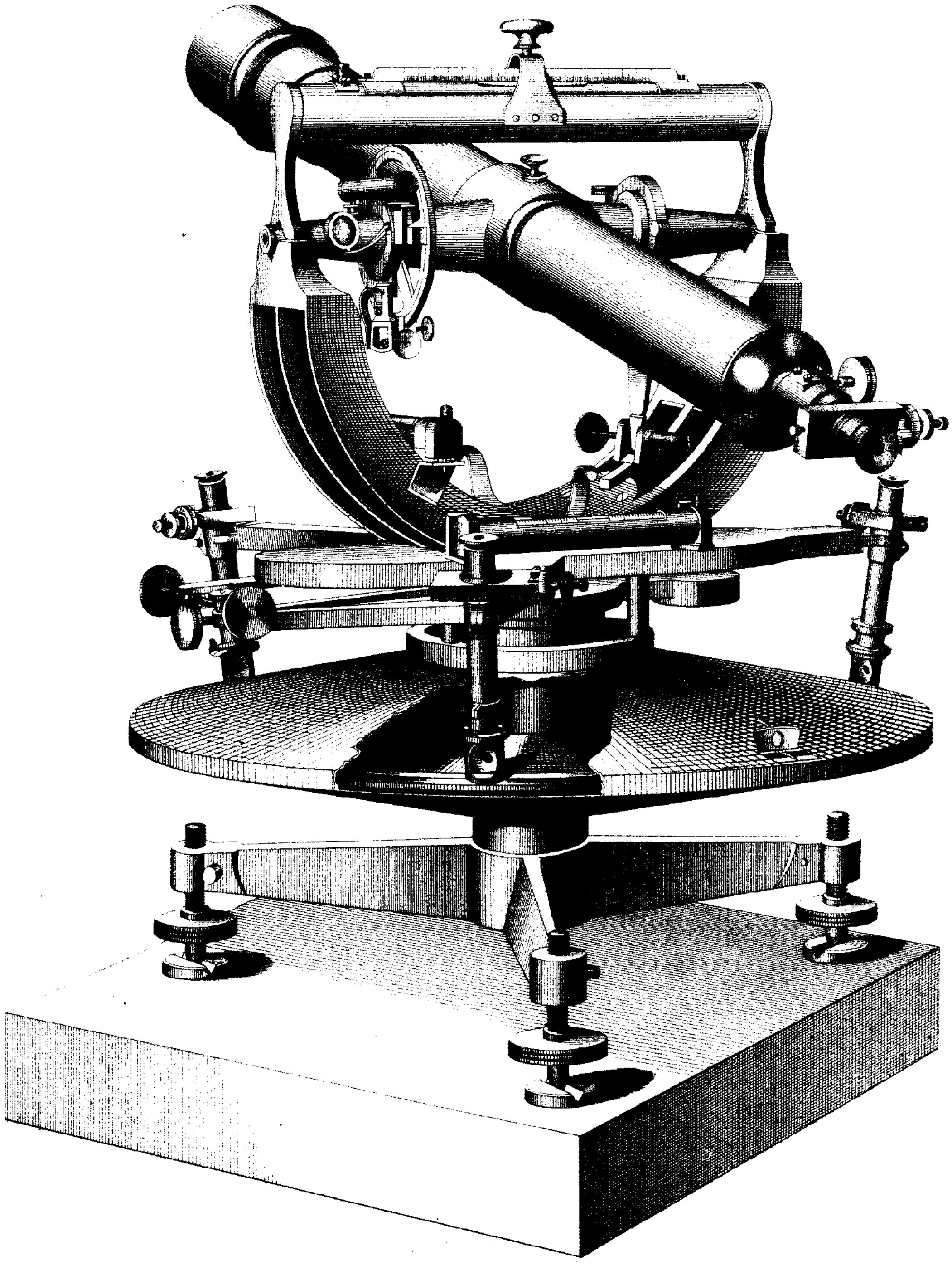
For second year after a leap-year add - -	$1^m.0$
For third year after a leap-year add - - -	$2^m.0$
For leap-year and before March 1 add - -	$3^m.0$
For the remainder of the year subtract - -	$1^m.0$

3. To allow for difference of latitude between the limits of 30° and 50°, correct the times of elongations as follows:

For Polaris,	add $0^m.14$	for each degree south of 40° and	subtract $0^m.18$	for each degree north of 40°.
For λ U. Min.,	add $0^m.11$		subtract $0^m.15$	
For 51 Ceph.,	add $0^m.29$		subtract $0^m.39$	
For δ U. Min.,	add $0^m.35$		subtract $0^m.48$	

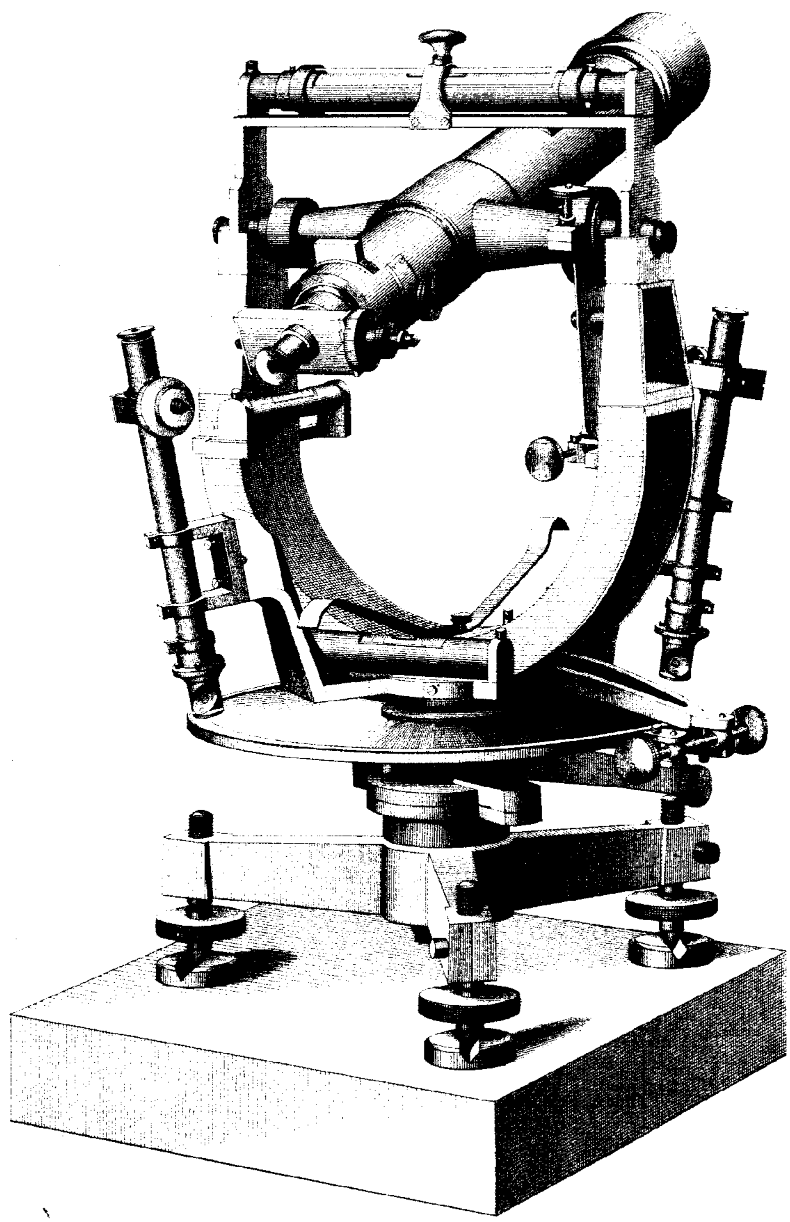


THIRTY INCH THEODOLITE.



P.E. del.

TWENTY INCH (50 C.M.) THEODOLITE.

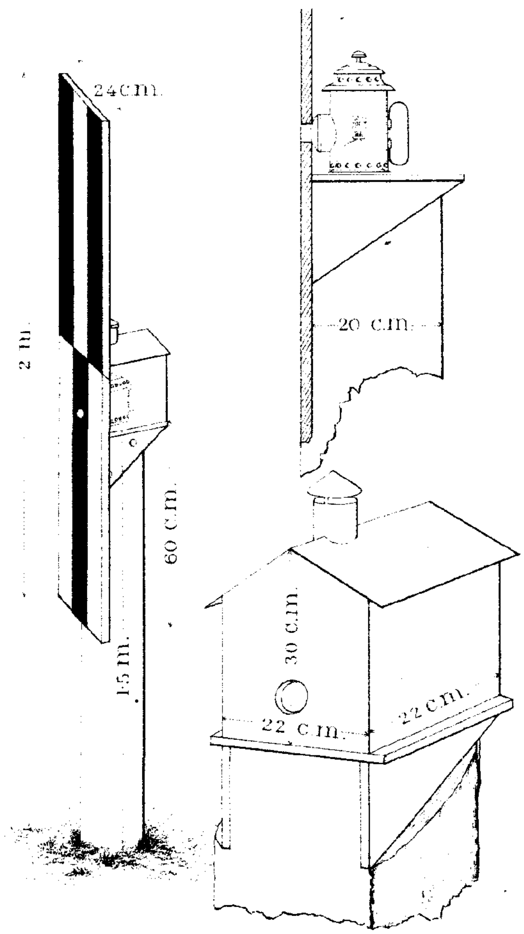


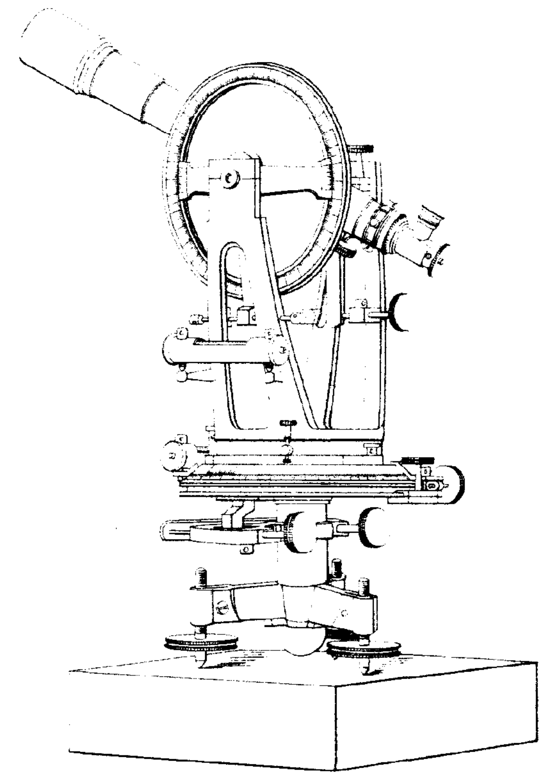
P.E. del.

EIGHT TO TWELVE INCH THEODOLITE

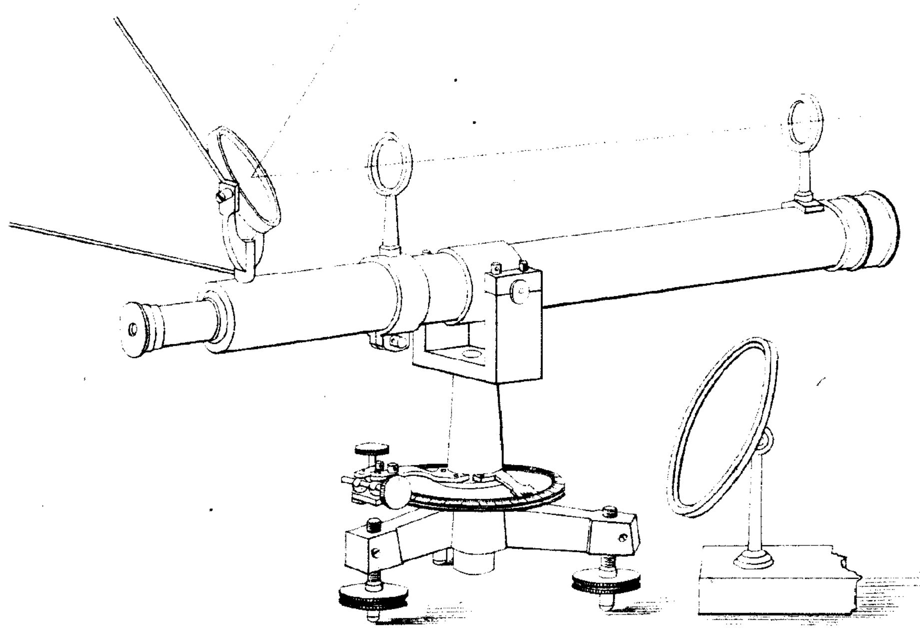
(20 to 30 CM)

AZIMUTH-MARK





FOUR INCH (10 c.m.) ALT-AZIMUTH



HELIOTROPE

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Appendix No. 15.

A COMPARISON OF THE RELATIVE VALUE OF THE POLYCONIC PROJECTION USED ON THE COAST AND GEODETIC SURVEY, WITH SOME OTHER PROJECTIONS.

Prepared by CHARLES A. SCHOTT, Assistant.

(Illustrated by 6 plates and a chart.)

SEPTEMBER 15, 1875.

In accordance with your direction it is proposed to present here those supposed considerations which appear to have led to the adoption, in the Survey, of the polyconic projection in preference to other projections more or less adapted to the same purpose. To do this satisfactorily it will be desirable to review briefly the various leading projections in use and to advert to their principal properties and practical advantages or conveniences.

It will be noticed that this ground has already been gone over by the late Maj. E. B. Hunt, United States Engineers and Assistant Coast Survey, who gave an exposition of the subject in Appendix No. 39, Coast Survey Report for 1853; but the length of time elapsed and the consequent increasing difficulty of ready reference to this article renders it desirable to restate the subject, at the same time taking advantage of the opportunity of introducing additional remarks and adverting briefly to a historical notice of the polyconic projection. I have also thought it desirable to change the classification.

The principal artifices adopted by geographers and navigators of representing on plane maps and charts the whole or portions of the surface of the globe or of the spheroid have been so often described as to require, in this place, no further detailed notice beyond the few references given below,* where the reader may find fuller descriptions, amplifications and theoretical expositions; other references will be given further on.

The object of maps and charts is to exhibit to the eye, by suitable representation, on a reduced scale and on a plane surface, with all possible accuracy, the relative position of points, lines, or objects on the earth's surface and, since such positions are usually defined by spherical co-ordinates, the primary object of the so-called projections is the delineation of these circles of reference according to certain assumed or fixed geometrical laws. Any point, line, or object intended for representation may then be laid down by means of its known co-ordinates and, conversely, the co-ordinates of any plotted point may be ascertained.

Owing to the geometrical impossibility of developing a spherical or spheroidal surface in a plane, it follows that such projections may be as varied in their fundamental principles as there are distinct purposes for which representation may be needed. Special projections must be adapted to special and prominent properties, features, or requirements.

Of true projections of the sphere or of perspective projections, as they may be more properly called, since they depend upon the supposed position of the spectator's eye and on that of the plane of projection, three kinds have been distinguished, viz:

With the eye supposed at an infinite distance and the plane of projection perpendicular to the line of sight, but situated otherwise anywhere on that line; this is known as the *orthographic* projection.

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* Traité de Topographie, etc., etc. Par L. Puissant. First edition, Paris, 1805; second edition, Paris, 1820.

Chorographie oder Anleitung zu Land, See und Himmels-Karten. J. J. Littrow, Wien, 1833.

An Encyclopædia of Geography, etc. By Hugh Murray, London, 1844.

Practical Astronomy and Geodesy, including the projection of the sphere, etc. By John Narrien, London, 1845.

The Encyclopædia Britannica, 8th edition, Art. Geography, Vol. X, 1856. [A new edition of this work is now passing through the press.]

Traité des Projections des Cartes Geographiques. Par A. Germain, Paris, about 1865.

Lehrbuch der Karten-Projektionen, etc. Von Dr. H. Gretschel; Weimar, 1873.

With the eye supposed upon the surface of the sphere and to occupy the pole of a great circle, the plane of which is that of the projection; this is known as the *stereographic* projection.

Supposing the eye placed in the center of the sphere and the plane of projection tangent to its surface; this produces the *gnomonic* or *central* projection.*

A projection intermediate between the first and second supposes the eye at a distance of $\sqrt{\frac{1}{2}}$ times radius above the surface of the sphere; it is known as the *globular* or equidistant projection,† and was designed to avoid as far as may be the contraction of orthographic and the exaggeration of the stereographic projections near their respective outer portions.

A further modification was made by Lieut. Col. H. James,‡ with a view of representing more than a hemisphere within a bounding circle. As in Lahire's projection, the eye is supposed above the surface of the sphere, but at a distance equal to half the radius; the plane of projection, however, is not that of a great circle having the eye perpendicular over its center, but is parallel to it and removed from it nearer to the eye by 23½°. With this position of the projecting plane fully two-thirds of the surface of the sphere can be shown.

According to the particular plane of projection adopted, that of the equator, of a meridian, or of the horizon of a place, there arise as many special cases for each of the preceding general projections, which, however, need not here be further specified by name.

The above perspective projections, in their application to astronomy and geography, are usually confined to the representation of a hemisphere,§ and but rarely to smaller surfaces. For the purposes of land and sea charts on a large scale and consequently of quite limited extent, they are not well suited, for one or more reasons: they are generally laborious of construction when embracing limited areas, and cannot be made to satisfy any special conditions which they do not already possess, but which may be of paramount importance, or they may possess certain features which are not desirable on the chart. We thus come to the construction of maps and charts by so-called development. These are of comparatively modern origin, whereas the preceding three principal prospective projections were all known to the ancients.

To render development possible, a cylindric or conic surface is substituted in the place of the ordinary plane of projection, which surface is afterwards developed in a plane. The eye is supposed either at the center of the sphere or else its position is altogether arbitrary. This conception gives rise to two kinds of developed projections, viz, those employing a cylinder tangent, generally, at the equator and those employing a cone tangent, generally, at the middle parallel. Various projections of this class may be produced by varying the position of the place of tangency with respect to the fundamental circles of the sphere, also by substituting for the tangent cylinder or cone an intersecting cylinder or cone to conform, for instance, to the condition that areas of spherical zones should, in their projection, bear the same proportion as the corresponding areas on the sphere. Intersecting surfaces, instead of tangent surfaces, can, in general, be made to reduce distortion.

It was found convenient to arrange charts depending on development and subject to certain conditions in three groups, *i. e.*, those possessing straight meridians and parallels, those of mixed systems of straight and curved lines of reference and those in which both the meridians and parallels appear curved. To the first group belong the following:

The square projection, the simplest but rude method in which meridians and parallels appear as straight and equidistant lines, forming squares. Degrees of latitude and longitude are all sup-

* It has been employed for the construction of star-charts and more recently for delineating the apparent track of shooting stars, on account of the facility with which the radiant point can be found, great arcs on the sphere appearing as straight lines on the projection.

† Proposed by Lahire in 1701.

‡ Ordnance trigonometrical survey of Great Britain and Ireland; London, 1858. See frontispiece to volume of plates.

§ Hemispheres of the following simple and effective construction are sometimes met with in atlases: the circumference of a circle is divided into equal parts representing degrees of latitude; the horizontal and vertical diameters, likewise, are divided into equal parts, the former representing degrees of longitude. We thus have given three points in every parallel of latitude, *i. e.*, two in the circumference and one in the central line through which we can pass an arc of a circle representing the parallel. Similarly we have given three points in every meridian, *i. e.*, the two poles and one at the equator through which we can pass an arc of a circle representing the meridian.

posed equal in length. Especially in an east and west direction distances and areas become grossly exaggerated, though for an *elementary* surface the true proportion of a figure is preserved. It is occasionally used for representing small surfaces near the equator.

The rectangular projection, a less defective delineation than the square projection, consists in presenting the length of degrees of longitude along the *middle* parallel of the chart in their true relation to the corresponding degrees on the sphere; they will, therefore, appear smaller than the length of the degrees of latitude in the proportion $1 : \cos \varphi$. In an east and west direction the chart is unduly expanded above and unduly contracted below the middle parallel.

The rectangular equal-surface projection differs from the first in this, that the distances of the parallels, instead of being equal, are now drawn parallel to the equator at distances proportional to the sine of the latitude. This gives it the distinctive property of the areas of rectangles or zones on the projection, being proportional to the areas of corresponding figures on the sphere. The distortion, however, becomes quite excessive in the higher latitudes.

Cassini's projection.—This projection makes no use of the parallels of latitude, but substitutes for them a second system of co-ordinates, namely, one at right angles to the principal or central meridian. It is consequently convenient in connection with rectangular spherical co-ordinates having their origin in the middle of the chart. The projection of Cassini's chart of France consisted of squares,* and had neither meridians (excepting one) nor parallels. It would seem, however, that in this simple form it is not the projection generally distinguished by this name. It has been described as follows:† Suppose a cylindrical surface with its generating line *at right angles* to the central meridian and enveloping the sphere along this meridian. This cylindric surface is supposed intersected by planes *parallel* to that of the central meridian and these intersections produce on the chart, after development of the cylinder, the straight representatives of meridians, but are in reality small circles on the sphere. Their distance from each other is defined by passing them through equal divisions of the prime vertical drawn through the center of the chart. The central meridian having been equally divided, the equidistant straight lines passing through these divisions form the prime vertical system. This projection is not now employed, as it offers no facilities for plotting positions by latitude and longitude; moreover, the distortion rapidly increases with distance from the center meridian of the chart.

Projection with converging meridians.—This is a modification of the square projection designed to conform nearly to the condition that arcs of longitude shall appear proportional to the cosines of their respective latitudes. The straight line representing the central meridian being properly graduated—that is, the true length, by scale, of an arc of a degree of latitude (or of a minute or a multiple thereof, as the case may be) having been laid off according to the scale adopted—two straight lines are drawn at right angles to the meridian to represent parallels, one near the bottom and the other near the top of the chart. These parallels are next graduated, the arcs representing degrees (multiples or subdivisions) of longitude on each having, by scale, the true length belonging to the latitude. The corresponding points of equal nominal angular distance from the middle meridian thus marked on the parallels, when connected by straight lines will produce the system of convergent meridians. The disadvantages of this projection are the facts that but two of the parallels exhibit the length of arcs of longitude in their true proportion and that the central meridian alone is at right angles to the parallels. This projection is suitable for the representation of tolerably large areas, the above defects not being of a serious nature within ordinary limits. It also recommends itself by the ease with which points can be projected or taken off the chart by reference to latitude and longitude.

Projection by development of an intersecting cylinder.—The cylinder with its axis perpendicular to the plane of the equator is supposed to intersect the middle parallel of the chart. On the cylindric surface the arcs of the meridian and of the middle parallel are duly represented in their proper length and the parallels and meridians are straight lines intersecting each other at right angles. Charts of this construction answer best for low latitudes. The projection is the same as the "rectangular," though it may be changed by putting the *sines* for the *arcs* of the degrees on the meridian. Its use was superseded by the following one.

* Puissant's Traité de Topographie. Second edition. Paris, 1820.

† Dr. C. M. Bauernfeind's Elemente der Vermessungskunde. Stuttgart, 1869.

Mercator's projection is generally employed for the purposes of navigation. The axis of a cylinder tangent at the equator is coincident with the axis of the sphere; and in developing the cylinder the projected meridians become parallel and equidistant straight lines. These are intersected at right angles by straight lines representing parallels so drawn that at every point of the chart the ratio of the degree (or rather of an infinitely small part of it) of longitude to the degree of latitude (or infinitely small part of it) is preserved the same as on the corresponding point of the sphere. Great circles on the sphere will not generally appear on the developed cylinder as straight lines, but any straight line on the chart represents a rhumb line and indicates a particular mutual bearing of two places so connected. On the sphere such a line is known as a loxodromic curve and it possesses the property of cutting the meridians at equal angles. The proportionality of the parts of infinitely small figures on the sphere and on the projection is preserved. In the higher latitudes, in consequence of enormous exaggeration, the projection loses its value. Its want of uniformity of scale ot distances is its great defect and renders it useless for any other than the special nautical purpose* for which it was designed.

The following projections present but one system of straight lines:

Flamsteed's projection.—The parallels of latitude on the sphere are here represented by straight lines. Perpendicular to these is the central meridian divided into degrees (multiples or parts of degrees) of latitude. The parallels passing through these points are divided, each in like manner as the corresponding parallels on the sphere; through these latter points curves are drawn, which represent the meridians. Its principal defect is the obliquity of intersection of the projected parallels and meridians, especially in the higher latitudes and at some distance from the central meridian. It preserves, however, the proportionality of areas of zones in the projection and on the sphere. It is most effectively employed in mapping equatorial countries.

De Lorgna's projection.†—It preserves the proportionality of corresponding surfaces on the sphere and projection. It is mostly used as a *polar* projection, in which case the parallels of latitude appear as concentric circles and the meridians as straight lines dividing the circumferences of the circles equally. The radius of the projection for any spherical segment is a mean proportional between the diameter of the sphere and the height of the spherical segment.‡ If the projection be made not on the plane of the equator, but on that of the horizon of any place on the sphere, azimuths and altitudes will take the place of the former system of longitudes and latitudes.

Babinet's equal surface or *homalographic projection.*—The distinctive character of this important projection§ is, as its name implies, a proportionality of areas on the sphere with the corresponding areas of the projection. The equator is developed into a straight line and graduated equally from 0° to 180° either way from the central meridian, which is perpendicular to it, and of half the length of the representative line of the equator. The parallels of latitude are all straight lines, on each of which the degrees of longitude are equal, but do not bear their true proportion in length to those on the sphere. Their distance from the equator is determined by the law of equal surfaces‖ and

* It may be remarked that even as a sailing chart the course indicated by a straight line between two given points is not generally the one the navigator ought to follow, since it is neither the shortest line nor a great circle (the two being practically identical in length). For track-charts it seems *desirable* to have constructed a series of charts on the *gnomonic projection*, which presents all great circles as straight lines. Taking from these the latitudes and longitudes of a number of points, these great arcs may be transferred to any other projection from which bearings or distances may be obtainable. It should, moreover, be borne in mind that in practice it is not so much the shortest course which is desired, but that along which the *shortest* passage can be made, thus making the minimum duration the criterion. The problem of finding the most advantageous course becomes complicated, since it must take into account the effect of set and drift of currents and of direction and strength of wind most probably to be expected at the time and place. The resolution of it, however, must set out with the great circle or a number of great circles drawn from one objective point to the next. On the chart of Northwestern America, showing the territory ceded by Russia to the United States and published in May, 1867, by the Coast Survey, Prof. Benjamin Peirce, Superintendent, there is a sub-sketch on the gnomonic projection, showing the great circle between San Francisco and Hakodadi. We refer to this chart simply to show that the value of this projection, especially for steam navigation, is duly recognized.

† Principi di Geografia; Verona, 1789.

‡ Which is the same as $\rho = 2 \sin (45° - \frac{\varphi}{2})$

§ See Nouv. Ann. des Voyages (August 1857), by Malte-Brun; also, A. Petermann's Geographische Mittheilungen 1858, p. 63.

‖ For latitude φ the distance h of a parallel from the equator is found by the relation $\sin \varphi = \frac{1}{\pi}(2h + \sin 2h)$

the numbers have been tabulated between the limits 0 at the equator to 1 for the pole. The meridian of 90° on each side of the central meridian appears in the projection as a circle and by intersection determines the length of degrees on the parallels; all other meridians are parts of elliptical arcs. Extending the projection to embrace the whole surface of a sphere, the bounding line of the projection becomes an ellipse, the area of the circle included by the meridians of 90° equals that of the hemisphere and the crescent-shaped areas lying outside of this circle between ± longitudes 90° and 180° are together equal to that of the circle; also the area of the projection between the parallels of ± 30° is equal to the same. The degrees of latitude near the equator appear exaggerated and infinitely small surfaces on the sphere and projection are dissimilar in form, yet the distortion is not excessive. Its chief use is for graphical illustrations relating to area, such as the distribution and density of population or the extent of forests, area covered by coal-measures and the like.

De l'Isle's conic projection.—If we imagine a conical surface with its apex in the axis (produced) of the sphere and tangent to its surface along a parallel, that parallel by development of the conical surface will become an arc of a circle having for its radius the slant side of the cone, which is equal to the cotangent of the latitude. A part of this developed arc of a circle, sufficient in length to include the desired number of degrees of longitude, is conceived drawn through the *middle point* of the straight central meridian and parallel therewith, or from the *same* center other arcs are struck, passing through the points marking the degrees of latitude on the central meridian. To define the meridians two of the parallels, one near the bottom the other near the top of the chart (generally at one-fourth and at three-fourths the height of the chart), are graduated—that is, the true length (by scale) of a degree of longitude is repeatedly laid off on each and through the corresponding pair of points straight lines are drawn which represent the meridians. They intersect at different points and do not refer to the center from which the parallels were struck. The central meridian and two parallels only present their respective arcs of a length proportional to the corresponding arcs on the sphere.

The simple conic projection.—It differs from the above in this, that the developed arc of the middle latitude (of a chart) *alone* is employed in the place of the two extreme arcs for the graduation of longitudes. All meridians are straight lines and intersect at the center from which the concentric parallels were swept. On the central meridian and on the middle parallel the degrees of latitude and of longitude, respectively, are laid off according to scale and proportional to those on the sphere. Parallels and meridians intersect at right angles and infinitely small parts on the sphere and projection are similar in figure. The length of degrees on all the parallels, excepting the middle one, is but slightly different from what it would be if they were of their true length proportional to those on the sphere. This very valuable projection was specially investigated by L. Euler (Petersb. Comment., 1777). It may be remarked that when the *planes* of the parallels are supposed produced to intersect the cone, the resulting divisions on the meridian would become *unequal.* This source of defect is avoided by developing the meridional arc on the side of the cone, as stated above.

*Murdoch's projection** was designed to improve a defect of the conic projection with respect to area and to render the same more nearly proportional to that corresponding to it on the sphere. He supposed an *intersecting* cone to pass through points of the central meridian somewhere between the middle latitude and the extreme parallels of the chart, its side *remaining* parallel to the tangent at the middle latitude, while the points where the cone intersects the meridian are so selected as to make the whole included conic surface exactly equal to the spherical surface which it represents. Otherwise the construction is similar to that of the first named conic projection. It also follows by principle that the degrees of longitude on the two parallels passing through the intersecting points appear of their true length. For the parallels between these the distances and areas are all too small; and for the parallels outside of these the distances and areas are too great when compared with the corresponding parts on the sphere. The meridians are straight lines perpendicular to the parallels, yet corresponding areas on the sphere and projection are not equal except for the whole zone, as by construction.

* Phil. Trans. R. S., Vol. 50. Part II; London, 1758. Two modifications were added.

A further modification is mentioned by Mayer* to extend the proportionality of the whole also to parts of the zone, which, however, necessitates unequal meridional distances of the parallels and throws the distances further out.

The following projections are of the third class, *i. e.*, have both systems of co-ordinates represented by curved lines.

Lambert's projection preserves the proportionality of its areas with those on the sphere, but neither its meridians nor its parallels are equally divided, and these curves must be constructed by the aid of tables. In the projection of a hemisphere the central meridian appears as a straight line and the bounding meridian as a circle, which latter is the only line equally divided. Starting from the center, the length of the degrees on the central meridian and on the equator are in proportion of the sine of half the arc and they crowd consequently towards the circumference of the chart. It has been but little used.†

Bonne's projection.—This most useful and extensively used projection and which is also known as Flamsteed's modified projection,‡ differs from the simple conic development in this, that *each* of the concentric parallels of latitude is divided the same as on the sphere; through these points of intersection the curved meridians are passed. The curvature of the arcs of parallels is given as before. It is the same as that of the middle latitude of the chart, the radius being equal to the cotangent of this latitude. We thus have the straight central meridian, as well as every parallel of latitude, divided on the projection the same as on the sphere respectively; all the meridians cut a parallel near the *middle* latitude at right angles; outlines on the sphere appear in nearly similar outlines on the projection, and the same scale of length may be used for all parts of the chart if not exceeding a few degrees in extent. It also preserves the proportionate equality of the areas on the sphere and on the projection. If the middle parallel of the chart coincides with the equator, the projection merges into that of Flamsteed.

The step from the pure conic to the Bonne projection was a simple yet important one. The propriety of another modification, however, becomes apparent when it is noticed that for very large areas and particularly in the higher latitudes, the meridians and parallels intersect quite obliquely. This defect is in a great measure removed in the following projection. Bonne's projection was adopted by the Depôt de la Guerre of France about 1803.

The polyconic§ *projection* employs not only one tangent cone for the development of its middle parallel, but also a tangent cone for *every* parallel (and theoretically uses an infinite number of them). Each parallel of latitude, therefore, is independently developed. This has the effect of gradually increasing the length of the degrees of latitude in proportion as we recede from the central meridian, upon which only they are correct. On the other hand, the angles of intersection of meridians and parallels approach to and nowhere differ extravagantly from right angles; but those facing the pole and central meridian are always in excess of it. On charts representing the whole surface of a sphere this angle when greatest is about 120°; for a hemisphere, when greatest, it is about 100°; for smaller charts the intersections are everywhere sensibly at right angles. Thus, on the chart representing the whole of North America in Coast Survey Report of 1865, p. 177, the unaided eye can barely perceive any defect in these intersections.‖ It follows that the similarity of the figures on the sphere and the corresponding ones on the projection is very close. The exact proportionality of the corresponding areas on the sphere and the projection is sacrificed. This, however, becomes only apparent for charts of large extent. Thus, for a hemisphere (+ and − 90° from the central meridian) the area becomes enlarged in proportion of 1 to $1\frac{1}{4}$ nearly. For all charts

* Praktische Geometrie, part 4. J. T. Mayer, Erlangen, 1828. Pp. 315–333.

†See Petermann's Geographische Mittheilungen; volume for 1858, p. 65. For other projections investigated by Lambert see his "Beiträge zum Gebrauche der Mathematik"; Berlin, 1772. Three parts.

‡ More *properly* Flamsteed's is a particular case of Bonne's projection.

§ So named by the late Maj. E. B. Hunt, Assistant Coast Survey, in 1853. The projection seems to have been conceived by F. R. Hassler, Superintendent Coast Survey, between 1816 and 1820.

‖ On charts of large and convenient size and sufficiently extended for the delineation of the United States—say, between latitudes 22° and 52° and between longitudes 64° and 128° and which may be projected on scales varying between $\frac{1}{7\,000\,000}$ and $\frac{1}{5\,000\,000}$—the want of perpendicularity of *meridians and parallels* becomes just perceptible. See, for instance, the geological map accompanying Vol. III of the Ninth Census, by Francis A. Walker: Washington, 1872. Its scale is $\frac{1}{5\,700\,000}$ nearly. It was originally projected in the office of the Chief of Engineers, War Department.

of limited extent the same linear scale can be applied to all parts, the same as on Bonne's projection—in fact, for all ordinary charts published by the Coast Survey (see catalogue of 1875), there is *no* appreciable difference whatever between the Bonne and the polyconic projections. It is only when they are compared on very large surfaces that the distinguishing features of the two become apparent.

On the accompanying comparative diagram these projections are shown for the whole sphere, the Bonne projection becoming transformed into a Flamsteed projection. Besides this there is shown a Bonne projection for middle latitude + 30°. The outline of the polyconic projection appears as two lobes with a cusp at each pole, noticed in Coast Survey Report for 1853, p. 99, and exhibited in Coast Survey Reports for 1856, plate No. 65, and for 1859, plate No. 38.

Respecting the history of the Coast Survey projections, I have but a few remarks to offer. The polyconic projection appears to have originated in conception with Superintendent F. R. Hassler, between 1816 and 1820, as may be inferred from the following extract, taken from a series of papers connected with the early history of the United States Coast Survey and communicated by him to the American Philosophical Society, of Philadelphia, March 3, 1820. On pages 406, 407 and 408 of an article "On the mechanical organization of a large survey, etc.," in Transactions of the American Philosophical Society, Vol. II, new series, Philadelphia, 1825, he says: "The projection which I intended to use was the development of a part of the earth's surface upon a cone, either a tangent to a certain latitude, or cutting two given parallels and two meridians equidistant from the middle meridian." This either refers to a simple conic, or to De l'Isle's or Murdoch's projections. Further on (p. 407) he seems to refer to Bonne's projection. "The central meridian alone should become a straight line and all the other meridians and parallels broken lines, nearest the curve to which they belong." The last paragraph, but one, of the article refers directly, but somewhat vaguely, to the polyconic projection. "This distribution of the projection in an assemblage of sections of surfaces of successive cones, tangents to or cutting a regular succession of parallels and upon regularly changing central meridians, appeared to me the only one applicable to the coast of the United States. Its direction, nearly diagonal through meridian and parallel, would not admit of any other mode founded upon a single meridian and parallel without great deviations from the actual magnitudes and shapes, which would have considerable disadvantages in use." There can be no room to doubt that the "successive cones" refer to the parallels on each particular chart and not to the middle parallels of a succession of charts.

The first detailed account of the polyconic projection was published by Maj. E. B. Hunt, United States Engineers and Asssistant Coast Survey, in Coast Survey Report of 1853, Appendix No. 39, p. 99.

The first large chart published by the Survey Office is that of New York bay and harbor (since superseded). It is in six sheets, scale $\frac{1}{30000}$. It has simply (and necessarily) a rectangular projection. It originated with Superintendent F. R. Hassler. His successor, Prof. A. D. Bache, in 1844, carried out the design of the chart of Long Island Sound, in three sheets,* scale $\frac{1}{80000}$; also in 1844–'45, that of Delaware Bay and River, likewise in three sheets,† and on the same scale; these have conic projections. The parallels of latitude are sensibly curved, but owing to their small latitudinal extent the meridians appear necessarily as straight lines and consequently the character of the particular conic projection is not revealed. There is, however, reason to suppose that it was Bonne's. The computations which had been made for these charts were extended in 1848‡ from latitude 42½° to latitude 50°, and from latitude 35° to 25°. These tables with additions applicable both to charts of large and small extent and with explanation of construction (also accompanied by some small tables useful for the draughtsman), were published in Coast Survey Report for 1853, pp. 96–163, and it should be remarked that these, as well as more extended tables, subsequently published, answer equally well for all kinds of conic projections. These tables take ready account of the spheroidal shape of the earth. In the report of 1856, pp. 296–307, Assistant J. E. Hilgard gave tables chiefly for charts of large extent. A third and still more extended set of tables

* Catalogue numbers 114, 115, 116.

† Catalogue numbers 124, 125, 126.

‡ See report of that year, p. 59.

is also given by him for the same purpose, in the report of 1859, pp. 328–358. More recently tables for facilitating the construction of Mercator's and of the polyconic projections were published in book form by the Bureau of Navigation, Navy Department, Washington, 1869.

On the general coast chart series,* scale $\frac{1}{400\,000}$ (catalogue Nos. 6 to 21), the meridians are still sensibly straight, but on the most extended charts (less than 7° in latitude and 10° in longitude, excepting one) issued by the office, the sailing charts† of the catalogue (Nos. 1 to 5), on a scale of $\frac{1}{1\,200\,000}$, the curvature of the parallels and meridians becomes well marked, though that of the latter is yet extremely slight. On these charts the difference between the Bonne and the polyconic projections just becomes perceptible in Nos. 1, 2, 3 and 4 (although it may be obscured by unequal shrinkage of the paper) and is well marked on No. 5, embracing the Gulf of Mexico, extending over 15° of longitudes.

In the ordinary Coast Survey practice of making projections for the use of topographic and hydrographic surveys it is absolutely the same whether the polyconic or the Bonne projection be used, since the curvature of the meridians never becomes sensible and that of the parallels only rarely. Indeed, the two almost merge into the rectangular projection on our plane table and hydrographic sheets, scale $\frac{1}{10\,000}$ or $\frac{1}{20\,000}$, their ordinary actual size being three-quarter by one and a third meter,‡ and at most one and a half meter square. The trigonometrical stations are plotted by latitude and longitude and verified by means of the computed and measured distances, the scale being perfectly applicable.

The preceding brief review of various projections and of those depending on conic development in particular, makes it sufficiently clear that the projection used for the Coast Survey charts is one well adapted to topographical as well as to harbor and coast charts in general and that it also fully meets the wants of the navigator in the Coast Survey sailing charts.§ These last charts (scale $\frac{1}{1\,200\,000}$) I propose to submit to a closer scrutiny with respect to amount of distortion and for direct comparison with Mercator's charts. For this purpose three lines have been selected, on chart No. 79, each of a length greater than an average day's run of a first-class ocean steamer and bearing (true) nearly east and west, southeast and northwest, and south and north respectively. The distances and azimuths of these lines have been computed and comparisons have been made between the corresponding results for the great circle of the sphere, for the rhumb line on Mercator's projection and for the straight line on Bonne's and on the polyconic projections,‖ passing through the same given terminal points. The formulæ needed for the numerical computation have been put in the following form:

1. *For an arc of a great circle of the sphere.*

Let $\varphi\ \lambda\ \alpha$ = latitude, longitude, and azimuth (counted from south through west) of the eastern point and

$\varphi_1\ \lambda_1\ \alpha_1$ = latitude, longitude, and azimuth of the western terminal point.

σ = length of arc, which we shall express in angular measure.

Then from the fundamental expressions of spherical trigonometry:

$$\cos\sigma = \sin\varphi\sin\varphi_1 + \cos\varphi\cos\varphi_1\cos(\lambda_1-\lambda) \qquad (1)$$

$$\sin\alpha = \frac{\cos\varphi_1\sin(\lambda_1-\lambda)}{\sin\sigma} \qquad (2)$$

$$-\sin\alpha_1 = \frac{\cos\varphi\sin(\lambda_1-\lambda)}{\sin\sigma} \qquad (3)$$

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* No 8 of this series was commenced in 1846.

† Commenced in 1863. It would be an improvement to these charts if some of the meridional degrees were graduated (as on No. 5) about the middle latitude.

‡ Or about 30 by 52 inches.

§ Charts even so extended as to represent the North Atlantic would still be useful.

‖ The distances have been computed, and not measured on the chart, in order to exhibit the result free of any effect due to distortion of the paper.

2. *For the rhumb line on Mercator's projection.*

Let α = the invariable angle between the line and the meridians; from the equation to the loxodromic curve

$\lambda_1-\lambda = \tan\alpha \log_e \frac{\tan\frac{1}{2}(90+\varphi_1)}{\tan\frac{1}{2}(90+\varphi)}$ we find the angle α by means of

$$\tan\alpha = \frac{M(\lambda_1-\lambda)\text{ arc }1'}{\log\tan\frac{90+\varphi_1}{2} - \log\tan\frac{90+\varphi}{2}} \qquad (4)$$

adapted to common logarithms ($\log M=9.6377843$) and $\lambda_1-\lambda$ expressed in minutes ($\log$ arc $1'=6.4637261$)

$$\sigma = \frac{\varphi_1-\varphi}{\cos\alpha} \qquad (5)$$

but when α is nearly 90°, or the line runs nearly east and west, we must use

$$\sigma = (\lambda_1-\lambda)\frac{\cos\frac{1}{2}(\varphi+\varphi_1)}{\sin\alpha} \qquad (6)$$

3. *For the straight line on Bonne's projection.*

Let ψ = middle latitude of chart and A = its central meridian

a = radius of sphere

$R\ R_\varphi\ R_{\varphi_1}$ = radius of projected parallel ψ and of projected parallels φ and φ_1 respectively

$\omega\ \omega_1$ = angle at apex of developed cone for 1° of longitude corresponding to latitudes φ and φ_1 respectively, then

$$R = a\cot\psi, \text{ for which we take } \cot\psi \qquad (7)$$

$$R_\varphi = R + \frac{\pi}{180}(\psi-\varphi) \text{ or for } \psi-\varphi \text{ in minutes} \quad R_\varphi = R+[6.4637261](\psi-\varphi) \qquad (8)$$

$$R_{\varphi_1} = R + \frac{\pi}{180}(\psi-\varphi_1) \text{ or for } \psi-\varphi_1 \text{ in minutes} \quad R_{\varphi_1} = R+[6.4637261](\psi-\varphi_1) \qquad (9)$$

$$\tan\omega = \frac{\frac{\pi}{180}\cos\varphi}{R_\varphi} = \frac{[8.2418774]\cos\varphi}{R_\varphi} \qquad (10)$$

$$\tan\omega_1 = \frac{\frac{\pi}{180}\cos\varphi_1}{R_{\varphi_1}} = \frac{[8.2418774]\cos\varphi_1}{R_{\varphi_1}} \qquad (11)$$

$$\left.\begin{array}{l} n = A-\lambda \\ n_1 = \lambda_1-A \end{array}\right\} \text{ expressed in degrees} \qquad (12)$$

ν = angle at vertex between radii to φ and φ_1 $= n\,\omega + n_1\,\omega_1$ (13)

We thus have the two sides R_φ and R_{φ_1} and the included angle ν of a plane triangle from which the third side or σ is readily found. It results in parts of the radius; to give it in minutes we add to its logarithm 3.5362739

4. *For the straight line on the polyconic projection.*

Radius on projection for parallel φ or $R_\varphi = \cot\varphi$ (14)

Radius on projection for parallel φ_1 or $R_{\varphi_1} = \cot\varphi_1$ (15)

$$\text{Tan }\omega = \frac{[8.2418774]\cos\varphi}{R_\varphi} \qquad (16)$$

$$\text{Tan}_1\,\omega = \frac{[8.2418774]\cos\varphi_1}{R_{\varphi_1}} \qquad (17)$$

The perpendiculars to the central meridian of the chart from points $\varphi\ \lambda$ and $\varphi_1\ \lambda_1$ will be $R_{\varphi_1}\sin n\,\omega$ and $R_{\varphi_1}\,n\,\omega$; the versed sines will be $R_\varphi - R_\varphi\cos n\,\omega$ and $R_{\varphi_1} - R_{\varphi_1}\cos n_1\,\omega_1$; let $\triangle\varphi = \varphi_1-\varphi$ and supposing $\varphi_1-\varphi$ expressed in minutes $\triangle\varphi = [6.4637261](\varphi_1-\varphi)$ (18)

Sum of perpendiculars to meridian $p = R_\varphi\sin n\,\omega + R_{\varphi_1}\sin n_1\,\omega_1$ (19)

and meridional distance between foot points $q = \triangle\varphi -$ versin for $\varphi +$ versin for φ_1 (20)

then by resolution of the rightangled plane triangle we find σ; the solution must, however, be adapted to the particular case in order to produce the maximum accuracy in the result.

Our three lines, as shown on the accompanying polyconic chart, pass through the following points:

Line I. From $\begin{cases} \varphi = +37^\circ \\ \lambda = +68^\circ \end{cases}$ to Cape Henry light house $\begin{cases} \varphi_1 = +36^\circ\ 55'\ 29'' \\ \lambda_1 = +76\ 00\ 32 \end{cases}$

Line II. From $\begin{cases} \varphi = +36^\circ \\ \lambda = +68^\circ \end{cases}$ to light-ship off New York $\begin{cases} \varphi_1 = +40\ 26\ 54 \\ \lambda_1 = +73\ 51\ 58 \end{cases}$

Line III. From $\begin{cases} \varphi_1 = +35^\circ\ 5' \\ \lambda_1 = +70^\circ \end{cases}$ to light-ship off Nantucket $\begin{cases} \varphi = +40\ 55\ 00 \\ \lambda = +69\ 50\ 20 \end{cases}$

Submitting these lines to calculation by the aid of the preceding formulæ, we obtain the following synopsis of results:

Resulting distances, in nautical miles.

	Line I (nearly east and west).	Line II (nearly south-east and north west).	Line III (nearly south-and north).
	′	′	′
Arc of a great circle on sphere	383.87	384.13	350.09
Rhumb line on Mercator's projection	383.99	384.19	350.09
Straight line on Bonne's projection	383.85	384.03	350.09
Straight line on polyconic projection	383.86	384.20	350.22

For so short a distance as three or four hundred miles and in latitudes below 45°, the error in distance, as compared with the arc of a great circle, is generally less than two-tenths of a mile, or about $\frac{1}{2000}$ of the length and is therefore of no consequence to the navigator. On Mercator's charts the distances (generally too great) can be measured very roughly, but on Bonne's and on the polyconic charts it can be done more accurately. In general, Bonne's projection gives the distance a little too short and the polyconic a little too long. These two projections also have the property of presenting very nearly within the limits of our charts arcs of great circles as straight lines; thus the loxodromic curve (see chart, on which it is laid down by computation) or the rhumb to our line I is fully 4′ south of the great circle and of the straight line of our projection; for line II the distance is still $2\frac{3}{4}$ miles, measured near the middle of each line.

Resulting azimuths or bearings.

	Line I.		Line II.		Line III.	
	α	α_1	α	α_1	α	α_1
	° ′	° ′	° ′	° ′	° ′	° ′
Arc of great circle on sphere	91 43.5	266 55.4	135 46.4	312 08.3	1 17.8	181 11.9
Rhumb line, Mercator's projection	89 19.6	269 19.6	134 00.2	314 00.2	1 14.7	181 14.7
Error	2 23.9	2 24.2	1 46.2	1 51.9	3.1	2.8
Straight line { Bonne's projection / Polyconic projection } from chart	91 40	267 00	135 40	312 05	1 25	181 10
Error	3	5	6	3	7	2

The azimuths or bearings as given by the straight line on Bonne's and on the polyconic projections are seen to accord with the corresponding computed azimuths or bearings of the arc of a great circle within a few minutes—an accuracy many times exceeding that required for the practical wants of the navigator.

In conclusion, it is believed that, with respect to projection, the above investigation tends to commend the harbor, coast and sailing charts of the Coast Survey to the fullest confidence of the geographer as well as of the mariner.

Yours, very respectfully,

CHARLES A. SCHOTT,
Assistant.

Mr. CARLILE P. PATTERSON,
Superintendent United States Coast Survey.

APPENDIX 16.

REPORT ON THE CURRENTS AND TEMPERATURES OF BERING SEA AND THE ADJACENT WATERS.

BY WM. H. DALL,

ASSISTANT U. S. C. AND G. SURVEY.

Since 1871, when I began to carry on the work of the Survey in Alaskan waters, every opportunity has been used for adding to the knowledge of the currents of the sea in that and adjacent regions, both by directing constant observations by the party under my charge, and also by obtaining a record of observations made by others, either from the logs of vessels employed in the waters of Alaska or from other sources. Only very recently has the accumulation of facts been sufficient to form a sound foundation for any theory of the currents which was entitled to consideration, and even now much remains to be done; but the material available has seemed sufficient to clear away much uncertainty, and to indicate with some probability the chief hydrological characteristics of the region.

The observations made by our party in 1880, taken in connection with the previously published data obtained by Onatsevich, in the western part of Bering Sea, for the first time brought into a clear light sundry marked discrepancies between the commonly received theory of the currents and the facts observed.[1] With a view of digesting all accessible material, the literature has been carefully examined and the results of previous observations collated with more modern data.

It has been generally held that a branch of the Japanese stream or Kuro Siwo passed north, between the western end of the Aleutian chain and the coast of Kamchatka, extending northward and eastward through Bering Strait into the Arctic Ocean. A polar current was supposed to extend from the Arctic Ocean, in a southwesterly direction, between the above-mentioned branch of the Kuro Siwo and the Asiatic shore. Another polar stream has been stated to extend from the strait southward, east of Saint Lawrence and Saint Mathew Islands, and then southwest, toward the Aleutians. This has been called the Bering current,[2] while the former was termed the Kamchatka current.[3] Such are in brief the views expressed in most works on the navigation of the Pacific and Bering Sea; such as "Pilots" and "Directories," as well as more pretentious treatises on general hydrology.

Before proceding to discuss the observations, it may be well to state the chief sources from which information has been derived. They are as follows: The voyages of King and Clerke (of Cook's expedition), in 1778–'79[4]; of Krusenstern, in 1803–1806[5], and Kotzebue, in 1816–'18 and 1824[6]

[1] See Coast Pilot of Alaska, Appendix I, Meteorology, p. 21, ¶ 3, 1879.

[2] Labrosse appears to have derived from Becher his authority for this supposed current, though he gives no references. Cf. The navigation of the Pacific Ocean (etc.), translated from the French of F. Labrosse, by Lieut. J. W. Miller, U. S. N., 8°, pp. xii, 360, Washington, United States Hydrographic Office, 1875 (p. 61). Also Becher, Navigation of the Pacific, 8°, London, 1860, p. 75.

[3] Cf. China Sea Directory, p. 25, *et seq.* Also Labrosse (original edition) pp. 65–68; North Pacific Pilot (W. Rosser, 1870), pp. 85–91; Onatsevich, Nabliudenie etc. (summary of various opinions on the subject), pp. 83–100, etc.; *also*, Becher's Navigation of the Pacific Ocean, 1860, p. 73, *et seq.*, etc.

[4] Cook (James), and King (James). A voyage to the Pacific Ocean [etc.] in the years 1776–1780, 3 vols., 4° Atlas, folio. London, 1784–1785; original edition.

[5] Krusenstern (Adam Johann von). Reise um die welt in den jahren 1803–1806, auf befehl Alexander's I. kaisers von Russland auf den Schiffen Nadeshda und Neva. Originalausg. 3 bde., 4°. St. Petersburg, Schnoor, 1810–'12.

[6] Kotzebue (Otto von). A voyage of discovery into the South Sea and Beering's Straits * * * in 1815–'18, &c., 3 v., 8°. London, Longmans, 1821. *Also*, A new voyage round the world in the years 1823–'26. 2 v., 12°. London, 1830.

of Beechey, in the Blossom, 1825–'28[1]; of Lütké, in the Seniavine, in 1828–'29[2]; Du Petit Thouars, in the Venus, 1837[3]; Moore, in the Plover, in 1849[4]; Kellett (and Trollope), in the Herald, 1850[5]; Lieut. (now Admiral) John Rodgers, U. S. N., in the Vincennes, in 1855[6]; Lieutenant Bullock, R. N., in the Dove, in 1861[7]; Capt. George E. Belknap, U. S. N., in the Tuscarora, in 1873[8]; Lieutenant Onatsevich, I. R. N., in the Vostok, in 1875; and the Vsadnik, 1876[9]; Nares, in the Challenger, in 1875[10]; Bailey in the U. S. R. S. Rush, in 1879[11]; and Hooper, in the Corwin, in 1880[12]. All these are published data, but of unpublished material there has been accessible the log-books (or transcripts from them) with temperature and current observations of the United States Coast and Geodetic Survey parties under my charge, on the Humboldt, in 1871 and 1872[13], and the Yukon, in 1873[14], 1874, and 1880; the "Remark books" of vessels commanded by Capt. L. C. Owen, in the whaling business, as follows: Ship Contest, in 1871; ship Jireh Perry, 1872, 1873, and 1874; bark Three Brothers, 1876 and 1877; bark Coral, in 1878 and 1879; all voyages from San Francisco or the Sandwich Islands to the Arctic Ocean during the season and returning.

Other logs affording material are those of the China steamers between San Francisco, Yokohama, and Hong Kong; abstracts of twenty-two voyages, during which temperatures were taken six or eight times a day, having been obtained by Prof. T. Antisell and most kindly placed at my disposal by him.[15] In addition to the above may be mentioned numerous isolated observations obtained from various navigators and recorded in the field books of the United States Coast Survey parties in Alaska, as well as the indications of currents derived from the navigators of the Russian-American Company, and recorded by Tebenkoff on the charts of Alaska, of which his atlas is composed.

The data obtained from these various sources relate both to currents and to sea temperatures, and, of course, in many instances, can be regarded as of merely an approximate character. In using these materials, therefore, it must be understood that in many cases there is an uncertainty of, perhaps, several degrees Fahrenheit in temperature, and that the rates of current in particular, from their very nature, are subject to rather large probable errors except when observed from a fixed point, such as a vessel at anchor, or a piece of grounded ice, and in many cases are only mere estimates. Some of the temperature observations have appeared in the Coast Pilot of Alaska, Appendix I[16], where they are summarized.

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[1] Beechey (Capt. F. W.). Narrative of a voyage to the Pacific and Beering's Strait (etc.), 1825–'28. 4°. London, 1831.

[2] Lütké (Capt. F. P.) Voyage autour du monde (etc.). Partie nautique, 4°. St. Pétersbourg, 1836. *Also in* Zapiski Hydr. Depart., 8°, St. Peterbourg, 1842–1852; 10 vols. (various articles). Cf. vol. ii, pp. 353–376.

[3] Du Petit Thouars (A. A.). Voyage autour du monde sur la frégate la Vénus, pendant les années, 1836–'39, 10 vols., 8°. Atlas, 4 vols., folio. Paris, Gide, 1840–'55. Cf. vol. vi., 1842, pp. 230, 280, et vol. ix, 1844, pp. 297–298. Best of the early voyages.

[4] Moore (T. E. L.). Nautical Magazine, 8°, London, 1850. Proceedings of H. M. S. Plover, pp. 176–184.

[5] Trollope (Com. H.) in Seemann (B.), Narrative of a voyage of H. M. S. Herald, 1845–'51 (etc.). 2 v., 8°. London, 1853; Nautical Remarks, vol. ii, pp. 290, *et seq.* Cf. *also* Nautical Magazine, 1850.

[6] Track chart published by the United States Hydrographic Office. No account of this expedition has appeared from official sources.

[7] Cf. China Pilot (various editions). London. Admiralty, 1864; pp. 449, *et seq.*

[8] Deep sea soundings in the North Pacific Ocean (etc.). United States Hydrographic Office No. 54. Washington, 1874, pp. 52. Illustrated.

[9] Sobranie nabliudenie (etc.), 1874–1877, 4°. St. Peterbourg, Admiralty, 1878; pp. 112. Many illustrations and maps. This work is referred to in note 3 of the preceding page.

[10] Thalassa, an essay on the depth, temperature, and currents of the ocean, by John James Wild, etc.; 8°, pp. 140. London, Marcus, Ward & Co., 1877. Maps and plates.

[11] Report upon Alaska (etc.), by Capt. George W. Bailey, U. S. R. M., 8°, pp. 52. Washington, Government Printing Office, 1880. Map and illustration.

[12] Report of the cruise of the U. S. R. S. Corwin (etc.), by Capt. C. L. Hooper, U. S. R. M., November 1, 1880; 8°, pp. 72, and tables. Washington, Government Printing Office, 1881. Map and plates.

[13] Cf. Report United States Coast Survey, 1872. Appendix No. 10, by W. H. Dall; pp. 36, with sketch. [1875.]

[14] Cf. Report United States Coast Survey, 1873. Appendix No. 11, by W. H. Dall; pp. 12, with map. [1875.]

[15] These abstracts formed the basis of his valuable paper read before the Philosophical Society of Washington, April 13, 1878, "On the temperatures of the Pacific Ocean," and which we may hope yet to see published in full.

[16] Pacific Coast Pilot. Coast and Islands of Alaska. Second series. Appendix I, Meteorology. 4°; pp. 376. Washington, Government Printing Office, 1879. Maps and illustrations. Prepared by W. H. Dall and Marcus Baker.

ON THE TEMPERATURE OF THE SURFACE OF THE SEA.[1]

As the motion of oceanic waters is partly determined by their temperature, so their paths may often be traced out by isothermal curves of the surface of the sea. As the motion is usually less measurable with accuracy, when normal, than the temperature, and is much more rapidly lost, it often happens that the distribution of current-water can be much more accurately determined by study of its temperature than in any other way, and that the effects of a special current may be determined with certainty to exist over an area far exceeding that in which it can be proved to have a perceptible constant motion in any given direction.

Conversely, if a large body of water be shown to have a nearly uniform summer temperature, corresponding in general with the normal of the latitude and with the local circumstances in its particular portions, this is, of itself, evidence that no large body of water intrudes within its borders from a region of a different normal temperature. In other words, in the general oceanic circulation a stream of water with a temperature normal to one latitude cannot move to a region where another temperature is normal without exhibiting its presence by deflection of the isotherms.

A study of the sea temperatures of the Okhotsk and Bering Sea basins develops the following facts: In shallow waters, that is in depths of ten fathoms or less, during the long days and under the scorching sun of the Arctic summer, a higher degree of temperature is found than that which obtains in adjacent deeper water. Consequently, in the sounds, gulfs, and bays, especially on the eastern or shoaler side of Bering Sea, we find a midsummer temperature which would only be normal to a much more southern latitude.

The same is true of the Arctic basin, and when, moved by wind, tide, and other influences, this warm water (as in the vicinity of Bering Strait) is transported into the midst of bodies of water of a lower temperature, it, for the time and area within which the change takes place, has an influence as great and of the same nature as that which might be exercised by a similar body of water which, in the course of oceanic circulation, had been brought to the same locality from China or Japan.

These bodies of warm water are necessarily rather small, and from their superficial character yield to the changes of the season and weather much more rapidly than the constantly re-enforced supply of a great ocean current. Hence the time of their maximum of temperature always accords with that of the aerial maximum of their local region, while the corresponding maximum of current-water frequently occurs in cold regions some time after the local seasonal maximum has passed.

The presence of ice after the warm season commences in the seas mentioned has less influence in keeping down the surface temperature than might be expected. It is surprising, in many cases, to note how the water retains nearly its normal temperature up to within a very short distance from a large field of ice. The use of the thermometer in dense fogs is a widely-extended practice among those navigators who have reason to think themselves in the vicinity of ice, and desire to guard against collisions. However, in searching for currents, etc., by the sea temperatures, especially in the Arctic, where ice is abundant, the neighborhood of the ice must be taken into account, or the conclusions will be untrustworthy. For the same reasons observations taken in Bering Sea after the ice is wholly gone are more satisfactory as a basis of discussion, and have in this paper alone been used, except where otherwise stated.

Another factor contributes to the condition of the shallows. When the large rivers which enter Bering Sea and the Arctic first break up in the spring, they carry with them large quantities of fresh-water ice, and hence for a few days are not much warmer than the sea into which they fall. Very rapidly, however, their temperature rises, and under the continuous beams of the hot Arctic sun their waters become much warmer than the adjacent sea, which is yet, in most cases, hardly free from its bonds of ice. In opening passages between the ice and the shore, the important influence of the large rivers has been recognized by most students of the Arctic regions, and in cases of large rivers heading far to the southward of their mouths, such as the Lena, the Mac-

[1] In this report all bearings are *true;* all rates in knots and tenths per hour; all distances in nautical miles; all depths in six-foot fathoms; all temperatures in the text are Fahrenheit scale, those in parentheses or tabulated in broad-faced type are of centigrade scale; all latitudes are north; all longitudes west of Greenwich; except where otherwise stated.

kenzie, the Yukon, and the Amur, during the summer season, the outpouring of water, unless otherwise counteracted, is known to give rise to definite, though local, currents in the adjacent sea. These currents are generally of higher temperature than the average of their vicinity would normally be.

The diurnal variation of temperature of the surface amounts, in extreme cases, to six or eight degrees Fahrenheit, but is generally about three or four degrees, and in the case of uniform conditions, as during calm, densely-cloudy weather, there may be less than one degree difference between the maximum and minimum. The maximum usually occurs between 2 and 6 p. m., and the minimum from 2 to 4 a. m.

The following table indicates the changes of the surface temperature with the vessel at anchor, or in nearly the same position, for every two hours during the day:

No.	Date.		2 a. m.	4 a. m.	6 a. m.	8 a. m.	10 a. m.	Noon.	2 p. m.	4 p. m.	6 p. m.	8 p. m.	10 p. m.	12 m.
			°	°	°	°	°	°	°	°	°	°	°	°
1	July 7, 1880	C	6.7	6.7	7.2	8.9	9.4	10.0	10.6	11.7	12.2	12.2	11.1	11.1
		F	44	44	45	48	49	50	51	53	54	54	52	52
2	July 9, 1880	C	11.1	11.1	11.1	13.9	13.9	13.9	13.9	14.4	14.4	12.8	12.8	12.2
		F	52	52	52	57	57	57	57	58	58	55	55	54
3	July 16, 1880	C	6.7	6.7	6.7	6.7	7.2	7.2	7.2	7.2	8.9	7.8	7.8	7.8
		F	44	44	44	44	45	45	45	45	48	46	46	46
4	July 26, 1880	C	1.1	1.1	2.2	1.1	0.0	0.6	3.3	3.9	3.3	3.3	2.2	1.1
		F	34	34	36	34	32	33	38	39	38	38	36	34
5	August 1, 1880	C	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
		F	36	36	36	36	36	36	36	36	36	36	36	36
6	June 10, 1880	C	0.6	0.0	0.0	0.0	1.1	1.1	3.3	2.2	2.2	1.7	1.1	1.1
		F	33	32	32	32	34	34	38	36	36	35	34	34
7	September 10, 1880	C	......	6.1	6.1	6.7	6.7	7.1	7.1	7.2	6.9	6.1	......	......
		F	......	43	43	44	44	44.7	44.7	45	44.5	43	......	......

Nos. 1 and 2 are series from the log of the Corwin, in Norton Sound, at anchor, half clear weather and light airs. No. 3 from the same, in Kotzebue Sound, weather half clear, wind light, except from 2 to 8 a. m., when it blew fresh from southeast. No. 4 from the same, near the pack, in the vicinity of Herald Island, wind moderate, sky wholly cloudy; some anomalies in the forenoon are due to the influence of fragments of ice. No. 5 from the same, at anchor off Cape Sabine, heavy gale blowing, sky wholly cloudy. No. 6 same, northward from Saint Paul Island, sky wholly cloudy, weather calm. No. 7 from log United States Schooner Yukon, at the Diomedes, at anchor, fresh breeze blowing, sky cloudy, with a few glimpses of the sun. The table also illustrates the difference between the temperature of the shallow waters of Norton and Kotzebue Sounds, Bering Strait, and that of the open sea, as well as the effect produced by cutting off the sun's rays and stirring up the cold bottom water, as in the case of No. 5. The following table of hourly temperatures, taken by the Corwin while running into or out of Norton Sound, after the ice had gone out, indicates very well the increased temperature due chiefly to the action of the sun on the shallow and quiet water, and to the warm river flow:

Hourly temperatures from east to west.

		°	°	°	°	°	°	°	°	°	°	°	°	
July 7	C	6.1	6.7	6.7	7.2	8.3	8.9	9.4	10.0	10.6	11.1	11.7	12.2	Norton Sound.
	F	43	44	44	45	47	48	49	50	51	52	53	54	
July 10	C	7.2	8.9	8.9	9.4	10.0	10.6	9.4	10.6	11.1	12.2	12.2	12.8	Do.
	F	45	48	48	49	50	51	49	51	52	54	54	55	
September 14	C	3.3	4.4	5.6	4.4	3.3	4.4	5.6	5.6	6.7	6.7	6.7	6.7	Do.
	F	38	40	42	40	38	40	42	42	44	44	44	44	
September 17	C	4.4	5.6	5.6	5.6	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	Do.
	F	40	42	42	42	44	44	44	44	44	44	44	44	
July 15	C	3.3	3.3	6.7	5.6	5.6	5.6	6.1	7.8	7.8	7.2	7.8	7.8	Kotzebue Sound.
	F	38	38	44	42	42	42	43	46	46	45	46	46	

The course of September 17 was run from the south and west, the others from the northwest. The temperature in Norton Sound, July 7 to 10, varied from 52° to 58° (11°.1 to 14°.4) later in the season, September 14 to 17, it was nearly uniformly 44° (6°.7). The temperature at Chamisso Island, Kotzebue Sound, July 16, 17, varied from 44° to 48° (6°.7 to 8°.9). Having seen that the diurnal variation in the same locality may amount to eight or more degrees of Fahrenheit, the variation in any one place during the year may be considered. This may be due to either of two causes, or to a combination of both of them. The first cause is the normal change of the seasons. The second is the intrusion of a current, with a temperature not normal to the sea-basin which it enters, and which temperature may fluctuate from the operation of causes existing in the region whence the current comes, but not existing in that region which it enters. The sea-temperature record of any locality not affected by currents as above should agree in general as to range and times of maxima and minima with the thermal characters of the adjacent terrestrial climate, and the differences should be chiefly differences of retardation and more limited range. This follows from the obvious fact that the sea water receives and parts with its heat more slowly than the air, and seldom to the same extent.

The following table shows the annual range of sea-temperature in a few localities about Bering Sea, and indicates in a general way the fluctuations and times of maximum and minimum temperature. Except when marked with an asterisk the figures are from continuous daily observations with standard instruments.

Locality.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Saint Paul Island	C..	2.7	3.2	1.2	0.9	1.9	4.4	7.1	8.7	8.8	6.6	5.1	2.3
	F..	36.9	37.7	34.1	33.7	35.5	40.0	44.8	47.7	47.8	43.9	41.1	36.1
Saint Michaels	C..	0.0	0.0	0.0	0.0	0.5	1.9	13.3	13.4	9.8	1.7	0.6	0.0
	F..	32.0*	32.0*	32.0*	32.0*	32.5*	35.5*	56.0	56.1	49.6	35.0*	33.0*	32.0*
Unalashka	C..	1.8	1.8	1.4	3.3	4.9	5.6	10.8	11.1	9.1	6.2	1.3	1.2
	F..	35.3	35.3	34.6*	38.0*	40.8	42.0	51.5*	51.9*	48.3	43.1	34.3	34.1
Aleutian Islands	C..	1.9	1.8	1.4	3.1	5.9	7.1	7.7	10.2	9.2	7.2	1.3	1.1
	F..	35.4	35.3	34.6	37.6	42.7	44.7	45.8	50.3	48.5	45.0	34.3	34.0

The means marked with an asterisk are approximate only, but are probably not far from the truth. In some seasons Saint Paul would exhibit a considerably higher temperature, as one of the winters included was much colder than usual and ice remained around the island until late in May—a thing hardly known before. The means for Unalashka are made up of parts of several years, Saint Paul of a year and eleven months, the islands of the Aleutian chain of parts of several years. Saint Michaels, Norton Sound, of parts of two summers only.[1] Parallel observations among the Aleutian Islands were taken for some time at five fathoms below the surface. The temperature averaged three or four degrees higher, except in very cold weather, and the changes were retarded from twenty-four to forty-eight hours in reaching that depth. These observations were all taken in quiet, well-sheltered harbors, and the series was necessarily fragmentary. Attention may be called to the fact that in bodies of water having a nearly equal temperature throughout, the long lines of temperatures which may be taken by a party on a steam-vessel have the advantage that a larger number of nearly simultaneous observations are obtained. But in bodies of water which are not homogeneous shorter lines are better, as there is less difficulty in eliminating the diurnal variation.

In the study of the Bering Sea temperatures, the various observations were platted in their proper position on a base-chart, and an endeavor was made to approximate to the normal average summer temperature, by applying the corrections of the following table to the several observations and thus reducing them to one common standard of comparison and obtain a basis for isothermal lines.

[1] Comprising one consecutive series for July, August, and September, and scattered observations during another summer.

Correction table for Bering Sea temperatures to reduce them to a mean summer temperature.

[Degrees centigrade in black.]

Date.	Corr.	Date.	Corr.	Date.	Corr.	Date.	Corr.
	°		°		°		°
January 15	**+5.0** + 9.0	May 9	**+3.3** + 6.0	July 4	**−1.7** − 3.0	October 2	**0.0** 0.0
February 11	**+5.6** +10.0	May 14	**+2.8** + 5.0	July 12	**−2.2** − 4.0	October 7	**+0.6** + 1.0
February 25	**+6.1** +11.0	May 20	**+2.2** + 4.0	July 21	**−2.8** − 5.0	October 11	**+1.1** + 2.0
March 1	**+6.2** +11.2	May 27	**+1.7** + 3.0	August 1	**−3.3** − 6.0	October 16	**+1.7** + 3.0
March 10	**+6.1** +11.0	June 2	**+1.1** + 2.0	August 16	**−2.8** − 5.0	October 22	**+2.2** + 4.0
April 6	**+5.6** +10.0	June 8	**+0.6** + 1.0	September 1	**−2.2** − 4.0	October 26	**+2.8** + 5.0
April 16	**+5.0** + 9.0	June 14	**0.0** 0.0	September 10	**−1.7** − 3.0	November 2	**+3.3** + 6.0
April 25	**+4.4** + 8.0	June 20	**−0.6** − 1.0	September 19	**−1.1** − 2.0	November 7	**+3.9** + 7.0
May 4	**+3.9** + 7.0	June 28	**−1.1** − 2.0	September 25	**−0.6** − 1.0	November 19	**+4.4** + 8.0

This table was derived from the above-mentioned annual means and parts of other broken series, and has necessarily a merely approximate character. The corrections often reduced to agreeable unison, observations taken on different voyages in adjacent spots, and the table especially for the open sea, was of much use; it was evident, however, that it did not take into account sufficiently the differences which give a different summer temperature to the shallows and deeper portions of the sea, and that one table could not be applied over latitudes extending from 45° to 65° without verging into extremes in the higher and lower latitudes, which did not agree with the facts. Some general ideas were gained from the attempt, however, and the discrepancies between various seasons which had before been noticed were more clearly brought out. It is evident from the following examples that different seasons differ widely in their aqueous as well as in their aerial temperatures, if such expressions may be permitted. In running from Unalashka to Saint Paul Island, in 1874 (July 21, 22), the temperatures varied from 48° to 54° (8°.9 to 12°.2). In 1880 (August 3–5), over the same line, they varied from 44° to 48° (6°.7 to 8°.9), when by theory they should have been warmer than the first series. But 1880 was a cold and cloudy season, everywhere a month late, while 1874 was a warm and sunny season.

Again, in making the passage from the coast of Kamchatka toward the western end of the Aleutian chain in July, 1873, Captain Belknap obtained temperatures varying from 42°.6 (5°.9) to 47°.2 (8°.4). These observations agree with those of Onatsevich a year or two later. On the other hand, the observations of Du Petit Thouars on the Venus, in September, 1837, a little more southerly but in the same general region, varied from 51° (10°.6) to 53° (11°.7), agreeing with those made earlier by Beechey. These observers all worked with standard instruments, and the difference is explained when, on referring to their logs, we find that the Venus and Blossom had fine sunny weather, while Belknap and Onatsevich, for the most part, had very cloudy or foggy weather.

It is evident, therefore, that no system except one based upon a much larger series of local and other observations can represent the summer temperature of this region within a range of several degrees Fahrenheit. Nevertheless, the mass of observations accumulated is sufficient to give us a good general idea of the temperatures, subject to the uncertainty above mentioned.

Winter temperatures.—The minimum sea-temperatures of the year seem to occur toward the end of March. At that time the ice attains its greatest extension, and exercises its maximum effect upon the temperature of the sea. The general oceanic circulation is then at its minimum. The Okhotsk Sea, from the best evidence we can obtain, seems ordinarily at this time everywhere incommoded by ice, either in extensive solid fields, or more or less moving smaller floes drifted by the wind.

In my discussion of this subject in the Meteorological Appendix to the Coast Pilot of Alaska (pp. 43–46), I showed that navigation opens on the northern shore about June 5 and closes about October 17, there being an unnavigable period of some 230 days; on the southern and western shores it opens about June 11 and closes about November 30, and for the eastern shore no data are obtainable. The rivers usually break up in May, and close in November, river navigation being practicable for a somewhat longer period than that of the sea.

The ice in Bering Sea varies in different years in its extent, depending much upon the direction and force of the winds, and upon the temperature of the particular winter season. The latter itself depends greatly upon the winds, being much lower in those seasons when the winds prevail from the north for long periods and bring loose floe ice from the north, which is prevented (by the formation of new ice north of it) from returning to its original station when the winds change to the south.

It is noteworthy that a study of the remark-books of various whalers shows that the ice breaks up and disappears much more rapidly when the wind and current pass from it than it does when they tend toward it, if the temperature be above that required for the formation of new ice.

Since the first work of the whalers on arriving in Bering Sea is to cruise along the edge of the pack, seeking to get to the northward, I have been able to determine for each of six or seven years, from 1870 to 1878, the average southern limits of the pack in April and May, between the meridians of 169° and 190° west of Greenwich. The remainder is tolerably well understood from reports of winter cruises by the fur-traders of the region, and from reports as to the opening and closing of navigation at various ports on this sea. From these sources we learn that the edge of the ice extends from a point in about latitude 57° on Aliaska Peninsula, curving to the northward and westward toward the Pribiloff Islands, and generally passing at least a degree to the north from them, then curving again to the southward it generally presents a broad tongue in longitude about 174°, often reaching south to the vicinity of latitude 56°, and then extending in an irregular line westward, usually between latitudes 56° and 58°, toward the coast of Kamchatka, off which it forms a belt 15 to 30 miles in width, which is often entirely dissipated for short periods by westerly winds. This ice disappears for the season usually about the middle or end of May, and begins to form anywhere from the end of October to the middle of December, according to the season.

The following notes, taken from the whalers' remark books, will illustrate the rate of decay in the ice, and progress in opening to navigation the waters of Bering Sea and Strait and the Arctic.

Apropos of this, attention may be called to the fact, elsewhere shown by me, that the sea opens to the westward of Saint Lawrence Island first, it frequently being navigable there and north of the island into Norton Sound, at a time in the season when the passage between Nunivak Island and Saint Lawrence is still blocked with decaying ice. It is noticeable that the water opens first where the southerly cold set away from the ice is strongest, according to all authorities, and where Onatsevich declares his conviction that no warm current exists.

Ship Contest, June 9, 1871, reached Cape Chaplin; June 14, was abreast of the Diomedes; June 16, passed East Cape; August 6, passed Icy Cape; September 14, beset off Wainwright Inlet without any chance of escape and was abandoned.

Ship Jireh Perry, June 12, 1872, entered Bering Strait, but heard that other vessels had entered as early as June 1. Entered the Arctic in loose ice June 19[1]; saw ice aground in 14 fathoms between Cape Lisburne and Icy Cape July 27. Reached Point Barrow August 15; left the Arctic October 11, 1872.

Ship Jireh Perry, August 15, 1872, on reaching Point Barrow found large floes grounded along shore and open water 8 to 10 miles off shore.

Ship Jireh Perry, 1873; June 3, met the ice in latitude 56° 30′, longitude 173° 30′, water 33°; June 15, reached Cape Chaplin, found very little ice anywhere; June 19, passed East Cape; June 21, made the pack in latitude 67° 30′; July 8, passed Icy Cape; July 20, reached Point Belcher; July 26, got around Point Barrow finding a lane of open water about ten miles wide, but the shallows and lagoons were still ice-bound. October 14, left the Arctic.

[1] "Entering the Arctic" here means passing north of the Arctic Circle in the sea of that name.

Ship Java, June 29, 1873, reached latitude 71° 10′ and longitude 165° 35′. "All say a very open season." Bark Helen Mar, July 16, reached Herald Island.

Bark Three Brothers, May 14, 1876, off Cape Chaplin; May 23, reached East Cape; much loose ice in Bering Strait; weather mostly cold and stormy. June 13, entered the Arctic. July 12, reached Wainwright Inlet; ice 15 miles off shore here, but fast to the land at the Seahorse Islands. July 27, reached Point Barrow. On the 17th of September escaped from the pack with bark Rainbow, leaving ten vessels beset to total loss; and on the 19th left the Arctic.

Bark Three Brothers came up with the ice May 29; latitude 58° 31′, longitude 189°; on June 16, 1877, reached Plover Bay; June 20, East Cape; entered the Arctic June 23; up to the time when the record ends, July 13, had not been able to get north of latitude 69° on account of the ice.

Bark Coral, in 1878, May 1, found ice in latitude 58°, longitude 179°; May 13, fast in the ice in latitude 60° 40′, longitude 182°; reached Plover-Bay June 10, entered the strait June 12, passed East Cape June 21, and entered the Arctic June 22; in 1879 had a similar experience, but did not get into the Arctic until June 27. Reached Point Barrow August 5 and got as far east as Return Reef, in longitude 149°, August 15; leaving the Arctic October 15, 1878. In 1879 he reached Icy Cape only by August 23, and got no farther north on that shore that season; such ships as got to the north side of the cape were beset and barely escaped by a favorable gale. To the westward they reached nearly to Herald Island by October 7, and left the Arctic October 20, after the hardest season Captain Owen had ever experienced.

In 1880 the bark Pacific entered the Arctic, May 22, but the Corwin reached Plover Bay June 27 and entered the Arctic on the following day, then found the ice solid near Point Hope; reached Cape Lisburne July 23; August 20 he was within a few miles of Herald Island, and on the 25th reached Point Barrow through a narrow lane of water.

In nearly all these cases it is to be understood that the vessels were following up the open water and advanced as fast as the breaking up of the ice would allow.

The time of breaking up of the ice between Cape Navarin and Plover Bay varies so much with the season that no general rule can be laid down. Vessels have reached Cape Thaddeus in April; on other occasions they have not gotten east of longitude 180° in that vicinity until nearly the end of June. The whalers never pass to the eastward of Saint Mathew and Saint Lawrence Islands, as the ice stays there later; in 1880 the Corwin found a narrow lane along the mainland shore by which she reached Norton Sound June 18. The earliest time at which Norton Sound has been known to be accessible to vessels is May 25 (in 1874), the latest, June 22. The average is about June 10. The Yukon breaks up in freshets lasting two weeks, beginning from May 15 to June 5, the average being about May 23. The high water arising from the melting snows lasts many weeks after the freshet which carries away the river ice. The northwesterly current thus generated carries away the rotten field ice toward Bering Strait when it has not previously disappeared. Captain Hooper of the Corwin saw a field of it drifting into the strait July 5 which he had to go to the west side to avoid; but this was a very unusually late season in all respects.

The southern portion of Bering Sea along the Aleutians is rarely if ever troubled by ice, and the northern border of the Pacific is practically always free from ice except possibly a rare fragment formed in some narrow passage or drifted south by some severe winter gale. The sea temperature is probably about 40° (4°.4) in winter, varying from 36° to 44° (2°.2 to 6°.7) according to weather. None lower than 36° (2°.2) has actually been observed so far as is known.

Summer temperatures.—The remarks previously made in connection with the correction table for summer temperatures indicate its merely approximate character; it will, however, be interesting to compare an actual reduction of observations taken with the mean resulting from a computation of the theoretically corrected figures.

The Okhotsk Sea is practically a closed basin partaking of a continental climate, and consequently might be expected to present us with a higher summer and lower winter temperature than an equal area of open sea in the same latitude, which being unconfined would be operated upon by the general oceanic circulation.

Again, the temperatures taken being mostly on soundings of less than 100 fathoms, the factors which determine a greater summer temperature for shallow waters might be expected to result in a more than normal warmth for the localities tested; winter observations when the sea is ice bound being, of course, yet to be made.

The fact agrees with the hypothesis, whether the latter be or be not correct, since the observations of one hundred and twenty different localities (due to Erman[1] and Onatsevich), ranging over nearly the whole summer season (July to September), theoretically corrected, give us a mean maximum summer temperature for this sea 50°.56 (10°.31). The mean of the observations as they were taken is 49°.26 (9°.59), a difference of less than a degree and a half. Localizing the observations, those of the east shore, uncorrected, taken in the early part of July, average 46°.1 (7°.8), those of the north shore, July and August, 48°.88 (9°.38), and those of the west shore, taken in September mostly on the shallows east from Sakalin Island, 50°.45 (10°.23). If the temperatures of the deeper central and southern parts of the sea had been as thoroughly tested we should probably find that the theoretical mean summer sea-surface temperature of about 45°.0 (7°.2) was not far from the truth.

It is true that some current passes through La Perouse Strait into the Okhotsk, especially toward the end of summer; but, from Onatsevich's observations, the resulting effect on the temperature of the sea near the strait would seem to be of a very insignificant character.

If, then, a sea free from great oceanic warm currents reaches a summer maximum of about 50°.0 (10°.0), should we not expect greater things from one in the same latitude into which a great warm current is said to bring borrowed heat in addition to its normal temperature?

Bering Sea may be divided for consideration of its temperature into three divisions: 1. The shallows, such as Bristol Bay and vicinity, Norton Sound, and the region off the coast of the mainland where the depth is less than twenty-five fathoms. 2. The moderate depths extending from the southern entrance of Bering Strait west of the line bounding the shallows and extending south to a line drawn from Cape Thaddeus toward Saint Mathew, the Pribiloff Islands, and the peninsula of Aliaska, following as nearly as we may the seventy-five-fathom curve. Lastly, the deep waters south and west from this line to Kamchatka and the Aleutian Islands.

Taking up these regions successively, we find the shallows of Bristol Bay and vicinity having a theoretical mean summer maximum of 54°.0 (12°.2), and an observed maximum of 56°.2 (13°.4), during the unusually warm season of 1874.

The shallows of Norton Sound from actual observations, by Riedell, have for July and August an average temperature of 56°.05 (13°.36), with a maximum of 62°.0 (16°.7), and, including September, have a mean temperature for the three summer months of 53°.9 (12°.2), at least for 1872. These observations were made with a standard instrument, furnished by the United States Coast Survey. Captain Hooper's observations made in a less favorable season, and covering only a few days, indicate a similar relation between the deeper waters and those of the sound.

The temperature of the area of moderate depths is considerably less. Taken as a whole, they present a theoretical mean summer maximum of 46°.2 (7°.9), and an average summer temperature of 40°.2 (4°.6). This is somewhat too high for the northern portion and too low for the southern portion, but agrees very fairly with the mean of actual observations 46°.8 (8°.2) and 42°.1 (5°.6) respectively, and the conclusions from more meager evidence, published in Appendix I to the Alaska Coast Pilot. These means are derived from observations taken in the open sea and appear low when compared with the observations taken at Unalashka, with a summer mean of 51°.1 (10°. 6), and at Saint Paul Island 47°.3 Fahr. or 8°.5 C.; but it must be remembered that these were taken in shallow water, near the shore, and do not adequately represent the off-shore temperatures. The high temperatures of Norton Sound are only comparable for the three months open-water period, with temperature taken farther south, for if the ice-bound months of May and June, and the cold October were included (as they might be at Unalashka), the temperature would be reduced to 44°.8 (7°.1 C.) for the season. For these reasons I have only considered the three months of July, August, and September in these comparisons. The deep area of Bering Sea is also a southern area, and might therefore be expected to have a higher temperature than the rest, even if it were not the part which by popular hypothesis should receive a body of warm water from the Japan Stream. A reduction of the actual observations from one hundred and twenty-two different localities, each representing, in general, the mean of a day's observations, shows that the maximum and mean summer temperatures are but little higher than those of the area of moderate depths,

[1] Journey in Siberia, vol. ii, Phys. Obs.

which covers in part a more northern region. The figures for the observations are 47°.1 (8°.4) and 45°.2 (7°.3), and for the theoretically corrected observations 47°.0 (8°.3) and 41°.0 (5°.0), respectively. Since the former represent only small portions of different seasons, it is by no means certain that the corrected means deduced from continuous series do not more nearly indicate true averages.

The region is of course warmer on the south and colder on the north, but warmest in the local shallows, along the Kamchatka coast, such as the Bay of Avatcha.

It is obvious that the mean temperature over a region partly cold and partly warm would fail to indicate its real character and its want of uniformity. Were such a distribution indicated by the facts in this region, its discussion would have been the first thing in order; since that is not the case, a discussion of that part of the problem will appear later, in connection with a review of the facts known in regard to the Japanese Stream and its extension north and west.

Since the Arctic basin is constantly more or less obstructed by ice, it is impracticable to apply any theoretical corrections to non-synchronous observations, and I have therefore attempted to obtain a mean summer temperature on the basis of the observations as they stand. Kotzebue Sound, when free from ice, bears the same relation to the rest of the basin as does Norton Sound or Bristol Bay to the basin of Bering Sea. I find from the mean of all accessible observations (reduced according to their weights), that the mean temperature of Kotzebue Sound for July and August is 49°.8 (9°.9); for July, August, and September (including one very cold September), the mean temperature is 44°.8 (7°.1).

The mean temperature for the Arctic basin from July to September (being the time when the sea is more or less open or free from ice), reduced in the same way, for the regions between Wrangell Island and America, exclusive of Kotzebue Sound and Bering Strait, is 40°.25 (4°.58). This hardly differs from the July temperature of the sea, west from Novaia Zemlia, according to Petermann, or the Polar basin, east from the Lena, along the Siberian coast, according to Nordenskiold.

The general temperature figures may, therefore, be summarized as follows: the column "max." indicating the greatest mean temperature for the warmest month of summer; the column "mean" indicating the average temperature of the period of open water (July, August, and September[1]) in the north. Except when marked by an asterisk these figures are from actual observations reduced according to their weights.

[Centigrade degrees in black.]

Sea.	Deeps.		Moderate depths.		Shallows.		Area of—
	Max.	Mean.	Max.	Mean.	Max.	Mean.	
	°	°	°	°	°	°	
Arctic	....	....	**5.6** 42.0	**4.58** 40.25	**11.7** 53.0	**7.1** 44.8	Kotzebue Sound.
Bering	**8.4** 47.1	**7.3** 45.2	**8.2** 46.8	**5.6** 42.1	**11.1** 51.9	**10.3** 50.5	Captain's Bay.
Do	....	....	....	....	**13.4** 56.1	**12.2** 53.9	Norton Sound.
Do	....	....	....	....	**13.4** 56.2	**12.2** 54.0*	Bristol Bay.
Okhotsk	....	....	**9.59** 49.26	**7.4** 45.3*	**12.7** 54.9*	**9.9** 49.8	West border.
North Sea[1] [July]	....	**13.9** 57.0	....	**15.0** 59.0	....	**16.7** 62.0	Baltic, &c.

THE KURO SIWO AND ITS EXTENSIONS.

The question of distribution of temperature in the sea is so intimately united with that of the character of its currents, that it is impracticable to separate them entirely. Consequently, as soon as one leaves the general question of mean temperature of a given area, and desires to decide whether that temperature is normal, and if not, from whence and how it is derived, the features of oceanic circulation must at once make part of the discussion.

To reach the root of the matter it is necessary to inquire into the origin, duration, and extent of the Kuro Siwo, outside of the Bering Sea region. The data furnished by Dr. Antisell enable me to do this in a more satisfactory manner than would otherwise be possible. It is true they relate

[1] Petermann, Gulf Stream Memoir Plate I.

almost wholly to its temperature, but, owing to the fogs which cover much of its course, determinations of its motion must long remain few in number and more or less inexact in character.

While other observers have noticed grave irregularities and connected them casually with the changes of the monsoons, Dr. Antisell, in his paper referred to, was the first to draw attention to the marked periodicity of the Kuro Siwo and the great extent to which it depends upon the southwest monsoon for its propagation.

Since his data were derived from the records and experience of those best fitted to judge (the commanders of the China, Japan, and California mail steamships), and cover a great number of voyages, his conclusions must be considered as of great weight.

The Kuro Siwo is produced by the impinging of the Pacific north equatorial current on the eastern shores of Formosa and adjacent islands. While the larger part of the equatorial current passes into the China Sea, a portion of it is deflected northward, along the eastern coast of Formosa, until reaching the parallel of 26°, it bears off to the northward and eastward, washing the whole southeastern coasts of Japan, and increasing in strength as it advances to a limit which appears to be variable.[1] Its average maximum temperature is 86°.0 (30°.0), which differs about twelve degrees from that of the ocean normal to the latitude. The northwestern edge of the stream is strongly marked by a sudden thermal change in the water of from 10°.0 to 20°.0 (5°.6 to 11°.2), but the southern and eastern limit is less distinctly defined, there being a gradual thermal approximation of the air and water.

A branch of the Kuro Siwo passes northward into the Yellow Sea, and another through the straits of Korea, into the Japan Sea, after entering which it becomes variable and irregular, but is believed to issue under favorable circumstances from Sangar and La Perouse straits. These branches for the purposes we have in view may be regarded as of little consequence.

The Kuro Siwo has its origin in almost exactly the same relative part of the Pacific as the Gulf Stream does in the Atlantic, but the parallel is otherwise far from complete. The differences of volume and of temperature between this and the Gulf Stream will be discussed later; assuming an equality in these respects there are still other important discrepancies.

The latter enters a deep ocean without obstructions and about seventy degrees of longitude in width. The Kuro Siwo, at its very outset, is obliged to force its way through the barrier of the Loochoo Islands, and a little later through that chain of rocks, shoals, and islets extending from Yokohama to the Bonin Islands. It then has nearly one hundred degrees of longitude to traverse before reaching the opposite shore of the Pacific. When to these barriers is added the strength of the northeast monsoon from the end of September to the end of February, blowing right in the teeth of the current (which is not, like the Gulf Stream, prevented by an unbroken line of coast from escaping in a westerly direction), it is not a matter of surprise that its force should be checked, and its continuity as an eastward current be for the time almost obliterated. The reports of the British naval officers who have examined it show that this "current is much influenced, both in direction and velocity, by local causes." "It is sometimes entirely checked for a day by a northeast wind." "In June, 1861, the current ran steadily at the rate of seventy miles a day toward the Gulf of Yedo, but, on approaching the great chain of islands south of the Gulf, it diminished in velocity and curved to the southward. During July and August it was not noticed off the gulf."[2] This, it may be noted, was in the period of *favorable* (southwest) *monsoons*. The remark is made in the China Pilot that the current appears to attain its greatest velocity (72 to 80 miles) between Van Diemen Strait and the Gulf of Yedo, but was on one occasion recorded for three successive days at only 24 to 27 miles. "It is sometimes deflected to the south by the chain of islands south off the gulf, or before reaching them. Changes of the stream will probably be found dependent on the seasons." It is hardly necessary to observe that in the Gulf Stream, during the equivalent part of its course, such violent fluctuations have not yet been recorded by scientific observers.[3]

[1] China Pilot, 4th ed., p. 449. [2] Report by Lieut. Bullock, R. N., H. M. S. Dove, 1861.

[3] It is likely that the Gulf Stream, also, when more fully investigated, will show important fluctuations, especially in the winter months. Such have already been referred to by several writers, especially Com. J. R. Bartlett, U. S. N. If they were as marked and important as those indicated by Antisell's documents for the Kuro Siwo, it would seem that widespread knowledge of them would long since have been attained by the navigators directing the enormous commerce which crosses the Gulf Stream continually. This matter is under investigation by the United States Coast and Geodetic Survey.

The course of the Kuro Siwo, as indicated by various authorities, when in its greatest strength, is from the vicinity of Yokohama in an easterly and northerly direction toward the northwest coast of America, which it reaches in about latitude 50°. For our purposes, the character of that part of the stream between the meridians of 220° and 185° west from Greenwich is of more tance. Lütké observes* that, in six voyages between Kamchatka and the south, while between latitude 30° and 42° and longitude 214° and 198°, a steady current, flowing eastward, even with easterly winds, was noted. In one southward voyage, it was first met with in latitude 38°, on a second at 40°. "North from the parallel of 42° in the western part of the Pacific Ocean, we chanced to have almost constant easterly winds, and with them westerly currents which, when the winds were very strong, amounted sometimes to 20 miles a day, and which, when it became calm, disappeared entirely. In some cases, on the contrary, when the wind blew from the northwest the current then turned to the southeast, the direct influence of the wind herein being evident" (Lütké, l. c., p. 190). Though Lütké reports that Mertens took observations of sea temperatures, it does not appear that they have anywhere been published, and the observations of Beechey are so much generalized in his appendix as to be untrustworthy for close comparisons. Du Petit Thouars, during the voyage of the Venus, took hourly temperatures, which have been admirably worked up in the published records of the voyage. In latitude 30° longitude 180°, he found the temperature of the axis of the Kuro Siwo to be 81° (27°.5). The normal temperature of the Pacific Ocean about latitude 40° to 45° is about 60°.0 (15°.6). He found that the temperatures rapidly decreased northward, falling from 75° (23.9) to 53° (11°.7) in only three degrees of latitude; but of this change twelve degrees (71° to 59° Fahr.) occurred upon one day (August 17, 1837), between latitude 40° and 41°, which would place the northern edge of the Kuro Siwo at the period of its greatest strength about latitude 41° in longitude 197°. The observations of Belknap, taken in June, show that the isotherm of 60°.0 (15°.6) does not pass much north of 42° north latitude, and that the temperature then very rapidly decreases northward, falling 15° Fahrenheit in 150 miles. The observations of Onatsevich in the same region, taken at different periods of the year, agree with those of Belknap.

With regard to the propagation of temperature (and inferentially of motion) in the waters, forming the supposed bed of the Kuro Siwo, the data obtained by Antisell are of high importance, and go far toward sustaining the view that the current is dependent for its existence, east of Yokohama, upon the southwest monsoon. In other words, that it is turned in a southeast direction or obliterated by the northeast monsoon.

The track of the Pacific Mail Steamships, in the voyages referred to (leaving out of consideration a few degrees at the San Francisco end) lies almost wholly between the parallels of 30° and 35°. Between the meridians of 220° and 190°, it cuts obliquely across the current, and if it be true, as there is reason to suspect, that the current has, in general, a considerably more southern course than has been supposed, the track would lie in its trough for a much greater distance.

The northeast monsoon begins to disappear in February. In March the North Pacific appears to be in its most homogeneous condition. The means of six or eight daily observations continued throughout the voyage (4,750 miles), the diurnal fluctuations being eliminated, show extreme differences of only four degrees Fahrenheit. From longitude 217° to 136°, in the mean latitude 33° 03′, the sea only varied from 60° to 64° (15°.6 to 17°.8). It is quite evident there is no warm current here. In April, over a course averaging a degree and a half further north, the temperature was somewhat lower and the variation a little larger (57° to 63° Fahr.), but still remarkably homogeneous.

In May the warm water begins to creep north, along the Japanese coast. In records of three voyages, amid some seasonal differences this change is clear. From longitude 217° to 208°, in these three years the temperature has risen in the last week in May to between 64° and 68° (17°.8 and 20°.0). Thence eastward it still retains a lower and pretty uniform temperature, which is in the mean latitude 36° 12′, from 57° to 63°; fifteen days later, in mean latitude 38° 29′, 53° to 60°, and in mean latitude 36° 16′, from 58° to 64° Fahrenheit.

In June the Kuro Siwo is putting forth its strength. From Yokohama eastward to longitude

* Voy. Séniavine, Partie naut., p. 189 *et seq.*

169° the temperature (except a cooler band ten degrees wide, between the meridians of 198° and 208°) has risen to between 70° and 73°[1] (21°.1 and 22°.8). This cool band, indicative of the Kamchatka stream, is also shown in the Challenger section.

In July (two voyages) we have still indications of the "cool band," but the temperature as far east as 205° W. has risen to between 75° and 81° (23°.9 and 27°.3), and thence during the first half of the month to longitude 180°, and in the latter half to longitude 172° (mean latitude 36° 20′), the surface does not fall below 70° (21°.1).

In August the temperature seems to reach its maximum. The locality of the "cool band" has 79° (26°.1) at the surface and the temperature appears to decrease very gradually from 84° (meridian of 218°) to 75°, (at 169°) and 70° (at 138°). In a voyage by the so-called "northern route," mean latitude (44° 48′), made in this month, the temperature of 70° (21°.1) proper to the Kuro Siwo, was lost in latitude 40° 30′, longitude 207°, and the temperature fell below 60° (15°.6) about 100 miles further north, in the very axis of the hypothetical northern branch, and did not rise above 60° (15°.6) again until the northern edge of the Japan Stream was reached, in latitude 47° and longitude 166°. The "cool band" on this line extended between the meridians of 180° and 202°, with a temperature of between 50° and 59°. In September, toward the end of the month, the southwest monsoon begins to fail and in the record the change is clearly revealed by the changing temperatures. Off the Japanese coast, for fifteen degrees of longitude, the temperatures which had been 78° to 82° (25°.6 to 27°.6) have fallen to 75° (23°.9), with bands 2° to 5° cooler. There is a trace of the "cold band" on the surface, in the region of 205°, with a temperature of 73°, but the water eastward, which in August varied from 72° to 77° (22°.2 to 25°.0), now shows temperatures of 69° to 73° (20°.6 to 22°.8), between longitude 158° and 188°. Other voyages in this month are taken on the "southern route" and show warmer temperatures but are of course not properly comparable with those herein considered.

Throughout the month of October water with a temperature of 70° is found stretching across the Pacific as far east as 140° with intervening narrow bands of slightly cooler water.

In November the southwest monsoon is at an end; the temperatures immediately off the Japan coast have fallen to from 66° to 64°; east of 182° (mean latitude 35° 20′) they vary from 62° to 67° (16°.7 to 19°.4) with a distinctly cooler band between 152° and 170°. Two "southern-route" voyages in this month in the mean latitude 30° 42′ show nothing warmer than 73° (22°.8) in the path of the Kuro Siwo, except a single temperature of 74°. The narrow bands of cooler water become a conspicuous feature.

In December, with the anti-monsoon blowing from the northeast, the temperatures have fallen to 62° (16°.7) on the coast of Japan and nothing warmer than 71° (21°.7) east from it even on the "southern route." The Kamchatka stream is indicated in 198° by a temperature of 64°.

In January and the early part of February for sixteen degrees east from the coast of Japan (mean latitude 35° 05′) the water varies from 64° to 66° (17°.8 to 18°.9), and later in February from 61° to 65° (16°.1 to 18°.3) (in mean latitude 33° 03′), while the eastern half of the Pacific in the same latitude during March is wholly below 60° (15°.6), indicating very clearly that the strong warm current of August has suffered a material change. By the following month, as already indicated, the ocean is almost homogeneous in temperature from Japan to California.

The following table is the result of a recomputation and reference to every *second* meridian of the original data, copied from the logs by Dr. Antisell, and from which he prepared his profiles which were referred to every *third* meridian.

It was thought advisable to do this, not only in order to eliminate any accidental errors of computation in the first instance (though none were found), but also to obtain a more extended, and therefore, more thoroughly representative, table. The result has been a slight modification of some of the minor details of the original, but nothing in any way changing the general tenor of the conclusions heretofore announced on the basis of these observations.

The temperatures of the table are to the nearest Fahrenheit degree, the variation from the

[1] Yet in this month also, Belknap passed the surface isotherm of 65° (18°.3) in lat. 39°, and after escaping from the influence of the warmer current from Sangar Straits, he found (from lat. 42°.30) nothing warmer than 50°.0 (10°.0), while the great gap between the Aleutians and Kamchatka varied on the surface from 40° to 47° (4°.4 to 8°.3), and below the immediate surface hardly rose above 35° (1°.7).

Table of North Pacific

Yokohama.			Mean sea-surface temperatures for every second meridian of																										
Date.		Bay temp.	220	218	216	214	212	210	208	206	204	202	200	198	196	194	192	190	188	186	184	182	180	178	176	174	172	170	168
Feb. 6, '72	Ar.	43	62	62	62	62	64	64	65	65	66	67	64	62	65	66	65	66	68	67	67	65	64	64	63	62	63	63	63
Feb. 5, '75	Ar.	50	62	65	63	63	64	65	64	64	66	66	66	65	65	66	67	68	67	67	66	65	65	66	66	65	64	64	64
Feb. 24, '74	Sld.	....	63	66	65	63	62	62	62	62	62	62	62	62	62	61	60	58	60	61	62	63	62	61	60	59	59	59	60
Feb. 28, '72	Sld.	42	58	59	60	61	60	60	61	61	63	65	63	62	61	61	61	61	61	62	62	62	62	62	62	62	62	61	61
Mar. 11, '75	Sld.	50	67	64	62	62	62	62	62	62	63	62	62	62	61	60	60	61	61	61	61	60	62	63	62	61	61	62	63
Apr. 27, '74	Ar.	63	65	64	64	64	63	63	63	63	63	62	62	62	61	60	61	61	62	61	60	59	57	57	57	57	57	57	58
May 1, '72	Ar.	62	69	66	66	65	65	65	65	65	64	64	65	65	65	64	64	64	64	64	63	63	63	64	65	62	62	64	59
May 28, '75	Ar.	68	68	68	69	67	68	69	66	63	62	61	61	60	60	60	60	60	60	60	60	60	60	60	60	60	60	59	59
May 23, '74	Sld.	63	70	68	66	66	66	66	66	66	61	61	61	60	60	59	58	57	58	58	58	58	58	58	57	56	56	56	56
May 25, '72	Sld.	67	68	66	66	66	66	65	64	64	63	62	63	63	64	62	62	62	61	61	62	62	59	59	58	58	58	58	58
June 24, '75	Sld.	....	71	73	72	72	71	70	69	69	69	68	68	68	70	71	71	72	72	73	73	72	72	70	70	70	69	69	68
June, July	Sld.	....	72	71	70	70	70	68	66	66	66	69	68	69	70	71	71	70	70	70	71	72	73	70	69	66	66	65	65
July 22, '74	Ar.	79	73	79	80	78	77	75	75	76	76	75	74	73	71	71	71	71	71	71	71	70	70	69	69	68	68	67	67
July 25, '72	Ar.	81	80	81	79	79	79	78	76	75	75	75	75	74	74	75	75	74	73	73	73	73	72	72	71	71	70	68	68
Aug. 27, '75	Ar.	80	80	84	82	80	80	80	80	81	80	80	80	79	78	78	78	78	77	77	77	77	76	76	75	75	75	75	73
Aug. 14, '74	Ar.	(?)	81	82	81	82	78	75	75	(59)	61	59	59	58	57	54	(50)	54	52	53	53	54	56	56	56	55	56	57	57
Aug. 22, '72	Sld.	83	79	82	81	80	80	79	78	76	75	75	75	77	76	76	76	75	77	78	75	73	72	71	71	74	73	73	73
Oct. 9, '73	Ar.	68	71	76	76	74	74	75	75	(73)	76	76	78	77	80	76	75	75	75	73	72	71	70	70	69	70	70	69	69
Oct. 25, '71	Ar.	....	74	75	75	74	75	76	76	(76)	77	77	77	78	78	79	79	79	79	77	76	76	75	76	77	76	76	74	74
Oct. 28, '74	Ar.	62	70	72	72	74	73	77	75	(73)	75	75	76	76	77	76	(73)	77	77	76	77	76	75	74	74	74	74	72	72
Nov. 2, '73	Sld.	50	(64)	70	69	70	72	71	72	71	73	72	72	(68)	72	72	72	71	69	69	68	67	66	68	67	65	64	63	62
Nov. 23, '71	Sld.	59	66	72	68	69	70	73	74	73	70	72	72	71	71	71	70	70	69	69	69	68	68	67	67	64	64	65	65
Nov. 23, '74	Sld.	51	67	73	70	71	72	71	71	72	(70)	73	74	72	73	73	73	72	72	72	71	69	70	69	68	68	68	68	69
Dec. 29, '73	Ar.	50	62	68	66	66	67	69	70	70	69	69	70	(64)	70	70	71	72	69	71	71	70	69	69	69	69	69	69	69
Mean		61.6	68.7	70.7	69.9	69.5	69.7	69.9	69.5	69.1	69.2	69.4	69.4	68.6	69.3	69.0	68.9	68.9	68.8	68.8	68.5	67.9	67.4	67.1	66.8	66.2	66.0	65.6	65.5
		....	72.2	75.7	74.5	74.2	74.4	74.4	74.0	73.4	73.5	73.9	74.1	73.6	73.6	73.4	73.3	73.1	72.8	72.5	72.3	71.7	70.9	70.4	70.0	69.7	69.4	68.4	68.1
		....	64.4	64.8	64.3	63.9	64.1	64.4	64.2	63.9	64.1	64.0	63.8	63.5	64.9	64.7	64.7	64.8	64.8	65.0	64.7	64.0	63.8	63.8	63.5	62.6	62.6	62.8	62.7

actual being less than the usual errors of observation and instruments in work not done by trained observers and with standard instruments. The employment of Celsius' scale, as I had at first intended, with its cumbersome and inevitable fractions of degrees, would have increased the size of the table (already too large for convenient printing) nearly one-third. The date of arrival or departure from Yokohama and San Francisco is given under its appropriate head at either end of the table, with a column showing the temperature of the water in the harbor at the time of arrival or departure. It will be observed that this is almost invariably colder than the sea water outside of the harbor, except under the influence of an August sun at Yokohama.

The columns of mean temperatures follow under their appropriate meridians. A few peculiar single observations (denoting, perhaps, cool bands of surface water) are inclosed in parentheses, as worthy of attention, instead of being swamped in the general means. A heavy line separates the observations of the last day of any month from those of the following day, so that the data relating to particular months may be singled out if desired.

The mean latitude of the principal part of the course, given at the right of the table, is that between meridians 140° and 210°. This was usually run on a nearly east and west line, and the means show the relative latitude of the several voyages. Two voyages by the "northern route" are marked with an asterisk, and are not included in the mean for the year or the other general means. The means for the year and for "June–Nov." and "Dec.–May" show the average annual temperature of the North Pacific in the mean latitude for every second meridian, as far as it can be deduced from the material in hand; also the same for the periods when the favorable (southwest) monsoon and the (northeast) anti-monsoon winds are blowing.

sea temperatures.

west longitude between San Francisco and Yokohama.																						Bay temp.	San Francisco.		Mean lat. between meridians 140° and 210° W.	Mean temp. for the latitude of voy.	No. of voyage.
166	164	162	160	158	156	154	152	150	148	146	144	142	140	138	136	134	132	130	128	126	124		Date.		° ′		
64	64	64	63	63	63	64	63	63	63	62	61	61	61	60	58	57	56	55	56	54	52	52	Jan. 5, '72	Sld.	29 51	62.5	1
64	65	65	65	66	67	67	68	68	68	68	67	66	64	64	64	62	61	60	56	55	54	52	Jan. 2, '75	Sld.	30 30	64.5	2
59	59	59	58	58	57	57	56	56	56	56	56	56	57	57	56	55	55	54	54	54	51	50	Mar. 19, '74	Ar.	35 05	59.1	3
62	62	62	62	61	61	61	61	60	59	59	59	58	58	58	58	57	56	55	54	54	52	53	Mar. 23, '72	Ar.	30 52	60.1	4
62	62	62	62	63	63	63	63	63	62	62	61	61	61	60	60	59	59	58	54	54	52	50	Apr. 4, '75	Ar.	33 03	61.1	5
58	59	59	59	59	58	59	60	59	59	59	60	60	60	60	60	59	58	57	56	54	....	....	Apr. 1, '74	Sld.	34 36	59.9	6
58	57	57	62	63	64	64	64	63	63	63	63	63	63	63	62	61	61	60	59	54	52	47	Apr. 5, '72	Sld.	31 54	62.7	7
58	57	57	56	56	56	57	58	58	58	59	60	61	60	60	60	60	60	60	59	56	53	53	May 1, '75	Sld.	36 12	60.4	8
56	56	55	54	53	54	54	55	55	55	55	55	55	56	58	58	60	59	59	59	56	55	57	June 15, '74	Ar.	38 29	58.6	9
59	59	60	60	62	64	64	64	64	64	63	63	61	60	60	59	58	58	56	55	55	55	56	June 17, '72	Ar.	36 16	61.3	10
67	67	67	67	68	68	69	69	69	69	68	67	66	66	64	64	63	61	60	59	55	56	55	July 15, '75	Ar.	36 03	68.0	11
65	65	65	66	68	68	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	Challenger.	......	35 30	(68.5)	12
67	67	69	68	67	67	66	66	65	64	63	63	63	62	62	62	62	61	60	60	58	56	52	June 27, '74	Sld.	36 29	68.4	13
67	66	66	66	66	66	67	67	67	66	66	66	65	65	65	64	63	62	61	58	56	56	54	July 1, '72	Sld.	36 10	69.8	14
72	72	71	71	72	72	72	72	71	71	71	71	71	70	70	66	66	64	62	61	60	56	55	Aug. 2, '75	Sld.	36 05	73.8	15
58	59	59	59	60	61	61	61	61	62	62	62	62	62	63	63	63	63	65	64	63	59	(?)	Sept. 3, '74	Sld.	44 48	61.7	16
73	73	73	73	74	75	73	74	73	74	73	72	71	71	69	67	66	64	62	60	57	57	....	Sept. 12, '72	Ar.	36 06	72.9	17
69	70	71	71	(68)	74	74	75	75	74	74	74	74	73	72	71	70	70	68	67	64	55	57	Sept. 16, '73	Sld.	36 28	72.2	18
77	78	78	77	77	77	76	75	75	73	72	71	70	69	69	68	68	66	65	65	62	58	....	Oct. 1, '71	Sld.	30 45	74.0	19
72	72	71	71	70	70	70	70	71	71	69	71	70	69	69	68	68	67	65	65	62	59	57	Oct. 3, '74	Sld.	33 44	71.9	20
62	62	62	61	61	61	61	59	64	64	64	65	66	66	66	65	65	65	60	59	58	53	....	Nov. 23, '73	Ar.	35 20	65.9	21
65	66	65	65	66	67	68	68	67	67	67	65	64	63	62	62	60	59	58	57	54	52	52	Dec. 17, '71	Ar.	30 20	66.4	22
68	68	69	68	67	67	67	66	66	66	66	65	65	65	63	64	64	63	62	62	59	56	52	Dec. 18, '74	Ar.	31 05	68.1	23
69	69	69	70	70	70	69	69	70	71	70	69	70	70	69	68	66	65	64	62	60	53	....	Dec. 1, '73	Sld.	30 06	68.1	24
65.5	65.6	65.7	65.5	65.8	66.1	66.1	66.0	66.0	65.8	65.4	65.2	64.8	64.4	63.9	63.1	62.3	61.5	60.1	59.0	56.9	54.4	53.2	Year		33 45	66.3	
68.2	68.3	68.4	68.3	68.4	69.3	69.2	69.1	69.4	69.0	68.3	68.3	67.7	67.1	66.6	65.4	64.9	63.8	61.9	60.9	58.7	56.1	....	June–Nov		36.14	69.7	
62.4	62.5	62.5	62.7	62.9	63.0	63.3	63.3	63.0	62.9	62.8	62.4	62.3	62.0	61.4	61.1	60.0	59.4	58.4	57.2	55.3	52.7	....	Dec.–May		32.08	62.7	

The last column in the table shows the mean temperature of the north Pacific for the mean latitude and season of each voyage.

It must be borne in mind, in considering the table and the subject to which it relates, that the Pacific, like Bering Sea and other bodies of water, as well as the atmosphere at any locality on land, varies in different years, so that in a relatively small series like the present there may be, and probably are, some anomalies due to this cause. A very much larger series would be required to eliminate these and other sources of error; but, notwithstanding all this, the general conclusions afforded may be safely taken as relatively correct, though the "bench-mark" of the series might be changed in absolute level by the discussion of a greater amount of material.

The general accuracy of the observations is attested by their agreement with those taken by the Challenger in the same region and at the same time of the year.

It is hardly necessary to point out that the anomalies of temperature due to current in any particular voyage are almost lost in the general means for the year or half year. Information on these points must be sought in the records of single voyages.

The cooler area about the meridian of 170° I take to be due, perhaps, not entirely to cold water from the north, but also in part to the fact that here in the given latitude the axis of the Kuro Siwo passes north of the usual track of the steamers. This, however, requires further observation. The fact that in the two most northern voyages, the cooler area occurs further to the westward (188°) tends rather to show that it is due to the Kamchatka stream, and that that has a more or less easterly tendency as it progresses southward.

In this connection the only data in the North Pacific for submarine temperatures, except those of Captain Belknap (and corroborating his in every respect), are those of the Challenger. There are, fortunately, sections taken by the Challenger party in the two oceans almost exactly comparable. In the Atlantic their section extends between Cape May and Madeira, covering about fifty-two degrees of longitude and in nearly the same latitude as the voyages of the China steamers just described. This section was taken from April to July.[1] The corresponding Pacific section is that from Yokohama to station No. 253, in longitude 156° 25′, covering some sixty degrees of longitude, beyond which some thirty degrees more intervene between station 253 and the California coast in the same latitude. This section was made during June and July. By redrawing the isotherm profiles, and taking off the values for every two and a half degrees, the sections have been made more comparable, and are presented in the following table.

Comparison of sea temperatures between latitudes 33° and 38° north in the Atlantic and Pacific Oceans, arranged from observations by H. M. S. Challenger, 1873 and 1875.

Meridian W.		Surface temperature.				Depth in fathoms, of the isotherm of—					
		Centigrade.		Fahrenheit.		10° C. = 50° F.		15° C. = 59° F.		20° C. = 68° F.	
Atlantic.	Pacific.	Atlantic.	Pacific.	Atlantic.	Pacific.	Atlantic.	Pacific.	Atlantic.	Pacific.	Atlantic.	Pacific.
° ′ [72. 10]	° ′ [220. 30]	° 10. 0	° 19. 2	° 50. 0	° 66. 6	0	185	—	70	—	0
70. 00	220. 00	18. 3	22. 2	64. 9	72. 0	465	206	355	100	—	50
67. 30	217. 30	18. 3	21. 7	64. 9	71. 0	475	240	350	137	0	30
65. 00	215. 00	22. 8	21. 4	73. 0	70. 5	455	250	330	137	40	20
62. 30	212. 30	23. 0	21. 2	73. 5	70. 2	445	250	330	147	35	25
60. 00	210. 00	22. 3	19. 9	72. 2	67. 8	430	212	300	100	25	5
57. 30	207. 30	21. 8	18. 7	71. 2	65. 6	440	115	320	50	20	—
55. 00	205. 00	21. 3	18. 8	70. 4	65. 8	440	70	295	25	20	—
52. 30	202. 30	21. 1	20. 7	70. 0	69. 3	430	200	275	100	15	10
50. 00	200. 00	23. 8	20. 3	74. 9	68. 5	440	190	305	80	30	15
47. 30	197. 30	22. 2	20. 6	72. 0	69. 0	530	185	355	60	25	10
45. 00	195. 00	21. 2	21. 1	70. 2	70. 0	515	230	340	75	20	10
42. 30	192. 30	21. 1	21. 7	70. 0	71. 0	470	240	335	70	35	20
40. 00	190. 00	21. 1	21. 4	70. 0	70. 5	450	200	292	50	35	10
37. 30	187. 30	21. 7	20. 9	71. 0	69. 7	440	195	120	27	20	5
35. 00	185. 00	21. 7	20. 8	71. 1	69. 4	315	190	100	27	15	5
32. 30	182. 30	21. 7	22. 3	71. 1	72. 2	345	235	150	40	17	8
30. 00	180. 00	20. 7	22. 8	69. 2	73. 1	380	210	92	45	25	20
27. 30	177. 30	21. 1	20. 9	70. 0	69. 6	370	150	60	25	20	5
25. 00	175. 00	21. 7	19. 4	71. 1	67. 0	345	145	60	25	20	0
22. 30	172. 30	21. 9	18. 6	71. 4	65. 5	412	160	55	25	15	—
20. 00	170. 00	21. 6	18. 1	70. 8	64. 6	418	170	70	20	15	—
[19. 17]	167. 30	21. 5	18. 3	70. 7	64. 9	440	175	80	20	15	—
....	165. 00	....	18. 3	....	64. 9	....	160	....	20	....	—
....	162. 30	....	18. 3	....	64. 9	....	150	....	20	....	—
....	160. 00	....	18. 8	....	65. 8	....	130	....	20	....	—
....	157. 30	....	19. 8	....	67. 6	....	110	....	20	....	—
....	[156. 25]	....	19. 8	....	67. 6	....	100	....	20	....	—

[1] I am indebted for the data to Wild's "Thalassa," Table III, p. 70, Table XII, p. 114, plates 8 and 18.

It should be noticed that the differences of observation about counterbalance one another, the Atlantic section being partly taken in a colder period of the year, while its eastern end is turned somewhat southward into presumably warmer water. On the other hand, the Atlantic section begins two hundred miles further away from the starting point of the Gulf Stream than does the Pacific section from the inception of the Kuro Siwo. On the whole, everything else being equal, it would seem as if the effect of the differences of observation would be to make the Pacific section somewhat the warmer of the two.

For a comparison between the average temperatures of the two masses of water, I have taken the fifty degrees of longitude between 20° and 70° W. in the Atlantic and 170° and 220° W. in the Pacific as comparable parts of the two sections.

One noticeable difference in the two profiles is the manner in which, in the Gulf Stream, its western edge forms an almost perpendicular wall of water at 50° (10°.0) or warmer, with colder water between it and the shore, and continues eastward for some 35° of longitude a nearly solid, unbroken mass; while, on the other hand, with the Japan Stream its warmest water is at the coast, 15° east of which the Kamchatka stream heaves the isotherm of 50° (10°.0) within 60 fathoms of the surface, while the whole mass of the water at 50° (10°.0) or more is hardly more than half as much in sectional area as in the Gulf Stream. The lower boundary of the mass of water at 50° (10°.0) reaches in the Atlantic a depth of 430½ fathoms. The following table shows a comparison of the two oceans to this depth within the boundaries assigned:

Pacific.			Atlantic.		
Fahr.	Cent.	Depth.	Fahr.	Cent.	Depth.
°	°	*Feet.*	°	°	*Feet.*
70.2	21.2	70.8	71.2	21.8	127.7
63.5	17.5	319.2	63.5	17.5	1,272.1
54.5	12.5	765.1	54.5	12.5	1,183.2
45.5	7.5	900.5	....	....	....
40.0	4.4	527.4	....	....	....
49.94	9.97	2,583.0	59.76	15.42	2,583.0

The temperatures are mean temperatures for a stratum of water extending 50° of longitude east from the point of beginning in each ocean, having the mean depth indicated.

It is evident that the average heat of the mass of Atlantic water is nearly 10° Fahr. greater than the average heat of the Pacific mass. When we bear in mind that the Pacific stream has to move over 90° of longitude, while the Atlantic stream has but 52° to cross, and that the Atlantic stream is supposed to be constant, while we may assume that for at least one-third of the time the Pacific stream is checked or diverted by the anti-monsoon, it will be evident that the proportional effect on the coasts finally reached of the two streams will be greatly in favor of the Gulf Stream. The ratio between the latter and the Kuro Siwo, considering only temperature and duration, would be as 1.0 to 0.558—not far from the inverse ratio of the distances traversed by them; that is to say, 0.578 to 1.0.

I believe that the comparative weakness and inefficiency of the Kuro Siwo, as compared with the Gulf Stream, has never before attracted the attention of hydrographers, and would suggest that, so far as the currents of the open sea are concerned, it is not improbable that the Kuro Siwo may be a type of the Pacific currents generally, as compared with those of the Atlantic. The Pacific is open to the influx of Antarctic cold water without stint, and in it, probably, goes on a great system of true oceanic circulation, such as might occur were there no continents. The more superficial currents, like the Gulf Stream, while not independent of the general circulation, do, as they actually exist, form no necessary part of it, except as it is augmented, guided, or controlled by continental shore-lines, trade winds, tides, and other cosmic phenomena less powerful. Consequently, it is conceivable that such currents will be less marked and constant (considering the effect of winds) in proportion to the size of the oceans they traverse, other things being equal.

It is not a matter of surprise, after the preceding review of the character of the Kuro Siwo, to learn that, after reaching the northwest coast of America, that branch which turns southward along the coast, by the time it has reached the latitude of San Francisco, has become rather a cold current than a warm one, while that one which turns to the north and west, and finally loses itself along the Aleutian chain, is warm only because it intrudes on a normally cold area. The fact that these two branches exist and have the above general course is determined beyond all controversy, and it is not necessary to go over that ground again. It may be observed, however, that to the westward march of the tide which prevails along the Aleutian chain is added whatever of impetus this current may have to give, so that the flood northward and westward through the passes of the Aleutian chain is much stronger than the ebb, and, when not interfered with by wind, tends to give the water immediately north of the chain a westerly set, especially in summer and autumn.

Currents of Bering Sea.—I have already pointed out that Belknap, in crossing the gap between Kamchatka and the Aleutians, found only comparatively cold water, and no indications of any warm stream setting through this wide opening. I may recall here that he not only found no northerly set of warm water, but that the only places where northeasterly surface currents were experienced while crossing this passage were observed to be, if anything, rather colder than the rest. The currents observed were probably due to wind and tide. Their general tendency was to the ENE., but in two places where submarine currents were observed for, it was found the greater the depth at which the observations were made, the more nearly south was the direction of the current, and the stronger its flow. Thus, in longitude 195° (approximate), while the surface current ran half a knot a little to the N. of E., at 80 fathoms it ran SE. by E. 1¼ knots, and at 100 fathoms SE. 1¼ knots. Again, in longitude 192°, it ran at the surface a little S. of E., at 25 fathoms three-quarters of a knot SE., and at 30 fathoms seven-eighths of a knot S. 5° W.

It is to be observed that the lines run by Captain Belknap and by the Venus are not exact sections of the narrowest part, extending in a northwesterly direction from Attu Island, but that the first extends from about longitude 200° and latitude 50° to Agattu Island, and the second in a slightly irregular line extending from Avatcha Bay to the intersection of the meridian of 185° with the parallel of 50°.

In the same region, all the currents observed by Onatsevich were southerly, with a westerly deviation; those observed on the voyage of the Venus were southerly, generally with an easterly but sometimes with a westerly deviation, with one exception of a weak current in a direction N. 59° E., of three-tenths of a knot. Between Saint Paul Island and Attu, Bailey, in the Rush, observed almost continuous S. by E. currents varying from half to nine-tenths of a knot per hour. The currents along the coast of Kamchatka observed by Lütké and Onatsevich ran in almost all conceivable directions, often, in nearly the same spot, in opposite directions at different times, showing clearly the influence of tides.

The following table shows the observations for current and temperature taken by the two expeditions above noted, Belknap's observations[1] extending from July 7 to 14, and those of the Venus from September 16 to 29; the latter, from the time of year, should show higher temperatures as a whole than the former, as is in fact the case.

[1] Deep-Sea Soundings, p. 46.

Comparison of the observations of the Tuscarora and the Venus.

Belknap's W. meridian °	200	198	197	196	195	194	193	192	191	191	190	189	188	187	187	186
′	20	52	40	37	30	35	34	38	50	0	18	32	45	58	19	46
Surface Temp. Fahr.	42.6	43.8	43.1	42.6	45.0	46.3	46.1	45.0	46.4	47.2	47.2	46.7	46.4	46.0	46.2	45.9
Surface Temp. Cent.	5.9	6.7	6.2	5.9	7.2	7.9	7.8	7.2	7.8	8.4	8.4	8.2	8.0	7.8	7.9	7.7
Dir. of current	S.	N. 25 E.	......	N. 25 E.	......	S. 40 E.	E. 25 N.	......	E. 18 N. to S. 5 W.	......	......	......	......	......	......	......
Rate per hour	0.37	0.5	......	0.5	......	1.25	0.5	......	0.5 to 0.87	......	......	......	......	......	......	......
Rate per hour	......	......	0.2	......	0.3	0.3	......	......	0.6	......	......	0.8	......	......	......	0.6
Dir. of current	......	......	S. 79 W.	......	N. 59 E.	S. 77 E.	......	......	S. 17 W.	......	......	S. 53 W.	......	......	......	S. 16 W.
Surface Temp. Cent.	10.8	11.5	11.6	11.6	11.6	10.8	10.0	9.8	10.0	9.7	9.3	9.4	9.4	9.2	8.8	9.0
Surface Temp. Fahr.	51.4	52.7	52.9	52.9	52.9	51.4	50.0	49.6	50.0	49.5	48.7	48.9	48.9	48.6	47.8	48.2
Venus W. meridian °	199	198	197	[196	195	194	[193	[192	191	[191	[190	189	[188	[188	[187	186
′	12	4	17	30]	37	18	30]	30]	23	0]	30]	29	45]	0]	15]	38

The positions in brackets are interpolated (by means of the hourly observations) between the noon positions given in the original. Belknap's interpolated positions appear in the original table.

At the time when Captain Belknap was getting temperatures from 42° to 47° (5°.6 to 8°.3 in the path of the hypothetical warm branch of the Kuro Siwo, the United States Coast Survey were finding between Unalashka and Saint Paul Island (where nobody has ever imagined any warm current to exist), in the eastern part of Bering Sea, temperatures from 49° to 54° (9°.4 to 12°.2), while the mean for the same month, in Norton Sound, some seven hundred miles further north, already reached 56° (13°.3), with a maximum of 60° (15°.6).

On a track chart issued by the United States Hydrographic Office (at an unknown date), of the United States North Pacific Exploring Expedition, under Captain (now Admiral) John Rodgers, in 1854–'56, on the track of the Fenimore Cooper, from Avatcha to Attu Island, arrows are marked pointing in a NW. and NNW. direction. Although no explanation is appended, I take these to indicate the currents observed, though they are without any figures indicating direction or rate. A little further south is the track of the John Hancock, from Paramushir Island of the Kuril group, toward San Francisco. On this track the current arrows for the same meridians point southward without exception. The first series were taken in July, the second in September. It is much to be regretted that the records of this expedition have never been made public. The uncertainty, indicated by the two series above mentioned, in the direction of the currents observed here, strongly recalls the words of Lütké, before quoted, in regard to the same locality.

The accompanying chart, showing the various currents observed in Bering Sea, will give an idea of their variety, which could not be attained by any mere verbal description; it will be noticed, however, that the majority of them tend southward.

My own conclusion, from a study of the data, is that the general tendency of the water in Bering Sea is to the southward, and where deep enough, as in the western part of the sea, it forms a tolerably well defined current (which I shall call the Kamchatka[1] current), whose outline is clearly perceivable in the Challenger section, whose influence is traceable in many of the Pacific Mail voyages before mentioned, and whose character and motion are probably very constant, if not especially pronounced. While a certain amount of water enters Bering Sea through the strait, under favorable circumstances, this amount is relatively insignificant, and the Kamchatka current can hardly be properly termed a polar current. It is a current proper to the cold, deep basin of that part of Bering Sea west of the shoal waters, and to a great extent re-enforced by precipitation and the river supply from the two continents.

[1]Though not the Kamchatka current of most hydrographers, which forms only a very small part of the one under consideration.

Over this, and forming a thin and entirely superficial stratum, the waters from the north edge of the Pacific and the southern border of Bering Sea, warmed by the heat of the summer season, have a general motion of translation northward wherever unimpeded, but this motion is not that of a persistent current, strictly speaking, and is liable to be at any time reversed by winds, and near the shore by tides. Moreover, this water does not appear from the evidence to attain a temperature sufficiently above the normal for it to have any exceptional effect on the climate, and it is unquestionably much cooler than the waters of the shallows in the eastern part of the same sea during the summer. There is not a particle of evidence to show that any mass of warm water constituting a warm current, as distinguished from a superficial stratum as above described, is given off in the direction of Bering Sea by the Kuro Siwo, or enters that sea from any source whatever. The merely superficial character of the water above 40°.0 between the meridians of 185° and 200°, is clearly shown by Belknap's section (Profile C), which, however, requires to be platted on a map, in order that its relations may be clearly understood.

Beechey remarks that, in June, after passing latitude 40°, on his voyage from the Sandwich Islands to Avatcha Bay, he had no current of consequence. Between Avatcha and Saint Lawrence Island, in all, the current only amounted to 31 miles, in a S. 54° W. direction. Lütké has already been quoted so far as his remarks relate to this locality.

Trollope, in writing up the nautical observations for the Herald's voyage (Kellett commanding) observes that going and returning they found, between Avatcha and Saint Lawrence Island, a current of about 9 miles a day in a direction S. 60° W.

The report of Brossal on the sea temperatures of the voyage of the Venus assumes the existence of a warm current from the fact that they found the temperature falling from 10° and 12° C. in longitude 194° W. to 8° and 9° C. But an examination of the log shows this change to be simultaneous with a change in the wind from southerly to northerly, and a record of the currents for that special locality shows that the lower temperature was coincident with both northwesterly and southerly currents, while the higher temperatures accompanied weak drifts, both easterly and westerly in direction.

The voyage of Krusenstern (1804–1806) in the Nadeshda[1] affords a few current observations in the region under discussion. The thorough scientific method of this author renders the observations worthy of preservation, though in most cases others, especially Lütké and Onatsevich, have more lately traversed the same seas.

On his way to Kamchatka from the Washington Islands, in July, 1804, in latitude 38° 44′, longitude 195° 05′, he encountered the Kuro Siwo running N. 46° E., with a rate of half a knot an hour. Thence to latitude 49° and longitude 199° 34′ he encountered moderate southerly and easterly currents. Subsequently the following observations were made:

Date.	Lat. N.	Lon. W.	Current.	Strength.
	° ′	° ′	°	
July, 1804	50 39	199 12	S. 65 W.	0.20
	51 53	199 30	N. 53 E.	0.20
	52 27	200 07	S. 36 E.	0.24
September, 1804	50 28	201 12	S. 46 W.	0.5
	47 37	202 00	S. 49 E.	0.3
April, 1805	48 24	215 53	None.	0.0
	47 39	215 16	S. 45 W.	0.5
	48 18	214 08	N. 83 E.	0.7
	48 37	212 01	N. 61 E.	0.4
	48 02	207 07	S. 57 E.	0.2
	49 34	205 22	S. 73 E.	0.9
	49 19	204 11	N. 83 E.	0.2
	50 38	202 03	South.	0.5
October, 1805	50 46	197 11	S. 75 E.	0.5
	51 34	199 13	S. 52 E.	0.7

From latitude 47° 37′, longitude 202°, in September, 1804, sailing toward Japan, to latitude 40°, when the northern edge of the Kuro Siwo was reached, Krusenstern encountered no currents

[1] Original German edition, vol. iii, various tables.

or only light northerly drifts not exceeding three miles a day, or less than the ordinary uncertainties of a sea position. In October, 1805, sailing from Kamchatka to China, from latitude 50° 46′ and longitude 197° 11′, southward to the Kuro Siwo, similar currents of four miles a day or thereabouts were experienced running in a northerly, northwesterly, or easterly direction, very much as the prevailing winds indicated.

On the same subject, Onatsevich[1] (l. c., p. 102) says that the surface water along the east coast of Kamchatka in spring and early summer may have, from melting snow, river freshets, and the cold outflow from Holy Cross Bay, a slight southerly set, with a temperature of 41° (5°.0), but later in the summer or early autumn this becomes imperceptible, or is replaced by a northerly drift of warmer water; that, nevertheless, whatever conclusions be drawn from the observations yet taken, there remains a certain number which are contradictory of the others.

The following notes by whalers are of interest, and worth recording:

Ship Jireh Perry, May 19, 1874: Ship 10 miles off Cape Navarin, becalmed, found a two-knot current setting westward; this continued three days, with light westerly winds.

Ship Jireh Perry, May 25, 1874: latitude 63°, longitude 177°, between Cape Thaddeus and Saint Lawrence Island. "Breezed up from the southward, current set ENE., at close of daylight hove to in loose ice." May 26: "Ice closed tight all day, wind shifted to E. and NE.: found that current changed to the westward; very little of it any way."

Bark Three Brothers, April 29, 1877: latitude 59° 45′, longitude 185° 57′, off Cape Oliutorsk; on this and the two succeeding days drifted 30 miles to westward, while making every endeavor to keep to the eastward. The wind was northeasterly.

Bark Three Brothers, May 29, 1877: latitude 58° 31′, longitude 188° 56′, near Cape Oliutorsk, came up with the ice; have a westerly set of one-half knot per hour. Wind very light.

Bark Three Brothers, June 5, 1877: latitude 59° 24′, longitude 183° 54′, found a strong current setting southwest, with fresh SE. wind.

Bark Coral, May 13 and 14, 1878: latitude 60° 50′ to 60° 36′, longitude 181° 40′ to 182° 10′ (near Cape Navarin); ship fast in the ice; barks Pacific and Helen Mar in company, all fast in the ice; wind fresh to moderate, from ENE. and NE.; drifted 23 miles SW. in twenty-four hours.

Bark Coral, June 5, 1879: latitude 63° 20′, longitude 179° (near Cape Thaddeus); wind light NNE. "Much current, setting SSW."

On the eastern side of Bering Sea, numerous large rivers pour the annual precipitation of an immense area into the sea, and, in addition to the westwardly and northwardly marching tide, create a distinct set in the vicinity of their mouths. This will be more or less directed by the local winds. Thus the current from the Yukon, noted by Bailey and Hooper, in a calm would proceed in a northwesterly direction, and with southerly winds, rising tide, or both, would be thrown into the gap between Saint Lawrence Island and Cape Rodney. In times of northerly winds or ebb tide, or both, part of it (perhaps, in extreme cases, all) would pass to the southward of Saint Lawrence Island, and be spent in adding to the general SW. set of the Bering Sea waters. The Kuskokwim and Bristol Bay rivers discharge more to the southward, the result being a SW. or SE. set of the waters near them, according to the prevailing wind and tide. This general southerly set of the SE. part of Bering Sea, observed by various navigators, is the basis of the "Behring Current" of Becher, Labrosse, and other hydrographers, which they (wrongly in my opinion) derive from Bering Strait. It occupies the region to which some have transferred the northerly "branch of the Kuro Siwo," when the western passage between Saint Lawrence Island and Asia, having been investigated and found to be cold water, no longer afforded an area for the expansion of that hypothesis.

In evidence of the existence of this tendency, the following notes have been brought together:

Captain Bailey, of the Rush (Report, p. 36, 1880), says that, on passing north from Unalashka toward the Arctic, eastward of the islands (except Nunivak), "We found the general set of the

[1] In 1878 (Coast Pilot of Alaska, App. 1, Meteorology, pp. 20, 21, 23), before receiving the confirmatory observations of Onatsevich, I called attention to the need of proof, before the existence of the supposed northwardly branch of the Kuro Siwo could be safely assumed. I recall this at the present time in view of some premature criticisms published by persons who have not investigated the history of the subject, and who have assumed (without waiting for the promised data, or, apparently, even reading what had already been printed on the subject) that the sole reason for the views advocated here was my limited experience in Bering Strait during the season of 1880.

current to the westward growing stronger from Nunivak to Saint Lawrence Island, and turning more to the northward after passing the latter." "We found on our return * * * about the same current, or, if anything, a little stronger." "Here, as well as in other parts of Bering Sea (away from the influence of the rivers), the current is influenced a great deal by the direction and force of the wind."

Schooner John Bright, June, 1872, cruising north of Saint Paul Island about 80 miles to the edge of the pack. Captain Archimandritoff reports a south current in this vicinity amounting to 15 miles a day. He thinks that the currents in Bering Sea vary with the winds, but in spring usually tend to the SW., rarely toward the E.

Schooner Lizzie Sha, becalmed off Cape Newenham, July, 1870; in twelve hours drifted 35 miles in a southeasterly direction, owing to the current from the Kuskokwim River.

U. S. S. Corwin, June 10, 1880, latitude 59°.03, longitude 169°.07. From Saint Paul Island northerly to noon, as above, experienced a current of one-third of a knot S. ¾ E.

June 13, noon, latitude 60° 41′ longitude 166° 01′. The vessel north of Nunivak Island working N. and E. through ice; Cook Strait, bearing SE. At 11 p. m. anchored to wait for day light; remarked an easterly current of 3 knots. The following day, being kept by the ice in about the same position, noticed that the ice moved with the tide from three-quarters to two knots per hour, NW. in the morning and SE. in the afternoon. On the following day, drifting with the ice, in about the same position, about half a knot per hour S. and E. in the morning, N. and W. in the afternoon; on the 16th and 17th, much the same.

U. S. S. Yukon, while running toward Plover Bay from Saint Paul Island, with strong easterly winds, experienced between latitude 63° and 65°, and in about longitude 175°, a set which amounted to about 50 miles in two days in a direction N. 70° W.

The U. S. S. Yukon, September 20 to 23, 1880, while sailing from Saint Lawrence Island (Southeast Cape) to Saint Mathew Island, experienced on the first day with a fresh SE. to SW. wind a SW. current of three-quarters of a knot per hour, with a temperature of 41° to 43° (5°.0 to 6°.1). In the same locality the U. S. S. Rush, Captain Bailey, had experienced a SW by W. current of a third of a knot on the previous year. On the second and third days with a strong westerly wind the current averaged two-thirds of a knot per hour in a S. 46° E. direction. In this vicinity Lütké had observed a quarter knot S. 48° E. current many years before. The temperature averaged 41° to 42° (5°.0 to 5°.6). The following day, September 23, on leaving Saint Mathew for Unalashka, a current of S. 44° E. of more than a knot an hour was experienced, water 41°.5 to 43°.5, the wind being strong NW. In about the same locality the Rush had had a strong southerly and easterly current the previous year, and on another occasion a southerly and westerly current of about a third of a knot. Variable as they are when acted on by wind, it would seem evident that there is a southerly tendency in this part of Bering Sea, which some hydrographers have indicated under the name of the Bering current. In the same region, and nearly at the same time, the Corwin was running from near Cape Nome in Norton Sound to Saint Paul Island and also experienced an easterly set, though she was not able to get observations to exactly determine its amount or direction, and found the water varying from 38° to 44° (3°.3 to 6°.7), the latter near Saint Paul. Knowing that September is the midsummer of the Pacific, and especially of the Kuro Siwo, if any such branch as has been asserted passed east of Saint Lawrence Island it is incredible that these temperatures should be so low. The entire practicable path of any such branch or warm current has been crossed by the Corwin, the Rush, or the Yukon, in every summer month, and the presence of water warmer than 45° (7°.2) in either of the passages separating Saint Lawrence Island from America and Asia has not been detected, while it has been demonstrated that in Norton Sound the water exceeds 55° (12°.8) for months at a time (even reaching 60° (15°.6) on occasions), while the temperature of Kotzebue Sound and the vicinity of the shore between the two sounds ranges hardly 5° less. The hypothesis of a submarine warm current can hardly be seriously held when it is known that the total depth of water does not exceed twenty-five nor average over fifteen fathoms on that side of Saint Lawrence Island.

Leaving the region of the straits for further discussion, we may refer to the general observations on the currents of Bering Sea by Lütké, who remarks (p. 192): "We had very few currents in this sea independent of the prevailing winds. The few exceptions to this rule seem to show that south of the parallel of latitude 60° the current has more tendency to the westward than to any other direction, for we remarked that although east winds always produced westerly currents, westerly winds did not always produce easterly currents. On the Asiatic shore the tendency is to the S. and SW. parallel with the land. But these exceptions, confirmed also by observations by some of the colonial navigators, were, nevertheless, too rare and indefinite to serve as a basis for any well-founded deductions; in general the currents correspond to the winds both in direction and in strength.

"At Saint George Island, however, a steady current of one or two knots from the west is sometimes observed for several days. In the Gulf of Anadyr we found no current, or only a very feeble one, which followed no particular direction. We experienced only once the action of that northerly current which some navigators have found in Bering Strait, on which occasion it took us 22 miles N. 26° E. in forty-eight hours against feeble northeasterly winds. We then found our; selves in the latitude of the entrance of Saint Lawrence Bay, and nearly in the middle of the strait, but during several preceding days we had had in the same place a feeble southeasterly current. In coming from the southeast toward the bay of Saint Lawrence, we also experienced a half-knot easterly current, which may be attributed to the freshets produced by the snows then melting on the mountains about this bay."

Onatsevich also declares that between Cape Chaplin and Saint Lawrence Island there is no warm current, and between Cape Thaddeus and Anadyr Gulf there is no northerly current (l. c.,

The remarks of these various navigators with regard to the westerly currents are especially applicable to the southern border of the sea along the Aleutians, where the westerly set, due to the stronger flood-tide in its march, has been noticed by nearly every navigator who has published on these regions. It also applies to the eastern part of Bering Sea near the great rivers. Beechey remarks (l. c., p. 639) that from Bering Strait to the Aleutians (Unimak Pass) going eastward of Saint Lawrence, Saint Mathew, and the Pribiloff group, westerly currents prevailed, and near the islands ran strong.

Bailey observes in his report (pp. 36, 37), "Here, as well as in other parts of the Bering Sea (away from the influence of the rivers), the current is influenced a great deal by the direction and force of the wind."

It is unnecessary to enlarge further on this subject. It will be seen that every navigator bears about the same testimony, and that, while some of them accept the theory of a warm current from the Kuro Siwo, these do it, not as established by their own observations, but as a supposed fact, which they try to make their observations agree with. The only exception to this is the deduction from the sea temperatures of the Venus's voyage, by Brossal, which, as I have shown, is not supported by the current observations of the same expedition.

It now remains before entering the Arctic basin to review the observations taken on either side south of Bering Strait, and to explain them, if possible, by a rational hypothesis. The first thing which will attract the attention of the careful reader is the testimony of numerous witnesses to a current southward through the strait in the very place where the warm northerly current should by hypothesis exist. Secondly, that in the absence of disturbing influences there is a tidal flow either way, but stronger to the northward, as usual in this region.

My own suggestions in solution of the problem will follow the evidence now quoted or recorded from the observations of my own party.

Commander Trollope, R. N., in his nautical remarks on the voyage of the Herald, Captain Kellett, (Seemann Nar., App., l. c., p. 290), recounts that between the NW. end of Saint Lawrence Island, and Sledge Island, on the American coast, near Cape Rodney, the Herald was set 37 miles S.76° E., in forty-eight hours. Between Cape Darby, Norton Sound, and Bering Strait, the whole amount of current experienced was to 37 miles S.58° W. "Captains King and Beechey both mention a strong northerly current, particularly the former, * * * through the strait. In our own case, both going and returning, we found it the reverse, particularly when leaving Kotzebue Sound for the southward. On each day the effect was so regular that it could hardly have been the effect of accident or error. It would seem from its direction to have *come from the American shore toward the coast of Asia*,[1] where, finding itself checked, it, with increased velocity, found vent between the

[1] The italics are my own.

Diomede Isles and East Cape; it was here we found it in its greatest strength. The daily set is seen in the table,[1] the whole amounting to S. 60° W. 160 miles, or 9 miles a day; the going and returning passage giving somewhat similar results." "When off Saint Lawrence Island, returning from Kotzebue Sound, in October, the current amounted to 22 miles S. 82° E., and, as mentioned before, in August S. 76° E. 37 miles, a sufficient resemblance at different times and under different circumstances to render it remarkable. A discrepancy appears, according to general report, in the currents we met with in the entrance to Bering Strait, and also in one respect in what we ourselves experienced. Captains Cook, King, and Beechey all speak of a northerly current; Sir John Barrow mentions it as a well-known and undoubted fact, but does not state his authority; the one instance in our case was in the boat off Tchukotsky (August 30), where its direction was ENE., true, one to two knots an hour." Beechey says (Voy. App., pp. 637, 638), off Saint Lawrence Island the current ran SSE. seven-eighths of a knot an hour, and on another trial, seven hours afterward, NE. five-eighths of a knot an hour, but between this island and Bering Strait it ran to the northwestward about three-quarters of a knot an hour. To the northward of the strait it takes a more northerly direction, and near the land runs first to the NE. (toward Kotzebue Sound), and then NW. (toward Port Hope).

According to Captain Cook (ii, p. 521), "Between Norton Sound and Cape Prince of Wales we found a current setting to the northwest, particularly off the cape and within Sledge Island. But this current extended only a little way from the coast, nor was it consistent or uniform."

H. M. S. Discovery and Resolution, at anchor in the NW. part of Norton Sound, August 4, 1778, 9 miles E. by S. from Sledge Island, "found that the flood tide came from the east and set to the west." The ebb set to the eastward. "The flood ran both stronger and longer than the ebb, from whence I concluded that besides the tide there was a westerly current (Cook Voy. ii, p. 440). Billings in 1791, S. 75° E., 9 miles from Cape Rodney, encountered, according to Sauer (l. c., p. 243), an east current of half a knot per hour.

United States steamer Corwin, June 19, 1880, steaming into Norton Sound, off the delta of the Yukon, experienced a current in a N. by E. direction. On the 23d, going out of Norton Sound, from 8 a. m. to 12 m., observed a half-knot northerly set. On the following day, being under steam going west, off the mouth of the Yukon River, from 6 a. m. to 8 p. m., "found a strong NW. set or current, with dark-colored water," "surface 38° (3°.3) (Hooper, l. c., p. 9),[2] after which the following successive currents were experienced: 6 to 8 a. m., half knot easterly; 8 a. m. to noon, a three-quarter knot set to WNW.; noon to 8 p. m., NW. current, one to one and a half knots per hour. Thence observations were impeded by the thick fog, but on the 25th, at noon, it was found that the vessel (as a resultant of the various currents she had experienced) had been set N. 70° W. 39 miles since leaving Saint Michaels—the general trend of the Yukon mouths being about N. 60° W., while the tide floods to the N. and W.

July 5 the Corwin passed south through Bering Strait, on the Asiatic side, being compelled to cross over to avoid a floe of ice coming through the strait from Norton Sound, on the east side.

United States schooner Yukon, September 18, 1880, while running from Cape Chukotski, along the north shore of Saint Lawrence Island, with light southerly winds, experienced a current in the direction of N. 60° E. of nearly a knot per hour.

Ship Contest, June 15, 1871, 12 miles NW. (true) from the Diomedes: Vessel in a water-hole, surrounded by ice; drifted NE. 12 miles in three hours, with light SSE. wind.

Ship Jireh Perry, June 2, 1874: Vessel off Plover Bay, the Heads about 10 miles northward; laying off and on under easy sail; much ice in sight; part of the time experienced a two-knot current to ESE; later in day it sets along shore into the strait. Following day much the same; light airs and calms continue. During this forty-eight hours the vessel drifts 50 miles to the eastward in the midst of loose pack-ice. June 4 and 5, vessel in the straits, wind to the eastward, current setting northward. June 7, passed East Cape.

Bark Coral, July 15 and 16, 1878: East Cape bearing SSE. 15 to 20 miles; four other vessels in company, carrying all sail they could bear, working southward against a strong S. wind; could

[1] Unfortunately not published.

[2] N. B.—There is an error in the June table for this and succeeding dates, in "Remarks" column of Hooper's Report.

ma.e no headway, the northerly current running apparently 2 or 3 knots; this current lasted several days, until, on the 19th, a northerly wind sprang up, after twenty-four hours of calms.

Bark Coral, June 17 and 18, 1878: Latitude 64° 50′, longitude 171° 39′; calm or light winds, current setting SW. Same date, 1879: Ship in nearly same position; wind light and variable, current setting NNE. so strong that vessels can make no headway against it southward. June 20, 1878: Ship trying to work to northward abreast of Saint Lawrence Bay, North Head, but making hardly any progress on account of SW. current. June 19, 1879: The same vessel, in the same locality, after strong SW. breeze, worked two days against northerly current, trying in vain to get to SW. That the current away from the ice opens it more than that toward the ice is shown by the fact that, under nearly similar conditions otherwise, in 1878, with SW. current strongest, the vessels entered the Arctic on the 22d of June; while with the NE. current strongest, in 1879, they were unable to enter the Arctic until June 27.

United States schooner Yukon: At anchor SE. from the S. end of the Big Diomede Island, in 23 fathoms, with 75 fathoms of hawser paid out; September 10, 1880, at 7 a. m., wind fresh from NNE. to N. (true), growing stronger later in the day. At 7 a. m. the tide was running to the ENE., and holding the vessel broadside-on to the wind, the current making a nasty short, choppy sea. At 7.50 a. m. the tide slackened, and the vessel swung to the wind. At 8.10 the tide began running to the WSW., and held the port side to the wind as before it had held the starboard; the sea smoothed down almost immediately. At noon the current was running W. by N. at the surface, with a rate of 1 foot per second, or about 1.6 knots per hour. In running hence to Cape Chaplin, no marked currents were experienced, or, if there were any, they neutralized each other. From the Diomedes to Cape Chaplin, the surface temperature decreased 8° or 9°, and through the passage between Saint Lawrence Island and Cape Chukotski the surface did not rise above 40° (4°.4), being 5° or 6° cooler than the waters of Norton Sound, Port Clarence, and the east side of Bering Strait. In August (14th to 16th), when running from Plover Bay toward the Diomedes, a similar difference was experienced.

U. S. S. Yukon, August 15, 1880: Entered Bering Strait; when off Cape Chaplin it fell dead calm; fine weather, and so remained. During a part of the day drifted to the NE. about half a knot an hour for six hours; later, lost this, and remained nearly stationary. Found surface of water 38°.5 and bottom 38°; air, 45°; weather, half clear. During four days of extremely light weather, made only one mile northing above our reckoning. On the latter part of the 18th, during the afternoon, being about 12 miles west of Cape Prince of Wales, a strong tide made from the south, which, against a moderate northerly breeze, produced quite a choppy sea. The temperature of this water was from 48°.5 to 50° (9°.2 to 10°), about 8 p. m. By noon of the 19th we had been set 22 miles north and 2 miles east by this current, which ran about 2 knots while it lasted.

H. M. S. Resolution and Discovery, beating through Bering Strait August 9, 1778, against a fresh NE. breeze, from 10 a. m. to 2 p. m., were unable, even with the assistance of the current, to make northing, and so stood to the westward, beyond the Diomedes. On the 11th, 12 miles from the American coast, N. 16° E. from Cape Prince of Wales, being at the northern entrance to Bering Strait, while anchored, from 6 to 9 p. m., "found little or no current"; wind light, or none.

Captain Clerke, July 4 and 5, 1779, in Bering Strait, was set twenty miles northward during that time, and notes that the same current had been experienced the year before.

U S. S. Corwin in Bering Strait, south of the Diomedes, August 9, 1880, hove to in fog, with gentle SE. breeze. From 4 to 8 a. m. vessel drifted WSW. half a knot an hour in the strait. At 12.45 p. m. anchored, found the current setting NE. by N., about a knot and a quarter per hour, which continued for six or eight hours. These data, taken from the transcript of the log, clearly indicate tidal action. On the 11th of August left Plover Bay for the strait toward evening, in thick fog. From 8 p. m. until midnight, and from midnight to noon of the 12th, a northerly set of two-thirds to three-quarters of a knot was observed. Afternoon (lat. 65° 15′), although still some thirty-five miles south of the Diomedes, it was not noted. The wind was southerly and easterly, very light.

By noon of August 13, having reached about 100 miles north of the Diomedes, the log states that at noon, with light SE. wind, the ice was drifting to the southward. In the evening a sight was had of the high mountains, back of Point Hope 45 miles distant, and by noon of the fourteenth of August a northerly current is recorded of over a knot an hour for the preceding forty-eight hours; but it is probably estimated, since no observations for position at noon were obtained.

U. S. S. Yukon running from Kotzebue Sound to East Cape, owing to bad weather could not accurately determine current experienced, but arrived at the edge of the ice, near East Cape, about 7 a. m. September 5, 1880, the cape itself being clearly visible about four or five miles distant surrounded by rather closely packed drift ice, in large and small pieces. The party then proceeded to take observations for a hydrothermal section of the strait. There was a fresh northwesterly wind blowing, which increased in strength gradually, and during the latter half of the observations produced a rather short, choppy sea. The depths being all small, an ordinary hand lead and line was used in sounding, tested for correction of shrinkage or strain before and after using. The water bottles used for obtaining water from the several depths were of the ordinary pattern and held about a gallon and a half. Instantly after being hauled up this water was allowed to flow into and over a specific-gravity cup of very thin copper, containing a fixed thermometer. This instrument was by Tagliabue, N. Y., metal scale graduated to 110° Fahr., with mercury column, and having a minus correction of 1°.5 (0°.8), the values as read off being too great by that amount, when compared with standard instruments used by the United States Signal Service at San Francisco. The cup held about a pint and a half, and was read at once, the whole thermometer being covered with the water to be tested. This method, by actual test, when the depths are not great, and the time is short and the temperature of the air not greatly differing from that of the water, is far more accurate than any which involves the use of the protected thermometers of Miller-Casella pattern, which necessarily must be used in deep-sea work. They take at least fifteen minutes to come to the temperature of the water, while the naked-bulb thermometer responds instantly.

The temperatures of the surface were taken every ten minutes. Every four or five miles, as determined by patent log, the vessel was luffed to the wind, the log read, the position determined by compass bearings, with standard spirit-compass, on the Diomedes, East Cape, and Cape Prince of Wales, and other visible objects of known position. The water bottle was then sent first to the bottom and then to every succeeding five fathoms less, and finally the surface water and air were tested, and the vessel filled away on her course. Individual soundings were taken from time to time. The air averaged from 38° to 43° (3°.3 to 6°.1), the sky was cloudy, the atmosphere pretty clear, except for an occasional spurt of fine rain.

Eight serial temperature stations were occupied, seven in a nearly direct line across the strait, when it became necessary on account of shoal water to run to the southward and obtain the last as near the American shore as the depth of water would permit.

Table of temperatures.

Depth of serial temperature.		Serial temperatures at stations and of intervening surface.															
		I.	Surf.	II.	Surf.	III.	Surf.	IV.	Surf.	V.	Surf.	VI.	Surf.	VII.	Surf.	VIII.	Surf.
		°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Top	C	3.1	......	3.0	......	5.1	......	6.2	......	8.1	......	8.6	......	8.9	8.6	8.3	8.3
	F	37.5	......	37.37	......	41.25	......	43.25	......	46.5	......	47.5	......	48.0	47.5	46.87	47.0
5 fathoms	C	3.1	3.3	2.9	3.1	5.1	5.2	6.1	6.7	8.1	8.4	8.7	8.6	8.9	8.7	8.3	8.4
	F	37.5	38.0	37.25	37.5	41.25	41.37	43.0	44.12	46.5	47.25	47.75	47.5	48.0	47.75	46.87	47.12
10 fathoms	C	3.1	2.8	2.8	3.6	4.8	5.6	5.7	7.2	7.6	8.4	8.6	8.6	8.6	8.7	8.1	8.5
	F	37.5	37.0	37.12	38.5	40.75	42.0	42.25	45.0	45.75	47.25	47.5	47.5	47.5	47.75	46.5	47.25
15 fathoms	C	2.8	2.5	2.8	4.3	4.7	5.6	4.3	7.6	7.6	8.4	7.9	8.7	8.6	8.6	8.1	8.6
	F	37.0	36.5	37.12	39.7	40.5	42.0	39.75	45.62	45.75	47.25	46.25	47.7	47.5	47.5	46.5	47.5
20 fathoms	C	2.6	......	2.8	......	4.6	5.3	4.7	7.6	7.4	8.4	8.2	8.7	8.4	8.2	......	8.5
	F	36.75	......	37.0	......	40.25	41.5	40.5	45.75	45.25	47.25	46.75	47.7	47.12	46.75	......	47.25
25 fathoms	C	2.8	......	......	......	......	6.1	......	......	......	......	......	......	......	8.3	......	8.3
	F	37.12	......			......	42.87	......	......	......	......	......	......	......	46.87	......	47.0
Bottom	C	3.1	......	2.6	......	4.2	......	5.4	......	7.4	......	8.0	......	8.2	8.0	8.0	......
	F	37.5	......	36.75	......	39.5	......	41.75	......	45.25	......	46.5	......	46.75	46.37	46.37	......
Depth of sounding		28 f.		26 f.		5 f.		26 f.		26.5 f.		28 f.		25 f.		23 f.	
Minutes of interval			10		10		10		10		10		10		10		15

The serial temperatures at each station (I–VIII) were taken in one spot, beginning with the bottom temperature and working as rapidly as possible; the time employed for each full station being about 11^{m}.3. The surface temperatures were taken every even ten minutes between the stations; the intercalary columns of surface temperatures above begin at the top. Those taken after leaving Station VIII were taken every quarter of an hour, running for Port Clarence, and terminate at its entrance.

The following table exhibits the currents experienced as shown by the vessel's drift:

From station.—	By reckoning.		By observation.		Time of run.	Hour of luffing. h. m.	Current.		
	Course.	Dist.	Course.	Dist.			Dir.	Dist.	Rate.
	°		°		m.	a. m.	°		
I	E. 21.8 S.	......	....	......	....	7.05	....	......	......
To II	E. 21.8 S.	4	E. 21.8 S.	10.50	40	8.00	E. 21.8 S.	6.7	3.4
II to III	E. 21.8 S.	4	E. 21.8 S.	4.20	38	8.50			
III to IV	E. 21.8 S.	6.5	E. 10.7 S.	5.50	50	9.50	N. 24.3 W.	1.53	1.5
IV to V	E. 21.8 S. E. 33.1 S.	2 4.5	E. 44.4 S.	5.75	40	10.50	W. 28.3 S.	1.72	1.7
V to VI	E. 33.1 S.	6.75	E. 3.6 S.	7.75	50	11.50	N. 33.3 E.	3.82	3.8
VI to VII	E. 44.4 S.	6.0	E. 57.1 S.	8.00	50	12.50	S. 1.3 E.	2.52	2.5
VII to VIII	S. 0.6 E.	12.0	S. 9.2 W.	11.00	71	2.15 p. m.	W. 31.0 N.	2.20	2.2
Total	S. 45° 41′ E.	40.75	S. 49° 32′ E.	44.011	7 h. 10 m.	....	E. 1.35 S.	4.35	0.6

The directions in degrees and tenths corrected for variation of the compass; the distances in nautical miles and tenths. The particular soundings will appear on the accompanying sketch map of the strait; the details of the temperatures in the section and in the preceding table. The totals above are the resultants of the whole run.

It will be observed that the drift, except that preceding Station III, is in alternate directions, and the several drifts so compensate each other that only the easterly current is left. I believe that we met the falling Asiatic tide at its greatest strength at East Cape; that opposite the Diomedes we encountered an eddy (Station IV); that we then encountered the falling tide (nearly done running) from the American side (Station V); that at Station VI, or thereabouts, the rising tide drifted us northeastward; while, on approaching the shoal water near Station VII, we encountered another eddy; and that the set encountered between VII and VIII was due to the rising tide coming around Cape Prince of Wales.

Too much stress must not be laid on these observations, for it is evident, considering the short distances run and the strong breeze, that they are liable to error both in amount and direction, and consequently in rate. Their general tendency, however, may justly be considered as having some weight.

Much more extended observations must be taken and continued over the summer months, to which must be added a better knowledge of the tides, before we can be said to have a sufficient fund of information upon the complicated currents of the strait.[1] Observations from a fixed point are alone satisfactory. The preceding notes and quotations show, however, that opposing currents exist in the strait at different times; that there is a gradual decrease in warmth of water from near the American side over toward Asia; that the verticality of the isotherms, as shown in the section, apart from other concurring circumstances, indicate there is no reason to suspect any submarine current of cold water; the strong northerly and southerly currents have been experienced on both sides of the strait by various navigators; and therefore, without further proof, it is unsafe to assume, in opposition to the present evidence, that a cold current runs south on one side while a warm one runs north on the other. What, then, is the explanation of these facts? My own opinion

[1] It should be noted that in the sketch maps engraved for the article in Petermann's Mittheilungen and that in the Am. Journal of Science, the meridians are laid down from the original computations based on one chronometer. This proves, on the final revision and application of seven chronometers (not then available), to be one minute (approximate) too far east. The true meridian of the boundary line bisecting the strait between the Diomedes is 168° 58′ 05″ W. ± 39″, and the discussion of the data will be found in the Supplementary Note to this article.

of them, subject to modification with greater knowledge, is about as follows: A glance at the chart shows that the eastern coast of Asia, bordering on the strait, is deeply indented by bays, the headlands of which are bold and projecting. The American coast, on the contrary, is smooth, and the action of the current has nearly closed the single indentation at Port Clarence by the formation of a long and narrow gravel spit, along which the tides run as if the coast were continuous. The opening would doubtless long since have been closed were it not that a considerable river discharges itself into Grantley Harbor at the head of Port Clarence. There are no rivers of any consequence on the Asiatic shore, and the rocks are of a much harder nature, and the currents are much weaker; hence the spits formed on that side are small and insignificant.

The still water between the headlands of the Asiatic side remains ice-bound long after the center and American side of the straits are clear, as there is no current to carry away the ice, and it is sheltered from heavy winds. Even after the ice has melted, if any is brought into the strait from north of East Cape by northerly winds and by the tide, it is carried into these bays, and may remain there during the remainder of the season. The water in these bays and their vicinity is thus kept cool; the air from the ice cools the immediately adjacent shore; the warm water from the American side, being (as I suppose) moved chiefly by the tides, rarely has persistence enough in motion westward to reach these recesses, and is repelled and limited (as Weyprecht has shown to be the case elsewhere) by the stagnant ice; the great freshets of the Yukon and other American rivers (these lasting about three weeks), which strew all these coasts with drift-wood, are in most cases long past before the ice barrier is melted, so that on this Asiatic coast, as compared with the American coast ninety miles away, the climate is colder, the vegetation less luxuriant (this also partly on account of difference in soil), and the drift-wood is prevented from landing, and carried farther north or south—being found abundantly in either direction.

We have seen that the tides on the American side march north and west; that the current of the Yukon, observed by Hooper and others, runs in a N. 70° W. direction; we know that the form of the earth and the prevalent southerly winds of summer combine to make the northerly tendency stronger than that in the reverse direction; we know that on certain occasions the tidal flow has been distinctly noted in the strait, and that currents in opposite directions have been there observed by different navigators. I conclude from this that the current through the strait is a resultant from these forces, and that its temperature in its warmest part is due to the movement of the warm waters of the Yukon, of Norton and of Kotzebue Sounds oscillating back and forth with the tide. We have shown definitely that the warm water cannot be traced into the bed of Bering Sea, but exists only in the shallows, and that it grows rapidly cooler as we pass northward, so that at Point Belcher we have, under ordinary circumstances, only the ordinary Arctic Ocean temperatures for the particular season of the year.

I consider, therefore, that this temperature of the water (like the high midsummer temperature of the lower Yukon Valley) is a strictly local phenomenon, though it has, as was observed in the Appendix I to the Alaska Coast Pilot, as much effect upon the vicinity of its location while it lasts as if it had been gathered in the China Seas and transported thither.

To descend to details, it is supposable that the rising tide and Yukon current, when not otherwise disturbed, would strike the Asiatic coast after passing Saint Lawrence Island, south and west of Cape Chaplin, and as far as Chukotskoi Noss, and would be by that land turned to the northeastward, thus producing the notable current so often observed just off Cape Chaplin, but whose force, as we ourselves observed, does not extend very far from that cape. The main part of the current northerly through the strait is produced by that part of the tide which hugs the shore of the peninsula north of Norton Sound, as has been so many times observed. This runs very strong off Cape Prince of Wales, and follows the shore around into Kotzebue Sound, and reappears for a short distance with a strong set off nearly every prominent headland on the American side, such as Cape Krusenstern, Point Hope, Cape Lisburne, etc., at each of which a spit formation drifted two ways (by the flux and reflux) is observable, either above or below water.

On the Asiatic side the falling tide rushes with great force SE., past East Cape.

As has been pointed out, the form of the land interferes with the existence of much current SW. from that promontory.

The ratio of the two currents around Cape Prince of Wales is probably pretty well measured by the length of the submarine spit-shoals due to their respective action. The ratio of the flood spit to the ebb spit is as 45 to 34, or $7\frac{1}{2}$ to $5\frac{3}{8}$ miles.

They are about equal at Point Hope, with a tendency to preponderance of the ebb. At Cape Lisburne the flood spit is much shorter than at Cape Prince of Wales, but there is no ebb spit indicated on the charts. At Icy Cape they are about equal, while at Point Belcher and Point Barrow the ebb spit is almost lost sight of. These are indeed but rough approximations, since neither the surveys nor the conclusions from them have claims to much precision; still they agree, for the most part, with the deductions from other data.

We will now consider observations bearing first on the region north of the strait on either coast, then on the Arctic in general and the Point Barrow region in particular, before summing up the conclusions from the investigations as a whole.

U. S. S. Corwin, August 30, 1880, off Cape Krusenstern, Kotzebue Sound, at 8 p. m., anchored and observed NW. $\frac{1}{2}$ W. current of $1\frac{1}{4}$ to $1\frac{1}{2}$ knots per hour. Wind fresh from ESE. On the following day, a few miles east of the cape, observed a similar current.

U. S. S. Corwin, July 29, near Cape Blossom, Kotzebue Sound, current in a. m. setting to the northward along shore about 1 knot per hour; wind moderate from S. and W. Following day running to the eastward, against a fresh SE. gale, along south shore of Kotzebue Sound, etc.; during first twelve hours a three-quarter knot current NNE. was experienced. On the 31st, having run in a nearly northerly direction from lat. 65° 30′ to Point Hope, find that in running this 100 miles they had experienced about nine miles current in a northeasterly direction, a strong SSE. gale blowing at the time.

Bark Vigilant, Captain Smithers, in July, 1879, off Cape Thompson, experienced a strong SE. current for ten hours; with a fresh NW. wind to beat with, could make no headway against it.

U. S. S. Corwin, July 28, 1880: On arriving at Cape Thompson the difference of reckoning showed considerable northerly current, but the amount and exact direction are uncertain, as the steamer had twice crossed a large part of the Arctic Sea between Herald Island and Point Hope within a week and had had no satisfactory observations for several days.

Observations off the coast of Asia.—Ship Jireh Perry, July 3, 1874: latitude 68°, longitude 176°; light airs and calms; ship among the loose ice off Koliuchin Bay, and cannot get out on account of the strong westerly current.

U. S. S. Corwin, latitude 68° 18′, longitude 171° 28′. August 7, 80 miles north of the Asiatic shore, near Serdze Kamen. This day having been passed working to the eastward in thick fog, an E. by N. current, somewhat less than a knot per hour, is recorded, probably an estimate, since no observations for position had been had since leaving Herald Island. Eighteen miles south of this locality Rodgers, in 1855, experienced a half-knot current in a W. by N. direction. Large quantities of drift-wood were seen hereabouts by the Corwin and by Onatsevich, which is worthy of notice, as it is frequently asserted that no drift-wood is found on the Asiatic side. On the 8th the Corwin steamed through the strait, finding a strong northerly set between the Diomedes. Before reaching the strait, by bearings on the land, an E. by N. set of 44 miles was found to be the difference between the reckoning and position by bearings during the preceding 48 hours. As no position had been obtained since leaving Herald Island, and the course had been irregular along the edge of the pack, both distance and direction of the set are subject to more or less error, and, in any case, only represent the resultant of currents over a distance of 240 miles.

Observations in the Arctic in general.—Captain Clerke, July 12, 1779, in latitude 68° 41′, longitude 170° 39′, with moderate southerly breeze, found current setting NW. half a knot per hour. A W. one-half S. current is recorded by Rodgers in 1855 in about the same locality, having about the same strength.

Bark Coral, September 5, 1879, latitude 70° 35′, longitude 175° 30′. "Fine whole-sail breeze from NNE., and clear weather. Ship working to the north between two packs of ice" in a water-lane 15 to 20 miles wide, "five or six ships in company. Saw Herald Island bearing N. 45 miles distant at 4 p. m. Lay by over night under easy sail." September 6: "Fresh breeze from NNE. and NE.; ship under easy sail working to the northward and eastward in the leads of water, as yesterday." "Herald Island in sight, about 30 miles distant. Find a current setting to the northward. Twenty vessels in sight. Heard that Bennett's steamer (the Jeannette) was seen by the Sea

Breeze three or four days ago steering to the northward. Had some fog to-day, but not continuous. Lat. 70° 45′ at noon." The weather of the 2d and 3d is reported as "foggy with snow squalls, light and baffling airs, the fleet working to the westward and SW." along the pack ice.

U. S. S. Corwin, latitude 70° 39′, longitude 175°: Near Herald Island, July 26, 1880, wind fresh, southerly and westerly, experienced a half-knot current to southward.

U. S. S. Corwin, latitude 69° 58′, longitude 173° 47′, July 25. No time observations, but a southerly current indicated by the difference between the observed latitude and the reckoning.

U. S. S. Corwin lying-to in thick fog about 35 miles southward from Herald Island. July 27 experienced from 1 to 4 a. m. half-knot current to SW., then shifted, and from 4 to 8 a. m. ran to NW.; wind light, variable.

U. S. S. Corwin, August 4, 1880, latitude 71°, longitude 174° 40′. In a. m., 40 miles SE. from Herald Island, experienced a strong current setting to S. and E. Wind fresh from S. and W.

U. S. S. Corwin, from 15th to 20th of August, east from Herald Island, working toward it through the pack. On the 16th, 4 a. m. to 7.45 a. m., wind light NE., vessel hove to in the fog, drifting to the SE., passing through heavy drift ice. On the 17th, 10.20 a. m., sent an officer with a boat to examine drift of ice along the edge of heavy pack; returned at 10.30, reporting the ice to be drifting SSE. three-quarters of a knot per hour. At 10.45 Herald Island bore SSW. 10 miles distant; wind NE., light. In the evening came to anchor about 7 miles east of Herald Island and tested the current, which proved to be about SW. half a knot, the wind as before, but lighter. On the 19th, at 1.25 p. m., got out the boat and found the current setting south three-quarters of a knot per hour; wind northerly, light. On the 20th, at 10 a. m., found same current, with light NW. wind. The general drift of the ice in this vicinity, according to Captain Hooper, is to the southward, from one-quarter to three-quarters of a knot per hour, but it is to a certain extent controlled by the wind (l. c., p. 36).[1]

U. S. S. Corwin, from 42 miles NW. of Point Hope, September 9, 1880, steering NW., noted a current setting NW. one-third of a knot; this continued until noon of the 10th, 180 miles NW. from Point Hope.

U. S. S. Corwin, 40 miles SW. by S. half S. from Herald Island. September 11, "found a strong easterly set for the first time" (Hooper, l. c., p. 49). Running thence direct to Point Hope in the afternoon, and on the following day made the point at 9.10 p. m., the landfall showing an E. by N. one-half N. current of 47 miles during the last thirty-three hours as the resultant of the currents, etc., experienced in running from Point Hope toward Herald Island, some 250 miles and return.

Captain Cook, August 21, 1778, when 12 or 15 miles north of Cape Sabine "sent the master in a boat to try if there was any current; but he found none." The weather was nearly calm.

Captain Cook (ii, p. 521) has the following remarks on the tides and currents of this region south of Icy Cape, which was his farthest north in 1778:

"The flood comes from the S. or SE., everywhere following the direction of the coast to the northwestward." "To the north of Cape Prince of Wales we found neither tide nor current either on the American or on the Asiatic coast, though several times looked for."

Captain Clerke, on the 20th of July, 1779, 15 or 20 miles N. of the coast near Cape Lisburne, with an ESE. wind, experienced a current of a knot an hour to the ENE., which seems to have come on suddenly with "the wind lessening." He further remarks, in regard to the currents of this part of the Arctic Sea, in general, "we found them unequal, but never to exceed one mile an hour. By comparing the reckoning with the observations we also found the current to set different ways, yet more from the SW. than any other quarter; but whatever their directions might be, their effect was so trifling that no conclusions respecting the existence of any passage to the northward could be drawn from them" (l. c. iii, p. 276).

U. S. S. Yukon, at anchor N. of the shore some 10 miles eastward from Cape Lisburne, August 21 and 22, 1880. During the twenty-four hours passed at anchor here, the current ran steadily to the W. and S., holding the vessel broadside to fresh SSW. and SSE. breezes. Toward evening an eddy ran in the opposite direction close in shore near the beach.

U. S. S. Yukon, at anchor 20 miles eastward of Cape Lisburne, during a calm on the afternoon

[1] See Supplementary Note.

of August 22, 1880. While at anchor the vessel tailedto th e W. and S., but the current seemed very moderate.

U. S. S. Yukon, at anchor 5 miles SW. from Icy Cape, from 10 a. m. to 4 p. m., during which time we experienced a northeasterly set of about three-quarters of a knot an hour.

U. S. S. Yukon, at anchor off Point Belcher, August 26 to 28, 1880, experienced a strong northerly current here, especially with the tide flowing. During the ebb the vessel swung to the wind, which was fresh NE.; but during the flood the current held her broadside to the wind. The rate of the current seemed to be about three-quarters of a knot during the flood tide.

U. S. S. Corwin: August 22, 1880, 45 miles NW. from Icy Cape, set of current half a knot to the northward and eastward. Wind variable, easterly. On the 23d, near Wainwright Inlet, observed an E. by N. current of three-quarters of a knot.

Ship Contest, August 5, 1871, 3 miles SW. from Icy Cape. Ice drifting SW. about one and a half knots per hour; strong breeze from N. and E.

U. S. S. Corwin, between Point Belcher and Icy Cape, August 27, 1880, standing to the westward along shore, encountered an easterly current of about a knot an hour; wind light, easterly.

Bark Coral, September 11, 1879, latitude 69°, longitude 173° 15′, near Cape Lisburne. "Airs light and baffling, with falling barometer and SE. swell, find current setting to W. and NW."

U. S. S. Corwin, near Cape Lisburne, July 31, 1880. Off the coal mine at anchor; experienced a NE. ½ N. current, of three-quarters of a knot an hour in the morning. The following day, in same locality, strong SSE. and S. gale, the current ran two knots to northward and eastward, and so continued until the afternoon of August 2, when the wind abated, and the Corwin sailed for Herald Island.

U. S. S. Corwin, near Cape Lisburne, at the coal mine, July 23, 1880, experienced strong N. and W. current; wind mostly southerly, variable.

U. S. S. Yukon, near Cape Lisburne, August 21, 1880, at 9.30 a. m., anchored in six fathoms; found the surface temperature 49°.1 (9°.5), and the bottom 48°.1 (8°.9); wind light, NE.; sky, overcast; air, 50°.0 (10°.0).

U. S. S. Yukon, off Point Belcher, August 28, 1880, at 8 a. m., anchored in 9 fathoms; found the surface temperature 42°.7 (5°.9), the bottom 41°.7 (5°.4); the air 40°.0 (4°.4); sky, overcast; wind, fresh NE.

U. S. S. Yukon, from 9 a. m. August 28 to 11 a. m. August 29, 1880, in making a straight run from Point Belcher to Cape Lisburne, with a fresh NE. wind, experienced a SW. set of 9 miles during that run. From Cape Lisburne to Point Hope, a distance of 40 miles as run, which took five hours, a set of 7 miles to the SSW. was experienced. The Yukon met the flood tide near Point Hope, where, against the NE. wind, it created white water and a smart choppy sea. Southward of Point Hope the U. S. S. Corwin and schooner Loleta, at anchor, were tailing with the wind, showing that the current was not very strong there. On the 20th of August, running toward Cape Lisburne, we were set 18 miles northward of our reckoning, most of which seemed due to a strong current setting round Point Hope to the northward. Between Bering Strait and Point Hope no indications of current were noticed.

U. S. S. Corwin, at Point Hope, July 21, 1880. Fresh gale from the SSE. starts the ice off the shore, and it passes northward in a current estimated at two knots an hour. On the following forenoon heavy gales continued. Drift-ice passing eastward north of Point Hope, along shore.

Rosser and others quote some rather extended remarks by Surgeon Simpson, of H. M. S. Plover, in 1852, on the currents of Bering Strait and the Arctic. As the author acknowledges "the absence of actual observations for determining the currents of these seas," and proceeds to argue upon suppositions, natural in themselves, but which later investigation and experience have shown to be largely erroneous, the paper does not require extensive criticism. Dr. Simpson supposes "an almost imperceptible set" to proceed between Saint Lawrence Island and the Asiatic coast into Norton Sound, thence to be reflected through the strait "with lessened speed," receiving "a further tribute from Kotzebue Sound, which is very palpable off Point Hope," and then extending in a NE. direction along the coast of America to Point Barrow, whence it proceeds NE. into the Arctic. Through all this course it is subject to retardations and accelerations from favorable and unfavorable winds. He notes that the current in the strait between Saint Lawrence Island and

Asia "is variable, and the passage seldom entirely free from ice until July"; also, that the coast NE. current in the Arctic, southwest of Icy Cape, is less than that sweeping thence to Point Barrow, and there is reason to believe the increase is derived from the waters on the NE. coast of Asia." Much of the preceding agrees with later observations, while it is not necessary to follow this author in his suppositions that the coal, the gravel beaches of the Arctic coast, and the Arctic shells of Icy Cape, "have a southern origin." (Short notes on the wind, weather, and currents * * * of the N. and S. Pacific, by W. H. Rosser, 8°, pp. 120: London, Imray, 1868, pp. 85–88.)

Captain Owen, of the Mary and Helen, and Captain Jerningham, of the Tropic Bird, stated, as the result of their experience, that there were three general sets or tendencies of the water in the Arctic—one from Cape Lisburne along the coast toward Point Barrow, another NW. from Kotzebue Sound by Point Hope to the vicinity of Herald Island, the last along the NE. coast of Asia, from East Cape, north and west. These currents are largely affected by the wind and tides, chiefly by the latter, while the motion of the ice depends more especially, though not wholly, on the winds.

Captain Hooper (l. c., p. 41) observes in regard to the ice: "The ice pack seldom moves more than a few miles off shore, between Icy Cape and Point Barrow, and is likely to close in at any time. A northeast wind, although it blows directly along shore, keeps the ice clear and allows the current to set up past Point Barrow (1). The heavy ice when close in shore stops the surface current entirely (2), and lowers the temperature to 36° (2°.2) or less, so that a vessel working up this shore may readily tell if the ice is on the Point by watching the set of the current and the temperature of the water. If the ice is clear of the shore the current will be setting to northward from one to three knots an hour, with a temperature of 40° (4°.4)."

With all deference to Captain Hooper, whose views are entitled to great weight, it must be conceded that these generalizations are not invariably borne out by the experience of others. 1. The observations of Owen and others recorded here show clearly that at times a strong northeaster reverses the current at Point Barrow instead of letting it set up by the point. 2. Exceptions to this general rule are found in the observations of Pullen in the Plover's boats, and those of Captain Hamill in 1870; the current has been observed by these navigators to run strong up to and under the very margin of the ice. Lastly, in 1880, when the surface water was at 40° at Point Belcher, and running with a good rate toward the NE., the ice was reported to us as on the shore both at the Sea-horse Islands near by and at Point Barrow, forcing the schooner Alaska aground between these places, and coming near to wrecking her.

Observations in the vicinity of Point Barrow.—Ship Contest, August 16, 1871, off Point Collie, one mile of water between the ice and land. Wind light SW., current running NE. 1½ knots. August 19, same place and current, with a light NE. wind.

Ship Jireh Perry, August 2, 1872, latitude 70° 30′, longitude 160° 30′, at anchor at the head of open water. Found current setting to the northward one knot, and off shore loose ice passing with it. Wind, light southerly. August 6, 1872, 10 miles west from Wainwright Inlet, wind strong SW., current strong NE.

Ship Jireh Perry, August 16, 1872, 15 miles NNE. from Point Barrow, at anchor in 22 fathoms. Light airs and calm. Current setting NE. 2½ knots, much loose ice with it; August 17, latitude 71° 40′, longitude 155°, attempted with light easterly winds to work out of the loose ice into clearer water, but current ran so strong that could make little headway southward against it, as the wind was in puffs and otherwise calm. Had to make fast to the grounded ice. Six or seven other vessels were seen in the same predicament August 19, beset in same situation and unable to get out of the pack. Wind westerly and southerly, moderate, ice drifting rapidly to the eastward. August 23 westerly winds, succeeded by light airs and calms. Easterly current nearly ceased and began in shore to run to the westward. Later in the day had fresh easterly winds and the ship worked out of the ice. September 4, beginning 4 miles WSW. from Point Barrow and continuing during the two following days, thence to the Sea-horse Islands, with SSW. and NW. winds had strong ENE. current along shore.

Ship Jireh Perry, July 20, 1873, at anchor off Point Belcher, strong southerly wind and NE. current, which continued strong on the following day, the wind hauling to the westward. July 22, anchored close into Sea-horse Islands, wind W., same current; July 24, light airs from S., and, later, strong breeze from SW., current running 2 knots to NE.

Ship Jireh Perry, July 31, 1873, latitude 71° 20′, longitude 155°, winds from fresh SE. and E. to NE. and N., light, and then calms. There seemed to be very little current at all.

Ship Jireh Perry, August 7, 1873, anchored off Point Tangent in 5 fathoms; sent boats off shore into the loose ice for whales; found on the ice the main hatch combings of Bark Roman, with official tonnage mark and number cut into it. She was lost two years previously in the pack, off shore from the Sea-horse Islands. The distance between the two points is only 120 miles.

Ship Jireh Perry, September 2, 1873, latitude 71° 15′, longitude 154°, wind strong NW., this and previous day gradually moderating. Current running to WNW., ship standing off and on shore in about this longitude all day amongst loose ice.

Ship Jireh Perry, September 8, 1873, working to the eastward, in about longitude 153°, 2 to 20 miles off shore, with fresh ESE. wind, which had blown for thirty-six hours and gradually moderated, encountered strong westerly current and finally anchored in longitude 153° 08′ to hold her ground.

Ship Jireh Perry, September 14, 1873, latitude 71° 30′, longitude 157°, strong S. wind continuing September 15, and then calm; encountered a NE. current of a knot and a half an hour. September 17, 15 miles NW. from Point Barrow, wind S. and SW., current running strong to NE. September 18, same vicinity, Point Barrow W. by S., 8 miles distant, wind shifts to W. and current runs E. September 19, same vicinity, west wind moderated and hauled to NW., current changed to SE., one and a half knots; ship at anchor. September 20, wind W. again; got under way to work to the westward of Point Barrow, and could barely get around the point on account of the head current.

Ship Jireh Perry, September 24, 1873, latitude 69° 48′, longitude 169°. Having been steering W. by S. (true) for forty-eight hours with moderate easterly winds, from vicinity of Point Barrow was carried some 60 miles southward by current during that time.

Ship Jireh Perry, July 13, 1874; NE. breeze, light airs and calm; ship near Point Belcher; a large floe along shore; outside, a strong current was running to the NE. "Saw one of the old wrecks of a whaler lost in 1871." July 14: "Foggy, light NE. wind; at 1 p. m., about 3 miles off Sea-horse Islands, current setting to NE. and E.; ship aback on both tacks, drifting; at 1 p. m., July 15, weather cleared up and found the ship half-way from Sea-horse Islands to Point Barrow, making a NE. drift of some 30 miles for the twenty-four hours." July 25, anchored off Smith Bay, E. from Point Barrow. This and following day "found it difficult to work the ship in a 3 or 4 knot breeze, on account of conflicting currents." July 29, latitude 71°, longitude 152° 40′; calm. Ship fast to the ice and drifting SW. August 3, latitude 71° 10′, longitude 152° 40′; worked to the N. and E. and anchored off shore in loose ice. A variety of winds and strong conflicting tides; later, fell calm, with little current.

Ship Jireh Perry, August 23, 1874, Point Barrow SSE., 14 miles distant; laid the ship aback. Drifted 15 miles SW. during the night; wind NE.; vessel continued in this vicinity; wind shifted to WNW. and NW., but the SW. current continued until the 28th.

Bark Three Brothers, July 12, 1876, anchored SW. from Point Belcher, near the land; wind had been strong from W. and S. for two days, and now died out. Found strong easterly current. July 14, strong easterly wind set in, continuing until the 16th, when the current was observed setting to the WSW. 1½ knots. July 22, at anchor under cover of grounded ice, off Refuge Inlet, 8 miles SW. from Cape Smyth. Strong NW. wind, and current setting along the land 2 knots to the eastward. July 29, at anchor to the eastward from Point Barrow; wind set in from NE., and the loose ice commenced to drift with current to the westward very fast. Same continued to August 3. August 4, the wind moderated, and the current changed and commenced to run "to the NE. very slow." Wind freshened the following day, and the current apparently ceased. On the 9th it is noted, "wind finally settled at SW. The current changed to-day, running to the eastward, having had it running SW. longer than I ever saw it before, no doubt on account of prevailing easterly and NE. winds." August 11, after moderate NW. winds, "wind worked round to the NE. and eastward." Ships were at anchor a little to the eastward of Point Barrow, or cruising east and west of it in open water 3 or 4 miles wide, to the northward. Ice plenty, current running to the NE. along the ice; but running to the westward south of the ice. August 17, "wind hauled to NE.," "current running 3 knots to the westward." August 23, "wind freshened to almost a gale from the westward, and started a strong current to the eastward." August 24, wind "still to the westward"; died out later in the day; "current running fast to the eastward." Next day, light airs; most of the fleet fast in the ice, drifting to the eastward with it very slowly. On the 27th, most of them had drifted past Point Barrow, and on the 28th it breezed up from the SW. and started the fleet and ice drifting quite fast to the eastward, the ships being in great peril. September 1, 1876, the wind changed to the NE., but light and baffling. On the 5th, the loose ice began drifting to the W. and SW., under the influence of light NE. winds, which, on the 6th, backed round to NW. and then fell calm, but started the current again to the eastward. On the 7th, the bark got round Point Barrow to the westward, and anchored in the bend west of the point, close to the shore. On the 9th, ten ships were abandoned in the ice, about 50 miles eastward from Point Barrow, and the men in boats passed Point Barrow, and on the 13th got out of the ice to the bark Florence, leaving the Three Brothers still hemmed in. A fresh gale from ESE., September 15, did not release her, the ice being aground outside of her, but they saw the Acors Barnes (one of the abandoned ships) in the ice 25 miles northward and drifting westward. On the 16th, they were still beset, but saw the abandoned Java drifting to the westward in the ice, 10 or 12 miles north of them. September 17, the Three Brothers and her companion, the Rainbow, got out into clear water, and by this time the wreck of the Acors Barnes had drifted SW. toward them, so that it was only 6 or 7 miles off, but in impenetrable pack. The bark Clara Bell was beset and abandoned about the same time off Refuge Inlet. Sixty men, mostly Kanakas, remained on board these vessels, of whom, since that time, nothing has ever been heard. On the 19th, the Three Brothers sailed for Saint Lawrence Bay, and left the Arctic.

Bark Coral, August 8, 1878, a few miles eastward from Point Barrow, experienced light W. and S. winds which were accompanied with some NE. current; it then fell calm and breezed up from NE., whereupon the current changed to WNW.

Bark Coral, August 21, 1878, at anchor under lee of Point Barrow, to west of it; a strong NE. wind blowing. Boats off looking for whales were unable to return on account of the current, and had to board vessels lying near Cape Smyth, 4 or 5 miles to the SW. The same conditions noted until the 24th (with the remark that the 23d was the 12th day), when the wind died out, the current slackened up; on the 25th, with light SE. breezes, the current changed to northerly and the vessels shifted to the east side of Point Barrow to get out of it; on the 28th the SE. wind died out and the current changed, running to the westward, on account of which the vessels shifted again to the lee side west of the point. August 29, wind from westward and WNW. Ship at anchor west of Point Barrow; "current setting to the eastward and ice passing the point all day." This continued unchanged until September 7, during which time the ship was on the lee (east) side of Point Barrow. It then fell calm, and, after midnight, "light airs sprang up from the eastward and increased slowly, and at 7 a. m. the current changed to the westward; got under way and went around to the westward of Point Barrow and anchored." All the fleet, which had been in some peril of being beset, worked out with this favorable chance and got to the southward.

U. S. S. Corwin, off Point Barrow, August 25, 1880, 7.20 a. m., found current setting northward and eastward two knots.

Bark Coral, August 15, 1878. Three miles SW. from Return Reef at anchor latitude 70° 30′, longitude 149° under the lee of the reef to escape a two-knot westerly current, which accompanied fresh NE. wind; got three boat-loads of spruce logs from the beach for firewood; there were many logs much decayed at this place.

Capt. Charles Hamill, in the Providence Journal (quoted in the New York Herald of April 30, 1881), states that in latitude 73° 28′, longitude 164°, he came up with a huge body of unbroken ice and found "a three-knot current setting N. under the ice," with no bottom at 90 fathoms. "A short distance to the SW. we found little or no current." In 1867 he found the current in the vicinity of Herald Island "very irregular and influenced by the winds, but hardly ever exceeding two knots, setting northwest."

The following notes by Parry, in regard to temporary currents in the Arctic regions, kindly communicated by Mr. George Kennan, are of interest in this connection. These observations were made on the southwest coast of Melville Island in August, 1820:

"Although the holes had certainly increased in size and extent, there was still not sufficient room for one of our boats to have worked to windward, and the impossibility of the ship's doing so was rendered more apparent on account of the current which is always produced in these seas soon after the springing up of a breeze, and which was now running to the eastward at the rate of at least one mile per hour." (Parry's Voyage, 1819–'20, p. 243. London, John Murray, 1821.)

"We found the current at the extreme point running at the rate of 2 or 2½ miles an hour, so as to require great caution in laying out our warps to prevent the ship being carried back to the eastward; and this not three hours after it first began to make. The frequent experience we had of the quickness with which currents are thus formed in consequence merely of the wind naturally leads to this useful caution, that one or two trials of the set of the stream in icy seas must not be too hastily assumed in drawing any conclusion as to its constant or periodical direction." (Parry, l. c., p. 248.)

In the foregoing series, most of which is now for the first time published, and has been derived from the log or "remark books" of the whaling vessels, I have given *all* reference to currents which occurred in those books I have examined.

I have taken especial pains in this matter, since the "opinions of whalers" have been largely referred to in several vague dissertations on this subject. We now have, not the opinions, but the facts observed by these hardy navigators, as they were taken down at the time of observation.

With regard to Point Barrow, it would seem clear to an unprejudiced mind that, while there is a tendency to a northerly set off that point, which, under favorable circumstances, develops into a temporary current of great rapidity, this is reversible totally, and frequently is totally reversed by the wind, and has a temperature not greater than the average of coast-waters not actually ice-encumbered, in most parts of the Arctic region, being in no sense a warm current. With regard to the general currents and their direction in this part of the Arctic region, the opinions previously quoted from Captain Owen seem to fairly represent the facts. The plausibility of Simpson's suggestion that part of the current near Point Barrow may come from north of the Asiatic coast may be doubted, yet this is worth considering, since the strength of the currents on the American coast south of Icy Cape does not seem sufficient to account for the phenomena observed occasionally at Point Barrow. There are indications that the basin north of Point Barrow and east from Wrangell Island is a closed basin—whether closed by land or by heavy ice cannot be now decided. That there is no well-marked current through Long Strait, and that the occasion of the usual ice blockade there is the meeting of two contrary currents, either one of which may for a time be subordinated to the other, is also indicated by the slender data we have on that subject. That the currents in this part of the Arctic have no necessary connection with any movements of the waters south of Saint Lawrence Island seems clearly established, and to this we may ascribe the fact that in no other part of the Arctic regions unobstructed by land (except the belt occupied by the polar current of the east coast of Greenland) does the permanent pack-ice retain such a low latitude.

Before summarizing the general conclusions, it may be desirable, for the further clearing up of this subject in the popular mind, to examine the capacity of Bering Strait for supplying warm water to the Arctic basin, were there an opportunity for it to fulfil that office.

The average depth of the strait near the line of our section, about the narrowest part (49.33 nautical miles), except that line passing through the Diomedes, is 23½ fathoms. The highest rate observed while at anchor by our party was 1 foot per second for the current. The highest temperature observed was 48° (8°.9), as will appear by a glance at the section.

These figures allow nothing for the space obstructed by the Diomedes, or occupied by stationary ice on the Asiatic side.

The area of the section thus taken, reduced to a rectangle, is 42,289,425 English square feet, and the rate being taken as 1 foot per second, this number represents the number of cubic feet of water which can pass into the Arctic Ocean through the strait at any one second of time. The amount per day is therefore 3,653,806,320,000 cubic feet, assuming the flow to be constant and in that single direction.

The basin of the Arctic immediately north of the strait, between Asia, America, and Wrangell Island, occupies an area considerably exceeding 150,000 square geographical miles, with a depth averaging rather less than 28 fathoms, so far as the data go. This contains 931,553 billions of cubic feet of ice and water, which, at the opening of the season, is doubtless at a lower temperature than 32° (0°.0). Assuming that half of it consists of ice at 32° (0°.0), which is a liberal estimate, we have about 466 trillions of cubic feet of ice.[1]

If the basin were empty, it would take eight months and a half to fill it by the flow through the strait.

The period of unobstructed flow of water through the strait does not usually exceed ninety days, and, when it does, the excess is at seasons when the water is cold. Assuming the flow to be continuous, and to be at its highest temperature (48° Fahr. or 8°.9 C.), and its highest observed rate (1 foot per second), heat enough would be carried in by the supposed current to reduce thirty-six and a half trillions of cubic feet of ice at 32° Fahr. to water at the same temperature, leaving the inflowing water also at 32°. It is true that other factors are at work, but what we wish to find out is the value as an ice-melter of this particular factor. The amount of ice which would be melted by the above process is a little less than eight per cent. But the weighted mean temperature of the water observed to flow through the strait is not 48° (8°.9), as assumed, but 42°.5 (5°.8). This would, therefore, reduce only five and two-tenths per cent. of the ice to water at 32° (0°.0).

But we know also that while the tendency of the flow is greater northward, it does not flow through uniformly in one direction, nor always with the highest rate observed; hence if we allow two-thirds of the time for the northerly flow, and assume that this is all at the highest rate, and that none of the warm water flows back with the tide and that it loses no heat by radiation into the atmosphere, we get as the probable maximum of ice melted a percentage of three and four-tenths, equal to an area of 5,100 square geographical miles, or a square 71.4 miles on each side, or, roughly, an area somewhat less than half that of Kotzebue Sound.[2] This is, of course, when the other circumstances are considered, almost inappreciable, and leaves us to conclude that, under any circumstances at all probable, the amount of warm water which could pass the throat of the strait is so small that it would have practically no effect on the Arctic basin into which it might enter. It seems somewhat singular that no one has hitherto computed the capabilities of the strait with assumed data; for the publication of the figures would seem of itself to be sufficient to quench most of the theories based upon the supposed influx of warm water by this entrance. We may sum up the results of the investigation as follows:

The Kuro Siwo compared with the Gulf Stream is cooler, has a much smaller volume, and is subject to serious fluctuations, which appear to be due to the monsoons.

The Kuro Siwo sends no recognizable branch northward, between the Aleutians and Kamchatka, nor from any other direction into Bering Sea.

The chief current of Bering Sea is a motion of cold water southward. This has a superficial stratum above it, which has, in summer when not interrupted by winds, a northerly motion of translation, but is not sufficient, either in mass, motion, or consistency of direction, to be entitled to take rank as an ocean current.

The surface currents of Bering Sea are formed by or chiefly dependent on tides, winds, river flows, the southerly motion of cold water, the distribution of floating ice, and the northerly motion of slightly warmer surface water, which are effective about in the order named.

No warm current from Bering Sea enters Bering Strait, with the exception of water from the neighboring rivers or the adjacent sounds. This water owes its heat directly to the local action of the sun's rays.

The strait is incapable of carrying a current of warm water of sufficient magnitude to have any marked effect on the condition of the Polar basin just north of it.

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[1] Ice has been frequently reported ashore in fourteen fathoms water. It is always aground on Herald Shoal, where there are not less than seven fathoms. The average height of the pack above the sea-level is from six to thirty feet, which is usually estimated as equal to one-seventh of its submerged mass, but is really somewhat less. See subsequent foot-note.

[2] If the thickness here assumed for the ice be considered excessive, let it be assumed to be only one-half that thickness, or seven fathoms thick, or one-quarter of the contents of the basin, which can hardly be taken exception to. The area which might then be melted by the influence of this water alone would be about 10,000 square miles, or less than seven per cent., which is still an insignificant proportion of the whole. Of course a much larger area than this is actually melted every season, but this is due to the direct action of the sun and various other causes quite independent of any warm current through the straits.

The currents through the strait are cool and chiefly tidal, but with a preponderating tendency northward, as before fully set forth.

The currents in the Arctic, north of the straits, are largely dependent on the winds, but have tendencies in certain recognized directions. Nothing in our knowledge of them offers any hope of an easier passage toward the pole, or, in general, northward through their agency. Nothing yet revealed in the investigation of the subject in the least tends to support the widely spread but unphilosophical notion that in any part of the Polar Sea we may look for large areas free from ice.

I have to thank Capt. L. C. Owen, of Vineyard Haven; Dr. Thomas Antisell, of the United States Patent Office; Mr. Marcus Baker, and other members of the United States Coast Survey, for data and assistance of various and most important kinds.

WASHINGTON, *June* 17, 1881.

SUPPLEMENTARY NOTE.

Before the return of the Yukon party to headquarters, the Superintendent of the United States Coast and Geodetic Survey thought best to publish[1] a portion of my preliminary report containing some of the generalizations drawn from the facts herein enumerated.

As some time must necessarily elapse after our return before the data could be published in due official course, it was thought best to publish a portion of the data before that time for the information of hydrographers, the subject being of considerable interest.

By the authority of the Superintendent, and the kind concurrence of the distinguished editor, Dr. E. Behm, a large part of the foregoing matter was made public in the chief geographical journal of Europe, Petermann's Mittheilungen, in a German translation, accompanied by a map and section.[2] Since this was published, a number of interesting data have come to hand, a few of which have been incorporated in the preceding text, while some of quite recent date find a place in this note.

It is believed that whether the conclusions reached by me are considered worthy of adoption or not, at least the facts collected show a sufficient deviation from the commonly received hypothesis to render the latter no longer acceptable without question by scientific hydrographers. To the complacent ignorance which declines to be moved by any accession of knowledge this document is not addressed, nor is it expected to find favor among the few remaining enthusiasts who still cherish a belief in an open polar sea.

Additional observations in the Arctic Sea.—On October 10, 1879, the whaleships Mount Wollaston, Captain Nye, and Vigilant, Captain Smithers, were last seen by Captain Bauldry, of the Helen Mar, in latitude 71° 50′, longitude 173° 45′, in a narrow channel of open water. The Helen Mar barely escaped being frozen in by crowding all sail and forcing her way through the rapidly forming new ice. In all human probability the two vessels which did not escape were frozen in then and there and never got out of the pack.

More than a month earlier the exploring steamer Jeannette, Lieutenant De Long commanding, was last seen (September 2, 1879) by Captain Barnes, of the whaler Sea Breeze, about 80 miles south of Herald Island. The next day her smoke is reported to have been seen 50 or 60 miles farther north, but the accuracy of this observation remains to be established.

In November, 1880, one of the whaleships came ashore on the northern Siberian coast in the vicinity of Cape North (Svernoi), stove, and only prevented from sinking by the ice which still encircled her. Her crew had disappeared, except a few who lay where they had perished, and it is probable that the wreck was that of the Vigilant. Another wreck was reported by natives to have come ashore farther west on the same coast, but this report does not appear to have been definitely confirmed.

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[1] American Journal of Science and Arts, 3d series, XXI, February, 1881, pp. 104–111, with a map. Reprinted as an extract, with cover and title, "Notes on Alaska and the vicinity of Bering Strait."

[2] Hydrologie des Bering-Meeres und der benachbarten Gewässer. Petermann's Geographische Mittheilungen, 1881; Heft X, October, pp. 362–380, mit Karte, Taf. 17, und Tabelle; Heft XI, November, pp. 443–448.

We do not know, of course, what had been the wanderings of this hulk before she was stranded, but the resultant of her drift for one year was about 200 miles in a southwest (true) direction. This is in accordance with the direction of the prevalent winds (NE.) of this region, which, as has been previously pointed out, govern the motion of the ice much more than the currents; but it is also evident that no such overmastering northerly current as has been claimed for this region could have been experienced by this vessel.

The Jeannette appears, from the few words yet transmitted from Irkutsk, to have gone into the ice in the vicinity of Wrangell Island soon after she was last seen, and to have drifted at the mercy of wind and tide, solidly beset, until the middle of June, 1881, when, in latitude 77° and longitude 203°, she was crushed and abandoned.[1]

It is uncertain whether she passed north or south of Wrangell Island; the resultant of the whole drift in either case would have been about northwest 500 miles in twenty-one months—the rate not greatly differing from that of the Vigilant, and the direction partly according with the more easterly winds prevailing in the higher latitude traversed by the Jeannette. This would also be in accordance with data as to currents about Herald Island, which are hereinbefore made public. The probability is that, as in the case of the Tegethoff, of the Polaris ice-party, and the floe-party of the second German Polar expedition, the rate and direction of her course varied considerably from time to time, and her track, if platted, would show an extremely irregular line.

A few additional observations have come to hand at the last moment, confirmatory of the position herein taken that the influence of the tides is the most important factor in determining the direction of the current in this part of the Arctic Sea, and showing the evil of too hasty generalizations.

"A long lane of open water, extending at least 100 miles northward from Herald Island, looking like an open river between the banks of ice, which was frozen to the shallow bottom. This stream sets northerly at about two knots." (John Muir, in New York Herald, October 22, 1881).

"Mr. Muir says that off the eastern side of Wrangell Land, and evidently lying between it and another undiscovered shore, is, during the open season, an open lane of water leading to the north as far as the eye can reach, through which a current flows steadily north at the rate of 20 or 25 miles a day. This current flows like a river between two ice-bound banks, the shore-ice on either side appearing not to have been disturbed for years, and possibly for ages. The coast-line of Wrangell Land was visible as far as the eye could reach." (San Francisco Bulletin, October 21, 1881).

"The floe outside of us (the Corwin, when at Wrangell Land) was drifting along shore to the northeast with a powerful current, at a speed of 50 miles a day, the majestic movement being made strikingly manifest by large bergs that were aground in water 60 feet deep, standing like islands, while the main mass of the pack went grating past them." (John Muir, letter of August 17, 1881, in San Francisco Weekly Bulletin of October 26, 1881). In the same letter, the writer speaks of ice a hundred feet thick near Wrangell Island. "The ice (near Point Barrow) is of tremendous thickness, 100 feet or more." (Same, in letter of August 18, 1881, same paper.)

The preceding observations were made and published before it was known that Wrangell Land was a comparatively small island, and the danger of drawing generalizations from too limited experience is illustrated by a comparison of them with the following notes of investigations by Lieut. Robt. Berry, U. S. N., commanding the U. S. S. Rodgers, a little later in the same season:

"Ensign Hunt's party were * * * instructed to encircle the island if possible, for he (Lieutenant Berry) felt pretty certain of its insular character since making our observations from Herald Island of the variable changes of currents and ice," &c. "Your correspondent says it was surprising to see the ice moving constantly to westward along the shore. * * * These rapid changes are most confusing to navigators," &c. (New York Herald, November 8, 1881. Also repeated by Doctor Rosse in letter of September 12, New York Herald of November 18, 1881).

"After cruising along the pack * * * we steamed toward Herald Island for the purpose of making observations upon the current reported to flow in a northwesterly direction * * *. As the fog continued we dropped anchor in 15 fathoms * * * on the afternoon of the 20th (September). During the following twenty-four hours the observations of the current were continued, which indicate a tidal current setting toward the northwest as the water is deepening

[1] Later dispatches, while this is passing through the press, confirm this supposition.

(flood), and toward the southeast when shoaling (ebb), while at high and low water there was no current perceptible. The measurements were made at the surface and at a depth of 10 fathoms." (Report in New York Herald of November 18, 1881).

Of the 6-knot northwesterly current discovered (according to statement of Captain Jacobson, published in New York Herald of November 5, 1881), by Lieutenant Berry, near Wrangell Land, nothing is said (of any such current) in his official report, and the statement doubtless arose from some misapprehension.

As an instance of anomalies of temperature met with in the shallows of the seas of this region, the following extract from a letter of the Herald correspondent on the Corwin, dated September 7, 1881, and published in the Herald of November 21, 1881, is of interest, "Some anomalies in the temperature of the water were noticed; for instance, near Herald Island, on July 30 it was 48° (at the surface) and 49° at the bottom. A few days later, off the Siberian coast, 100 miles southward, it measured 37°, while later, in Bering Sea, over 600 miles to the southward, it fell to 35°. Similar observations have been made by several navigators.

The following remarks by Captain Fisher, of the Sea Breeze (Daily Alta California, San Francisco, September 28, 1881), have had a somewhat extended publication, and may be compared with the previously mentioned details extracted from the "remark-books" of several whale ships, which relate to observations made and recorded at the time of occurrence, and with the conclusions of Lütké and Kellett. "All summer long a strong current sweeps northward through this (Bering) Strait, and it is only in September or October that strong northerly winds affect it. I, myself, have been swept many miles northward in October. * * * Off Point Barrow a 3 or 4 knot current sets regularly along the land northeastward, which does not extend 50 miles off shore. In 1872 the Sea Breeze, while becalmed, drifted 20 miles off shore, entirely out of sight."

It is needless to observe that Captain Fisher never spent "all summer long" in the strait, nor is it probable that he ever spent twenty-four consecutive hours in the same spot in the strait Doubtless he has observed on various occasions a current similar to that experienced by many other navigators in the strait and at Point Barrow, but there is no doubt that he has overestimated the rate at the latter point, and that his conclusions as to the regularity at both places are based on insufficient evidence. In this, as in many other cases, when observations are recorded by persons unfamiliar with the need of exactitude in such matters, it is probable that currents were noticed only when they forced themselves on the navigator's attention by interfering materially with his reckoning or progress, while the (for our purposes) equally important, but feebler, counter currents passed without notice. I have called attention to the circumstances of this particular statement, not because it is more remarkable or more erroneous than many others, but because upon it and similar slipshod statements persons unfamiliar with the subject have seen fit to base disquisitions on the currents of Bering Strait, and to call in question the result of observations, which, however limited their scope, were made with care, and are entitled, so far as they go, to the confidence and due consideration of hydrographers.

The following extracts from the report of Mr. Marcus Baker, astronomer of the United States Coast and Geodetic Survey party on the U. S. S. Yukon, under my charge, will give a fair idea of the value of the determination, and the manner in which it was made. The full account, by permission of the Superintendent of the Survey, was published in the Bulletin of the Philosophical Society of Washington, vol. IV, pp. 123–133, 1881, with a map. As noted previously, the longitude of the maps accompanying the article in the American Journal of Science, and that in Petermann's Mittheilungen, was necessarily dependent upon the results by one chronometer, the computations not being finished then, and therefore requires a plus correction of about 1′ westerly:

Boundary line between the territory of the United States and of Russia, passing through Bering Strait.

The present boundaries of the Territory of Alaska were defined in the treaty of March 30, 1867, whereby Russian America was ceded to the United States. In that treaty the western boundary, or rather so much of it as is here considered, was defined as follows:

"The western limit, within which the territories and dominion conveyed are contained, passes through a point in Behring's Straits on the parallel of sixty-five degrees thirty minutes north latitude, at its intersection by the meridian which passes midway between the island of Krusenstern or Ignalook, and the island of Ratmanoff or Noonarbook, and proceeds due north without limitation into the same Frozen Ocean."

The longitude of this meridian was very properly left out of the treaty on account of its uncertainty. In order to show our knowledge of the subject at the time of the framing of the treaty, the following table has been prepared from all known authorities upon the subject down to the present time.

The last three determinations entered in the table, it must be borne in mind, have been made since the treaty was drawn up.

Date.	Longitude.	Authority.
	° ′	
1761	155 00	Map published by the Imp. Acad. of Sciences of St. Petersburg.
1778	169 52	Cook's Atlas.
1802	168 48	Billings.
1822	168 59	Kotzebue.
1827	168 55	Beechey. Br. Adm. Ch. No. 593.
1828	168 54	Lütké's Atlas.
1849	168 57.5	Tebenkoff's Atlas.*
1852	168 54	Russian Hydr. Chart No. 1455.
1855	168 48	Rodgers. U. S. N. Hydr. Chart No. 68.
1874	169 04	Russ. Hydr. Chart.*
1878	168 58	Onatsevich.
1880	168 58	U. S. Coast and Geodetic Survey, 1880.

In the case of the two determinations marked with a * the two Diomede Islands are so represented on the chart that the boundary line is tangent to each island.

During the summer of 1880 an attempt was made by the party on board the United States Coast and Geodetic Survey schooner Yukon to make a more careful determination of the longitude of this meridian than had been attempted hitherto. For longitude purposes the party had one pocket and six box chronometers. For determining time the sextant was used, recourse being had to equal altitudes whenever possible.

Plover Bay in Eastern Siberia is about 150 miles to the southward and westward from the Diomede Islands in Bering Strait. This bay was visited by Prof. Asaph Hall, of the United States Naval Observatory, in 1869, for the purpose of observing the total solar eclipse of that year, and, in connection with the eclipse work, Professor Hall made a careful determination of the longitude of his station. After a careful examination of all the longitude determinations known to exist, and because the facilities for determining the longitude of this place by the Yukon party were not sufficient to improve upon the determination by Professor Hall, his results have been adopted, and the longitude of the boundary meridian made to depend upon his determination. * * *

Previous to 1848, Plover Bay, though an extensive arm of the sea running inland some 20 to 25 miles, appears not to have been known. It is not shown upon any map before 1850. In the period from 1845 to 1848 it seems to have been visited by the whalers. The first information touching it upon which we can lay our hands is the report of Commander Moore to the Admiralty, published in the Nautical Magazine, March, 1850. From this it appears that Commander Moore first anchored in Plover Bay October 17, 1848. Later he moved his vessel, the Plover, farther in, and wintered in the harbor named by him Emma Harbor. He remained in Emma Harbor until June 23, 1849. Concerning the scientific or surveying work accomplished in this period of eight months he says: "At intervals Mr. Martin, assisted by Mr. Hooper, made a survey of the place in which I had secured the ship for the winter; which, connected with Mr. Martin's and my own observations on the coast to the westward, will, I hope, give a tolerably correct representation of these shores, and when associated with magnetic observations on every attainable point, will, I trust, meet their lordships' approbation."

The results foreshadowed by this report have not come to light. No map or plan of Emma Harbor or Plover Bay has been published by the British Admiralty Office, and no statement or account of the observations at Plover Bay, if any were made. General Sabine, in his contributions to Terrestrial Magnetism No. XIII, gives some results which he credits to a MS. in the Magnetic Office by Commander Moore, but no *magnetic declination* or *intensities* are given; whence we conclude that no observations, or at least no satisfactory observations therefor were taken. A few results for *dip* are given. The geographical position of the station where the dip observations were taken is given by General Sabine, and this position, if due to Commander Moore, is the earliest determination on record of a position for Plover Bay. The position given probably refers to some point near the northern shore of Emma Harbor. * * *

A rough sketch of Plover Bay was made in 1866, by the exploring parties of the Western Union Telegraph Company, and this sketch was published in 1869 by the Coast Survey. The observations were made by Lieut. J. Davison, of the United States Revenue Marine Service, and the resulting position is stated to depend upon nine observations, referred by a crude triangulation to the mountain Bald Head. * * *

In 1876 the bay was visited by Lieut. M. L. Onatsevich, of the Russian Navy, in the Vsadnik and a rough survey made of the bay, with a somewhat detailed survey of the anchorages. At the same time astronomical and magnetic observations were made.

In 1877 the Russian Hydrographic Office published several charts embodying the results of Onatsevich's observations, and among them a chart of Port Providence, or "Plover Bay," as it is usually called by the whalemen. * * *

The station occupied by Lieutenant Onatsevich is clearly marked upon his chart, and as we had this chart with us, the place was quite closely identified, probably within a few feet. The attempt was made to have our station identical with his. * * *

Our adopted value of the geographical position of the astronomical station of the United States Coast and Geodetic Survey at Plover Bay, Eastern Siberia, is

Latitude, $64^\circ\ 22'\ 00'' \pm 6''$ N.

Longitude, $\left\{ \begin{array}{l} 173^\circ\ 21'\ 32'' \pm 6'' \\ 11^h\ 33^m\ 26.1^s \pm 0.4^s \end{array} \right\}$ W. Gr.

Our station was marked by driving a piece of whale's rib into the ground and piling rocks around it. Being identical with the station of Lieutenant Onatsevich, any one visiting the place will, by the aid of that chart, readily identify it. * * *

The Yukon arrived at Plover Bay at ten in the evening of August 11, 1880. The following day was cloudy in the morning, afterward rained, and later partially cleared up so that we obtained two pairs of equal altitudes of the sun for time, the interval being about three hours. During the afternoon we succeeded in getting four sets of six each of double altitudes of the sun for time. From the equal altitudes, the time of local mean noon by the chronometer was $11^h\ 18^m\ 13.9^s$, and from the double altitudes it was $11^h\ 18^m\ 14.2^s$, a very satisfactory agreement. By means of the intervals the probable errors of each of these determinations have been made out. For the equal altitudes it is $\pm 1.7^s$, and for the double altitudes it is $\pm 0.30^s$, values which may be taken as fairly representative of the different conditions under which the observations were made. From these observations the corrections of our chronometers to Greenwich mean time on August 12 were determined.

On August 14, we sailed from Plover Bay to the eastward and northward, cruising along the Arctic coast as far as Point Belcher, and returning thence passed through Bering Strait to Port Clarence, and afterwards returning to Bering Strait made a landing on the southeastern shore of Ratmanoff, or the Big Diomede Island, on September 10. We came to anchor at seven in the morning, about a mile off shore, and sailed away about three in the afternoon. During our stay observations were made for latitude and time, and all the magnetic elements, declination, dip, and intensity. Of time observations, three sets of six each of double altitudes of the sun were obtained with sextant and artificial horizon. These three sets give as the correction of our "hack," or observing chronometer, to local mean time

$$+1^h\ 03^m\ 26.9^s \pm 0.35^s,$$

this probable error resulting from computing the eighteen observations singly and treating in the usual way. The sky was nearly covered with cumulus clouds, the wind fresh, raw, and chilly, and thermometer 39° Fahr. Near noon the sun appeared again for a short time, and nine pointings were obtained for latitude, giving the following results, each depending upon a single observation:

	°	′	″
	65	44	54
			50
			38
			54
			44
			52
			53
			60
			65
Mean latitude,	65	44	51 ± 1″.5 N.

Leaving the Diomedes on the afternoon of September 10, we sailed directly for Plover Bay. That night we were stopped by ice, the next day delayed by calms, but on the following day, September 12, we reached our anchorage in Plover Bay a little before noon, just in time to get a good series—39 observations of circummeridian altitudes of the sun for latitude. In the afternoon we obtained a good series of time observations, but the following morning was cloudy. We succeeded, however, in getting four altitudes corresponding to those of the preceding day, thus enabling our time determination to hang upon four pairs of equal altitudes, the epoch being local mean midnight September 12 and 13. The times of local apparent midnight from these four pairs by our "hack" were

h.	m.	s.
11	09	0. 2
		1. 2
		0. 3
		0. 7

from which the probable error is found to be ± 0.15ˢ.

For the longitude of our station upon the Big Diomede Island we have, therefore, as follows:

	s.
Plover Bay, 1880, August 12, noon, chronometer correction determined	± 1. 7
Big Diomede Island, 1880, September 10, 8ʰ.9, a. m., chronometer correction determined	± 0. 35
Plover Bay, 1880, September 12, midnight, chronometer correction determined	± 0. 15

By means of the time determinations of August 12 and September 12, the rates of the chronometers are determined, and then the Greenwich time determination at Big Diomede Island, September 10, is made to depend upon the determination at Plover Bay, September 12, and the rates of all the chronometers carried back to September 10, a period of 2.64 days.

The resulting longitude by each chronometer is shown in the following table:

Chronometer.	h.	m.	s.
214	11	16	18. 3
866			17. 9
1131			18. 0
1713			19. 0
2535			14. 7
311			16. 6

Chronometer No. 2535 was our "hack," and 311 a sidereal chronometer used in making comparisons. Each had rather large rates, that of 2535 exceeding *nine* seconds, and that of 311 *five* seconds per day. The indiscriminate mean of all is 11ʰ 16ᵐ 17.4ˢ. Assigning only half weight to chronometer 2535, the longitude resulting is

11ʰ 16ᵐ 17.7ˢ

The probable error of the Greenwich time at the Diomedes, based upon the agreement of the chronometers, is ± 0.36ˢ.

For the probable error of the longitude, therefore, we have

Probable error of longitude of Plover Bay	$= \pm 0.39$
Probable error local time determination, Plover Bay, September 12	$= \pm 0.15$
Probable error local time determination, Diomedes, September 10	$= \pm 0.35$
Probable error Greenwich time determination, Diomedes, September 10	$= \pm 0.36$

Resulting longitude adopted, $11^h\ 16^m\ 17^s.7 \pm 0^s.65$.

The astronomical station of the United States Coast and Geodetic Survey at the mouth of the ravine, on the southeastern shore of the Big Diomede Island in Bering Strait is, therefore, in

	°	′	″	
Latitude,	65	44	51	N.
Longitude,	169	04	25 ± 10	W. Gr.

From bearings and angles taken from the astronomical station and from the schooner at anchor, using the distance of the schooner from the station as a base line, together with other bearings taken while in the vicinity of the islands, a sketch of the two islands has been prepared from which it appears that the meridian tangent to the extreme eastern edge of the larger island is 2.1 nautical miles, and the meridian tangent to the extreme western edge of the smaller island is 3.1 nautical miles, east of the astronomical station. The boundary line is to pass midway between these meridians, *i. e.*, the meridian which forms the boundary is 2.6 nautical miles east of the astronomical station.

In latitude 65° 45′, the latitude of the astronomical station, 2.6 nautical miles is equal to 6′ 20″ of longitude, and, deducting this from the longitude of the astronomical station, the longitude of the boundary line is found to be

168° 58′ 05″ W. Gr.

If we assume an uncertainty of one-quarter of a nautical mile, equal in this latitude to 37″ of longitude, in thus transferring the position of the station to the boundary line, and this seems to be quite large enough, we have finally as the longitude of the boundary line between Alaska and Eastern Siberia

168° 58′ 05″ ± 38″

or, in time,

$11^h\ 15^m\ 52^s.3 \pm 2^s.5$ W. Gr.

WASHINGTON, *January* 25, 1882.

REFERENCES TO THE PLATES.

1. Bering Strait. Surface and Vertical Isotherms.

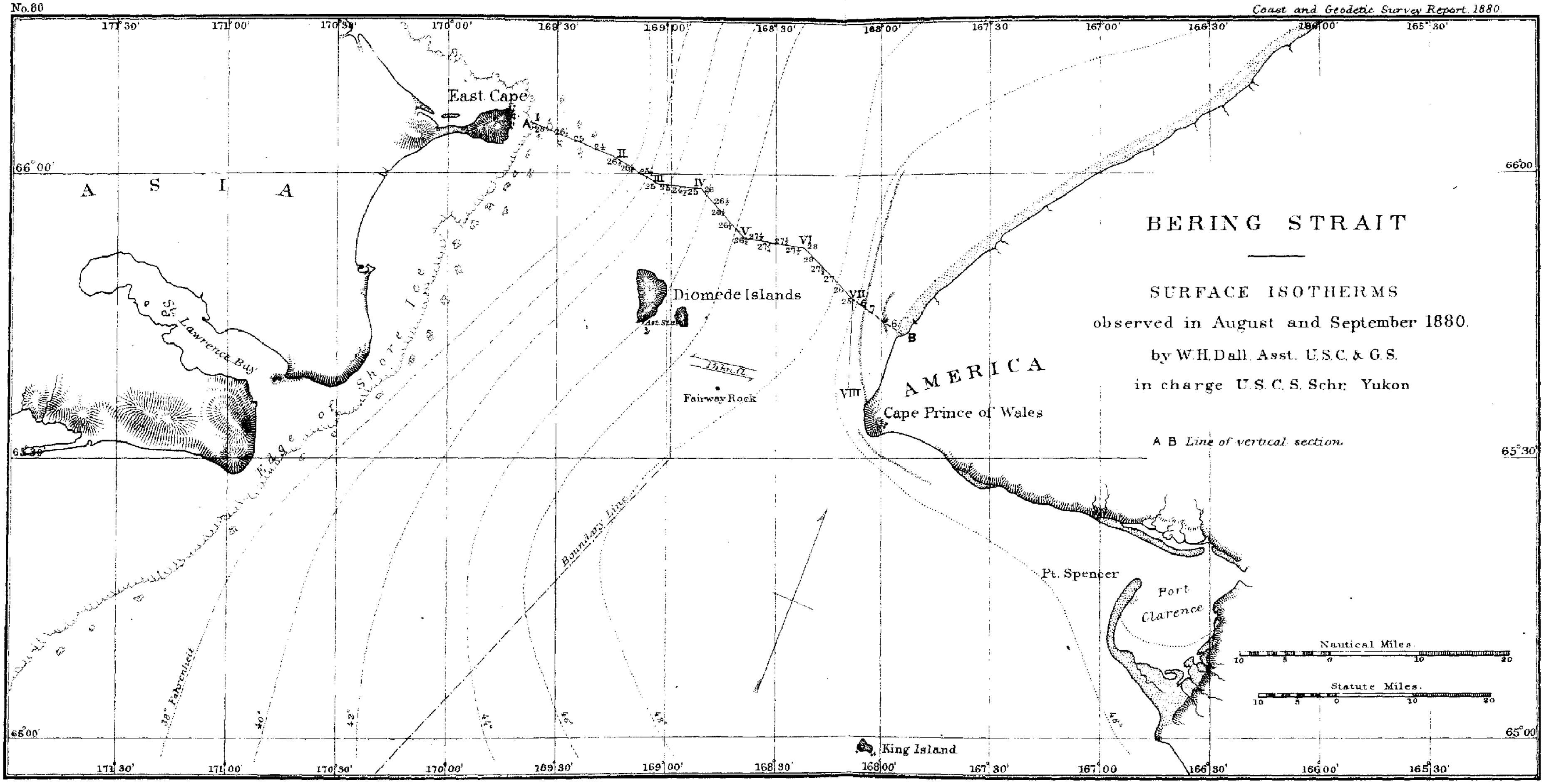
The line of the vertical section and the locality of the eight stations at which serial temperatures were taken are shown in the upper part of the plate. The soundings from Station VII to the shore are from the chart of Beechey, the shoal water on the bars there represented being unsafe for the purposes of navigation. The other soundings are from observations by the party. The temperatures are in degrees of Fahrenheit scale. In the section the vertical isotherms of 40°, 41°, and 42° are somewhat distorted by the eddy caused by the interruption of the current around the Diomede Islands.

The shorelines of the chart are taken from the charts of Beechey and Tebenkoff, with some corrections resulting from observations by the party on the U. S. S. Yukon.

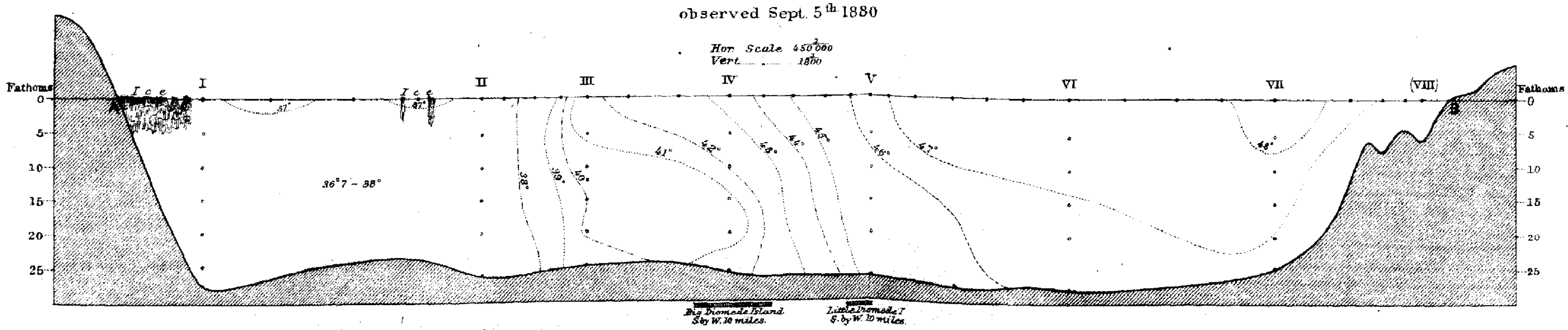
2. Chart showing direction and strength of currents observed in Bering Sea and adjacent waters by different navigators, and also the approximate borders of the pack ice of Bering Sea in spring for various years.

The sources from which this chart has been compiled are referred to in the text. The open water in every case is that part of the sea south and west from the lines indicating the margin of the ice.

The regions usually occupied by ice during the summer in the Arctic Sea, north of Bering Strait, are approximately indicated by the absence of current observations on the map. In cases where the number of observations is too great for them all to be represented on the chart (as in Bering Strait itself), the selection has been determined by attempting to choose characteristic observations which should represent the varying currents reported by different navigators.



VERTICAL ISOTHERMS
observed Sept. 5th 1880



APPENDIX No. 17.

AN ACCOUNT OF A PERFECTED FORM OF THE CONTACT-SLIDE BASE APPARATUS USED IN THE COAST AND GEODETIC SURVEY.

By J. E. HILGARD, Assistant.

The Coast Survey Reports for 1856, 1857, and 1870 contain accounts of a base measuring apparatus, designed by Assistant J. E. Hilgard and Mr. Joseph Saxton, in consultation with Superintendent Bache, and intended originally for work of secondary accuracy.

The results obtained by its use in the field have surpassed the expectations entertained of its merits, and have shown that the degree of exactness of distances measured with it is as great as can be maintained in any system of triangulation based upon them. In illustration, the recent measurement made with bars of this construction, but 6 meters in length, by Assistant O. H. Tittmann, of the "El Paso" base, Colorado, may be cited. The base line, 11.3 kilometers long, was measured twice, in opposite directions, in twenty-three working days. It was divided into fifty-four sections, and from comparisons between the two measures of each section a probable error of less than five millimeters has been deduced for the whole length of the base line, as that due to the uncertainty of measuring only. Taking into account also the uncertainty of the temperature correction, the probable error assigned to the length of the base is 16.5^{mm}.

As showing the capacity of the apparatus to overcome grades, it may be mentioned that the difference of elevation between the termini of this base is 172 meters.

The apparatus consists of two measuring bars 4 meters long, exactly alike, supported on trestles. The measurement is made by bringing these bars successively into contact. This is effected by means of a continuous screw motion, and defined by the coincidence of lines on the rod and contact-slide.

The simplicity, ease, and rapidity of this mode of making the contact left nothing to be desired, and was found to introduce much smaller errors than were caused by our imperfect knowledge of the temperature of the bars on which their absolute length depends.

In the form of the apparatus hitherto used, the temperature was at first indicated by a mercurial thermometer, the bulb of which touched the rod, let into the wood encasing the latter, on one side of the bar. Afterwards another thermometer was inserted on the opposite side, but it was found that the indications of the two differed considerably, particularly in the early part of the day, and when the direction of the measurement was such that the sun shone on one side of the apparatus only.

In order to make our knowledge of the absolute lengths of the bars conform more nearly to the measuring power of the apparatus, it was decided by Assistant Hilgard to combine the measuring rod with two zinc tubes, one on each side of the rod, into a metallic differential thermometer. It is the object of this paper to show how this has been accomplished without materially increasing the weight of the apparatus, and to give an account of a new device for aligning the bars and to describe the apparatus as now perfected by him. Originally a bar carried at each of its ends an aligning pin, and it was intended that the alignment should be made by sighting with the eye along the pins, but this method was found insufficient because the two bars were not always at the same inclination, nor were they nearly enough level when placed on the trestles to insure the verticality of the pins. It was, therefore, customary to station an observer behind a theodolite mounted in the line of measurement, at a convenient distance in front or behind the bars.

To simplify the procedure, a small aligning telescope has been attached to the forward end of the bar.

The accompanying plate shows the details of the apparatus.

Fig. 1 shows a cross-section of one of the 4-meter bars. The wooden bar is 8 centimeters wide and 14 centimeters deep, and is composed of two pieces firmly held together by long screws passing from the top through the upper piece into the lower. Encased in this bar is a brass frame carrying three rollers, on the central one of which rests the steel rod, which is 8^{mm} in diameter. On each side is seen a zinc tube 9.5^{mm} in diameter. A brass plate extends across the rod and tubes, holding them in place, but not in contact with them.

The rod and tubes are supported throughout their length on similar systems of rollers, at distances apart of about $0^{m}.34$, as shown in Fig. 4.

Fig. 2 shows the rear bar on the left in contact with the forward bar on the right. It should be borne in mind that what will be said about the forward or rear end of one bar, applies equally to the corresponding ends of the other, as they are exactly alike in construction.

In the figure the tops of the wooden bars have been taken off to show the details of the arrangement of the rod and tubes. Looking at the rear end of the forward bar we see one of the zinc tubes soldered to the rod, as indicated by the discontinuation of the broken lines on the millimeter scale. This scale is screwed to the united end of the tube and the rod. The other zinc tube is left free to expand at this end, and carries a vernier corresponding to the scale.

At the other end of the bar the arrangement is reversed, as shown on the left at the forward end of the rear bar. To avoid a vertical displacement of the vernier and scale plates, they are held in place by a bridle fastened to the vernier and overlying the scale, and carrying a spring which presses the latter against the former. The upper portion of the bar is perforated from two sides, and the perforations are closed by lenses having their foci in the plane of the scales. By this convenient arrangement one of the lenses concentrates light on the graduation, while it may be read through the other. This arrangement is not shown in detail in the drawing, but the position of the lenses is shown in Fig. 5 by the little squares, near the ends of the bars.

It need hardly be explained that the absolute length of the bar must be determined for any particular reading of the scales by comparison with a standard, and that the difference in the coefficients of expansion of the steel rods and the zinc tubes will cause different scale readings, for differences of length due to changes of temperature.

A mercurial thermometer is retained near the middle of the bar, as shown in Figs. 4 and 5, for comparisons of the bar with the standard. The thermometer can be read while it remains in position, by merely withdrawing a wooden slide which covers it.

The tubular form was chosen for the zinc because of the inelasticity and brittleness of that metal.

We revert to the figure. The rod and tubes fixedly united are movable lengthwise on the rollers by means of a milled head nut, working in threads cut on the steel rod which passes through a circular opening in the brass plate screwed to the wooden bar, and against which the nut presses. This motion is counteracted by two strong springs at the forward end of the bar, which are fastened at one end to the wood and at the other to a cross-piece which is firmly clamped to the rod, and by means of which the tension of the springs can be regulated. To prevent the twisting of the rod when the milled nut is turned, a brass piece is clamped to the rod and slides horizontally on two guide plates. The amount by which the rod may be screwed in or out is limited by four stops on the guide plates, between which the cross-piece slides, as shown in the figure. The rear end of each rod carries the contact-slide, which has on its extremity an agate with a horizontal knife-edge. The contact-slide is a short tube which slides over the end of the rod and is pushed outward by means of a spiral spring, rather more than sufficient to overcome its friction (see Fig. 3). A slot in the tube shows an index plate with a line ruled on it, fastened to the rod. The coincidence of these lines defines that position of the slide in which the knife-edge is at a known distance from the plane of the agate at the other end of the rod. This plane agate is shown in the figure as the abutting surface of the rear bar.

The contact-slide and rod are perforated with a small hole and supplied with a pin, not shown in the drawing, by means of which the guide lines can be fixed at coincidence for the purpose of making comparisons with the standard bar, or of transferring a point on the ground to the end of the bar.

When the whole bar is nicely adjusted on trestles or stands in elevation and alignment, and within a few millimeters in distance either way, the exact adjustment is effected by turning the milled head nut which slides the rod within the bar until the lines on the index plate and contact-slide coincide; the knife-edge on the latter abutting meanwhile against the agate surface plane of the preceding bar, which suffers no pressure, except that due to the small spiral spring within the abutting-slide.

In judging of the coincidence of lines, a magnifier is made use of, which can be carried by the operator or be attached to the bar, as shown in Fig. 5.

Fig. 5 shows the general appearance of the bar when on the trestles. The bar is painted a bluish gray color, and has on it a designating numeral (not shown in the drawing). Two black bands are painted on it at a distance of one-fourth of the length of the bar from each end, to show where it should be supported by the trestles. The level sector is also shown. By its means the bar is made horizontal, or its inclination can be read off on its scale, which is graduated to minutes.

On the forward end the aligning telescope is shown, a side and front view of which is given by Figs. 6 and 7.

The telescope rests in wyes, in which it is reversible, and is mounted on a stiff spring, one end of which is fixed to the bar, the other to a tangent screw, by means of which the axis of the telescope can be made horizontal, as indicated by a small level carried between the wye standards. As the bar is made very nearly horizontal by means of the level on the trestles, the eccentricity of the telescope caused by the final adjustment with the tangent screw is but an insignificant quantity.

Fig. 8 shows the trestle. On a tripod stand with double legs of the usual construction is screwed a frame carrying two upright guides for the two wooden cross-slides, shown in the drawing as separated by a wedge. Each cross-slide is composed of two pieces of wood, on opposite sides of the guides, held together by a clamp at each end, by means of which it can be fixed at any elevation on the guides. A spring, which reacts against the clamps, is introduced between the two pieces of wood and throws them apart when the clamping screws are loosened, to admit of an easy vertical movement along the guides. For this purpose, furthermore, friction rollers are inserted in the ends of the cross-slides moving between the guides. The design secures an easy movement under all changes of heat and moisture.

The parallelism of the two cross-slides is insured by their contact with the wedge, and their horizontal position is indicated by a small level affixed to either the lower or, as in this instance, to the upper slide. When the lower one is fixed and the wedge in its average position between them, the upper one can be moved about 2 centimeters up or down parallel to the lower.

An equable motion without jarring and with certain bearing is secured for the wedge by causing it to move between friction rollers. As the wedge moves with great ease on the rollers and is liable to fly out when under the pressure of the bar, a flat spring is introduced between the side of the wedge and the side of the cross-slide, which presses the wedge against the guides and causes a uniform friction independent of the weight of the bar.

The trestles are alike in construction, with the exception that the upper slide of the trestle intended for the forward end of the bar carries a roller on which the bar rests, while the other has a fixed semi-cylindrical surface for the support of the bar.

Before beginning the measurement of a base line the aligning telescope should be collimated, the milled head nut giving the sliding motion to the rods in the bars should be put at its mean position, and the level of the sector should be adjusted to the zero of the arc when the bar is horizontal. This is done by putting the bars on the trestles, and bringing the knife-edge at one end and the middle of the agate at the other, into a horizontal plane described by a leveling instrument or theodolite, set up equidistant from the two ends of the bar. As this adjustment is liable to a slight derangement during measurements, it is customary to test it at the end as well as at the beginning of a day's work, and when such a derangement has occurred its amount as shown by the arc must be recorded and a correction applied to the observed inclinations.

In making the measurement, the bars being four meters in length, the stands are set up at distances of two meters, each bar being supported at one-fourth its length from the ends, as indicated by the black bands.

The tripod legs are so placed that one of each stand is in the direction of the line towards the middle of the bar.

The height of the stands is approximately adjusted by the spreading of the legs. The proper distance for the stands is ascertained by a light rod of two meters laid on the ground.

The wedge is placed at its midway position, between the two cross-slides, which are clamped at a suitable height. This is ascertained by sighting across the tops of the slides to a bar already in position. At the same time they are kept horizontal by means of the attached level, which should be kept on the forward side, so as to be under the eye of the person adjusting the height.

The bar is next placed on the trestles in approximate alignment, for which the space between the uprights makes ample allowance, if the stands are set with moderate care. It is then adjusted in elevation by means of the wedges, and either placed level or at a slight inclination, which is read on the sector scale. The alignment is now perfected by means of the telescope on the top of the bar. The bar is shifted by hand, as it is in no way clamped to its support, its weight being sufficient to insure stability. At the same time its distance in reference to the preceding bar is adjusted to the range of the screw motion.

In launching the bars backward or forward by hand, the operator should lift the contact end slightly off the trestle, while the assistant at the forward end, with his hand placed under the bar, merely takes some of the weight of the bar off the trestle, leaving the operator free to move it either way, in which he may be assisted by a slight swinging movement of the hand.

While it is always preferable to use the bars nearly level, considerable irregularities in the ground may be overcome by means of the trestles. A vertical offset with a theodolite may be resorted to in overcoming a sudden change of grade in preference to using the bars at a considerable inclination.

The apparatus is provided with three pairs of stands, one of which is always kept in position in advance of the two which support the bars.

Two men are required to carry forward the trestles to set them and to adjust the cross-slides approximately. Two others are required to carry forward the bars and to assist the operator who makes the contact in manipulating the bar for its nice adjustment. Two more for carrying forward tools and other appliances and necessaries, and a recorder whose duty includes check readings of the temperature scale and sector arc.

It is requisite that a standard should accompany the bars into the field for the purpose of making comparisons between the former and the latter, since the scale readings depend, aside from the changes due to temperature, on the unalterable relation between the zinc and steel, and it is desirable to verify this frequently. A series of comparisons between the standard and the measuring bars will then enable the computer to arrange a table in which the absolute length of the bars corresponding to the observed scale readings will be given irrespective of our knowledge of the temperature of the bars. The knowledge of the length of the standard, however, depends on the indications of mercurial thermometers, but the time and circumstances under which the comparisons are made may be so chosen as to afford very much more favorable conditions, as regards *stability* of temperature, than could be expected during the measurement of a base-line.

The mercurial thermometer retained in the measuring bars should, however, be read not only as a check against gross misreadings of the scales against which the fact that two scales must be read already provides, but also to complete the record by furnishing information in regard to the varying temperatures of the day.

The scale readings should be recorded at equal intervals of time, or if the measurement is progressing at a nearly uniform rate of speed, for, say, every ten bars. But the frequency should depend on the rate at which the scale readings change as shown by the record.

A form of record is appended.

No 82

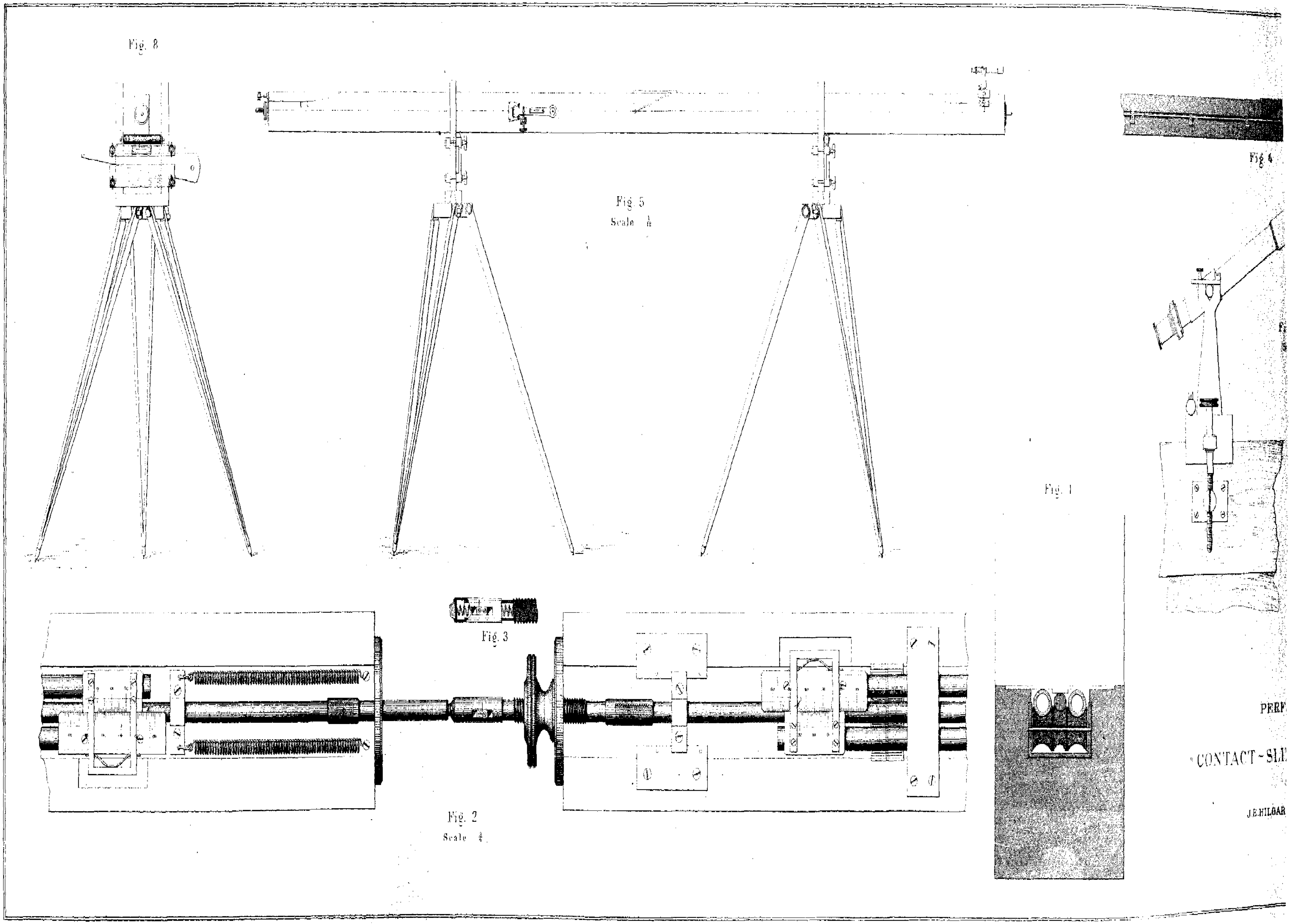


Fig. 8
Fig. 5
Scale 1/8
Fig. 4
Fig. 1
Fig. 3
Fig. 2
Scale 1/4
PERF
CONTACT-SLI
J.E.HILGAR

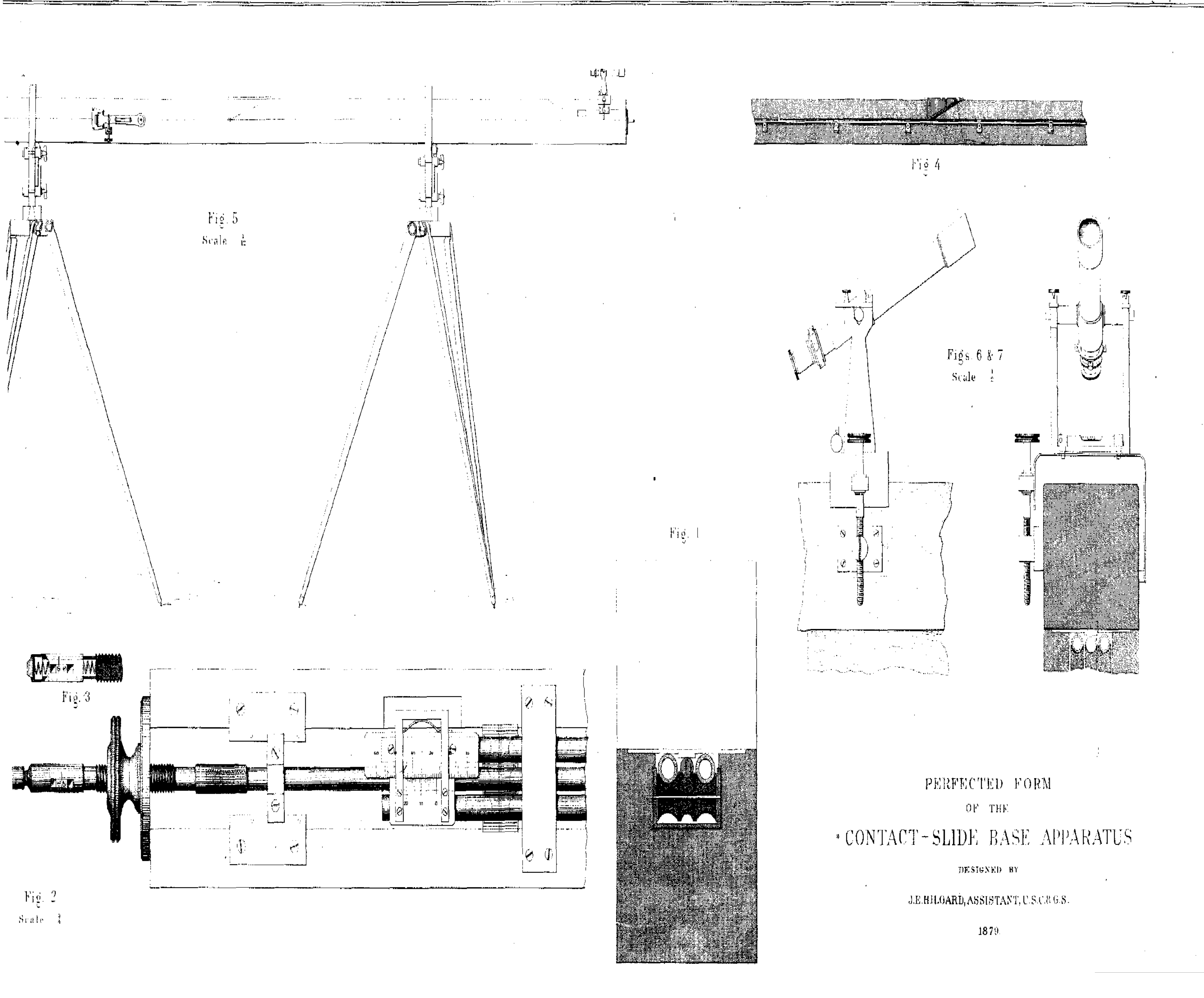


Fig. 5
Scale 1/12

Fig. 4

Figs. 6 & 7
Scale 1/2

Fig. 1

Fig. 3

Fig. 2
Scale 1/2

PERFECTED FORM
OF THE
CONTACT-SLIDE BASE APPARATUS
DESIGNED BY
J.E. HILGARD, ASSISTANT, U.S.C.& G.S.
1879

A form of record is appended:

Time.	No. of bars.	Designation.	Scale readings.		Thermometer.	Sector readings.			Correction for inclination.	Remarks.
			Forward end.	Rear end.		+	—	Corrected.		
4h.00 p. m..	1090	9	25.55	26.70	82.9	1° 02	....	....	....	Cloudy, calm.
	91	10	27.30	25.35	82.0	33	....	....	....	
	92	9	....	....	......	30	....	....	....	
	93	10	....	....	......	....	5	....	....	
	94	9	....	....	......	0	....	....	....	
	95	10	....	....	......	12	....	....	....	
	96	9	....	....	......	....	16	....	....	
	97	10	....	....	......	....	25	....	....	
	98	9	25.50	26.65	80.9	....	13	....	....	
15	99	10	27.25	25.35	80.7	....	4	....	....	Light rain.

APPENDIX No. 18.

AN ATTEMPT TO SOLVE THE PROBLEM OF THE FIRST LANDING PLACE OF COLUMBUS IN THE NEW WORLD.

By Capt. G. V. FOX, Assistant Secretary of the Navy from May, 1861, to November, 1866, Member of the Massachusetts Historical Society, etc.

I.

INTRODUCTION.

The discovery of America by Christopher Columbus is, perhaps, the most important event recorded in secular history. Ancient philosophers had suggested the sphericity of the earth, the zone of water, and the theoretical possibility of reaching the Indies by sailing west; and Columbus recalled these suggestions before the great councils that ridiculed and rejected his proposal.

The art of navigation is as old as civilization, and the practice of it must have begun when bartering commenced. Its early development in European waters was, probably, in the eastern part of the Mediterranean, with open boats, such as Homer mentions. Vessels of this character could not make a commercial nation like that which throve in Phœnicia. Therefore we find that her ships were large and that they used both sails and oars.(1) More than three thousand years ago the sailors of this little state had passed out of the Mediterranean, had founded Cadiz, and were trafficking along the Atlantic shores of Europe and Africa.

The maritime spirit of the Phœnicians descended upon the Carthagenians, the Italians, and the Portuguese. The last named began that golden age of geographical discovery which characterized the fifteenth century.

All navigators antecedent to Columbus followed the same way in searching for new countries. They crept along the shores of contiguous lands making no discoveries beyond unless by chance, through the stress of storms, or by the letting loose of birds.

The Vikings tribe of Norway were an exception. The area of sheltered fiords in their fretted coast exceeds all the arable land in the country. Hardy venturesome seamen grew here from the law of environment, and their vessels also were evolved in a tempestuous ocean and by means of a business very different from trade. In shape these resembled the present whale-boats,(2) which are proved to be the best type for rough seas.

A well-preserved specimen, supposed to have been made about the tenth century, was dug out of a tumulus at Gogstad, Norway, in the spring of 1880.(3) It is 72 feet long, 17 wide, and it probably drew 5 feet of water. There are twenty benches for rowers. Near the middle is a wooden step for a mast, and indications that this might have been lowered at will. The vessels of the Northmen were obviously good sea-boats and from their light draft and the alternative of oars, they must have been very handy in the neighborhood of land, but under canvas they could make no headway unless by "sailing large."

The Phœnicians used the Pole Star in navigating and the ancient mariners of Ceylon regulated their track through the ocean by observing the flight of the birds which they set free at intervals.(4) In this mode, and also from being forced to scud in gales, the Northmen extended

(1) Ezekiel xxvii, 5–7 [about 588 B. C.]. Probably this time was the height of her power.
(2) See frontispiece. *Denmark in the Early Iron Age.* London, 1866. C. Engelhardt.
(3) See *La Nature* for 1880.
(4) *History of Merchant Shipping and Ancient Commerce.* W. S. Lindsay; 4 vols. London, 1874. Vol. I, pp. 14 and 359

ERRATA TO APPENDIX No. 18—COAST AND GEODETIC SURVEY REPORT FOR 1880.

Page 347, 19th line from top: For "for," read "and."

Page 347, 8th line from bottom: For "these facts," read "this fact."

Page 347, 2d line from bottom: Omit the second "of."

Page 350, 3d line from bottom: Between "and" and "are," insert "they."

Page 351, 23d line from bottom: Omit, "'s landfall."

Page 351, 8th line from bottom: For "Hesselgerritz's," read "Hessel Gerritz's."

Page 352, 14th line from top: For "later," read "shortly."

Page 352, 13th and 14th lines from bottom: Omit, "exists only in manuscript but it has been, and is, accessible to scholars," and insert "was printed at Madrid in 5 vols. 8vo., in 1875–'76."

Page 352, 12th line from bottom: For "1559" read "1561."

Page 374, 24th line from top: For "was" read "were."

Page 375, 7th line from bottom: For "later" read "soon."

Page 376, 6th line from top: For "the first" read "his first."

Page 380, 13th line from top: After "above" insert "cited."

Page 385, 15th line from top: After "Columbus" insert "was."

Page 385, 21st line from top: For "about 12," read "12.6."

Page 386, 3d line from bottom: For "has" read "have."

Page 386, 17th line from top: For "all" read "fall."

Page 386, 19th line from bottom: For "be" read "are."

Page 387, top line: For "of" read "from."

Page 387, 5th line from bottom: After "ocean" insert "then."

Page 388, 8th line from top: Omit "speed of the vessels," insert "distance sailed."

Page 388, 10th line from top: After "$9\frac{1}{2}$" insert "nautical, or 11.3 Italian."

Page 388, 3d line from bottom: Omit "and M. Valcknaer."

Page 388, 8th line from bottom: For "Nautic*us*" read "Nautic*as*;" for "Na*r*io" read "Na*v*io."

Page 393, 2d line from bottom: Insert "moisture" between "this and "is."

Page 393, 11th line from bottom: For "bevery" read "be very."

Page 394, top line: For "makes" read "make."

Page 394, 27th line from top: For "were" read "is."

Page 395, 8th line from bottom: Omit "previous," insert "time"; between "it" and "the" insert "in."

Page 396, 21st line from top: Omit "truly;" insert "truthfully" before "answered."

Page 396, 8th line from bottom: After "the," insert "Guanahani and."

Page 397, 13th line from top: After "leagues," insert "and."

Page 397, 13th line from bottom: Omit the last "S" in "S. W. $\frac{1}{4}$ S.;" insert "W."

Page 398, 23d line from top: For "narrative above," read "foregoing narrative."

Page 398, 4th line from bottom: For "another," read "an other."

Page 399, 28th line from top: For "there," read "here."

Page 400, 12th line from top: For "was," read "is."

Page 400, 4th line from bottom: For "A. M. *E.* Elliott," read "A. M. Elliott."

Page 403, 17th line from top; For "was," read "is."

Page 404, bottom line: Omit "above."

Page 405, top line: Insert "above," after "quoted."

Page 407, 3d line from top: For "above log," read "foregoing log."

Page 408, 26th line from top: For "log," read "log line."

Page 410, 7th line from top: Omit the first "and."

their discoveries until finally, in a storm, they saw Greenland in the ninth century and Labrador in the tenth. There is a sequence of land across, which points out the successive steps they took. West 180 miles from Norway, are the Shetlands; thence west-northwest 170, to the Faroes; 240 miles farther, on the same course, lies Iceland; and northwesterly, 165 more, is Greenland. The longest distance is from this to Labrador, 500 miles, whence the coast-line is continuous.

It is indisputable that the Northmen were the ablest seamen and boldest navigators of ancient times; but they were neither traders nor colonizers. The lands which they discovered in the west were supposed to be an extension of the European Continent. They derived no advantage from them, neither did the world. In the graceful language of Washington Irving, "If the Norsemen saw the New World, it was but a transient glimpse, leading to no certain or permanent knowledge, and in a little time lost again to mankind.(1)

Columbus was an efficient seaman and he was also a religious enthusiast—a rare combination. In his correspondence with Toscanelli, in 1474, is the first mention of his decision to seek the Indies by sailing west. Three years afterwards he visited the northern regions, Iceland probably, where he must have found the tradition of western discoveries, although the secret of the Sagas was not published until the last half of the sixteenth century. Whatever he learned there had no influence upon his previous resolution. He did not propose to hunt after the lands which the Northmen had discarded. His purpose was to open a way, by water, to the rich and populous countries spoken of by Marco Polo, for this was linked in his mind with the propagation of the Christian faith and the rescue of the Holy Sepulcher from the Infidels.

Everything essential to such a voyage had been ready for a long time through the growth of navigation. In the previous century, Edward III, of England, had good, stout sailing ships and plenty of seamen. The mariner's compass was in use as early as 1100–1250 A. D.(2) Latitude by observation was familiar to sailors (see Appendix D) and dead reckoning of some kind had always been practiced. Parallels and meridians were applied in the second century. Columbus himself made maps, and globes are mentioned in his journal. This plan, and the reasoning by which he supported it, seem clear enough now; but then every council rejected it. In his letter to the King and Queen of Spain, narrating his fourth voyage, the Admiral wrote: "For seven years was I at your royal court, where every one to whom the enterprise was mentioned treated it as ridiculous; but now there is not a man, down to the very tailors, who does not beg to be allowed to become a discoverer."(3)

His first proposal was to the King of Portugal, to steer west from Lisbon. This would have taken him to America, at a point five miles south of Cape Henlopen; distance, 3,095 miles. Japan is 9,801 miles west from Lisbon; but along the great circle, which goes through Europe and Siberia, it is only 5,768 miles.

Columbus gives no reason for going to the Canary Islands to take his final departure. Irving says it was the damaged state of the Pinta's rudder that led him to go there to exchange it;(4) but on the very day he sailed from Spain, August 3, 1492, he entered in his journal that he was steering for the Canaries,(5) and the mishap to the Pinta was not till the 6th of August.(6) Martin Behem's globe and Toscanelli's map agreed in placing Cipango (Japan) due west from the Canaries. Columbus knew these facts, and his desire to steer across the ocean, *in the same latitude*, was accordant to a usage of navigators which has been given up only since the introduction of chronometers. His going to the Canary Islands was providential, because a west course from there is within the influence of the trade winds, of which he was ignorant, and these wafted him continuously onward, while his crew were grumbling at his persistence. If he had sailed west from Lisbon, or from Palos, he would have been antagonized by variable, and by westerly winds, thus lengthening the passage and thereby adding to the discontents of the men, all of which might have compelled him to abandon his voyage.

(1) *Irving's Columbus.* Revised edition, 1854. Vol. I, Introduction, p. 2.
(2) *Hallam's Middle Ages.* Vol. III, p. 394; and *Ersch und Grüber's Encycl.* III, p. 302.
(3) *Coleccion de los Viages y Descubrimientos, etc.* *Navarrete.* Madrid, 1825. Tomo I, p. 311.
(4) *Irving's Columbus.* Revised edition, 1854. Vol. 1, p. 130.
(5) See Appendix D.
(6) See *Navarrete.* Tomo I, p. 4, August 6; also *prologue*, pp. 2–3.

In his first log across the Atlantic, he likened the weather to that of Andalusia in April. It lacked nothing, he said, except the songs of the nightingales. Such it has been, where he crossed, for æons of time. On this route the vessels of the Crusaders might have gone to America in the twelfth century with less peril than they went from England to Joppa then.

In recent years small boats from the United States have arrived safe in England, in spite of bad weather and faulty observations.

The unfolding of physical laws has dissipated the artificial terrors of the ocean; but in the time of Columbus superstition and ignorance brooded there, making it truly a "sea of darkness," which the imagination only had pierced.

The world is not indebted to the wisdom of the learned for the eventful voyage that opened the oceans to commerce, and continents to trade and settlement. To Columbus belongs the merit of this inestimable boon. He inspired the wise and good Queen Isabella(1) equally with the humble sailors of Palos to put their trust in his scheme. He was as persistent in maintaining it through the rebuffs of eighteen years as he was steadfast in holding to his predetermined course across the Atlantic.

It takes not a jot from the glory of his discovery that he underestimated the size of the earth; or that he died in ignorance of the transcendent importance of his deed; or that the Northmen had preceded him. The fulfilment of his design, to steer west until he reached the Indies or found intervening land, was the triumph of human reasoning; it was the soul's work, into which neither chance nor the fickle winds intruded.

The aim of this monograph is to try to solve the problem of the first landing-place of Columbus in the New World. It is founded, as all others are, upon Las Casas's (abridged) copy of the "log-book", or journal, of Columbus. Nothing has been raked from the arcana of the past to impeach this; and it will continue to be used until the original journal is produced or this copy is shown to be spurious.

It is manifest that no landfall, or track, can stand which is supported by assertions that are in opposition to Las Casas's narrative. Knowing this to be true I have tested in the following pages every track, by placing paragraphs from each author and from the journal in juxtaposition so that any one, with the help of the correct appendix chart, shall discern the contradictions.

The selection of a new landfall, and track through the Bahamas, different from all hitherto ascribed to Columbus, is the natural result of this sifting. The track which I have laid down was chosen because it appears to be the only one that can be made to fit the courses, distances, and descriptions in the log-book.

WASHINGTON, D. C., *May* 31, 1881.

(1) Columbus wrote—*Navarrete*, Vol. I, p. 266—"In the midst of the general incredulity the Almighty infused into the Queen, my lady, the spirit of intelligence and energy, and while every one else, in his ignorance, was expatiating only on the inconvenience and cost, her Highness approved of it, on the contrary, and gave it all the support in her power."

NARRATIVE AND DISCUSSION.

Columbus made four voyages to the New World. The first was from the village of Palos, which he left on Friday, the 3d day of August, 1492, with a squadron of three small vessels and about ninety men. The largest vessel was his flag-ship, the Santa Maria; the next, the Pinta, commanded by Martin Alonso Pinzon; and the smallest, the Niña, under command of Vincente Yañez Pinzon, a brother of Martin. He went directly to the Canaries, where he arrived August 12, and he refitted and reprovisioned his vessels there. Thursday, the 6th of September, he sailed from the harbor of St. Sebastian, in the island of Gomera, but was becalmed among the Canaries until Saturday night, when he met the usual northeast wind and steered west, his predetermined course for the Indies. He crossed the Atlantic and made the land at 2 a.m., Friday, the 12th of October (old style).(1) After sunrise he landed and took formal possession of a small island of the Lucayos [Bahamas], called by the natives Guanahani, but named by him San Salvador. The 15th and 16th of October he visited and named the second island Santa Maria de la Concepcion. The 17th and 18th, and part of the 19th, he was at the third, named by him Fernandina. Part of the 19th, and to the 24th, he explored the shores of the fourth, which he thought the natives called Saomete, but he gave it the name of Isabella. On the 26th he anchored south of seven or eight islands which he called, Sand Islands. Leaving these early on the 27th he brought his squadron to anchor Sunday, the 28th of October, in a harbor of Cuba; this island he named Juana. From this date until December 5 he examined the northeast coast, and the harbors of Cuba; then he crossed over to Hayti, which he called Española. While exploring the harbors and north shore the Santa Maria was wrecked on the evening of December 24, near the present Layeul Bay. This calamity led Columbus to make a settlement from the crew in this bay.

He left here on the 4th of January, 1493, and followed the coast to the bay of Samana. Hence, on the 16th of January, he sailed for Spain. On the 18th he arrived at the Azores, and left there the 24th. On the 4th of March he was compelled by stress of weather to put into Lisbon. He sailed thence the 13th, and on Friday the 15th of March, after an absence of two hundred and twenty-four days, he returned in the Niña, to Palos.

He sailed on his second voyage from Cadiz, Wednesday, the 25th of September, 1493, with three large vessels and fourteen small ones, and about 1,500 men. He anchored at the Canaries and remained from the 1st to the 13th of October; thence, steering more to the southward than on his first voyage, on Sunday the 3d of November he discovered an island which he named Dominica. From here he steered to the northward and westward, visited several of the Caribbean Islands, Porto Rico, north side of Hayti, south side of Cuba, Jamaica, the south side of Hayti, around the east end to the north side, thence to the island of Guadaloupe, and on the 10th of March he left there for Spain and anchored at Cadiz June 11, 1496.

On his third voyage he sailed from San Lucar May 30, 1498, with six vessels; he touched at Porto Santo, Madeira, the Canaries, and anchored June 27 at the Cape de Verd Islands. He left there July 5 and steered still more to the southward, which brought him on the 31st of July to an island which he named Trinidad. The next day, while coasting the south shore, he discovered the continent of South America. He continued along the main land until August 14, when he stood over to Hayti where he was detained for more than a year by the disorganized condition of affairs.

On the 23d of August, 1500, a new governor-general, Don Francisco de Bobadilla, arrived. His instructions were so vague that his wicked heart construed them to permit him to put irons upon the limbs of the discoverer of the New World, and in this pitiable condition Columbus arrived at Cadiz on the 25th of November, 1500.

His fourth and last voyage was also from Cadiz. Leaving there on the 8th of May, 1502, with four small vessels and 150 men he touched on the coast of Morocco, sailed from the Canaries May 25, and anchored at Martinique (2) June 15; thence along Santa Cruz and Porto Rico, and on the 29th

(1) If the Gregorian Calendar of 1582, but which is reckoned from the Council of Nice, is applied to Columbus's discovery, it will make the date Friday, the 21st day of October.

(2) *Irving* and *Major* say Martinique; *Navarrete* says Santa Lucia.

of June he arrived on the south side of Hayti; left there July 14, touched at the Morant Cays, and the islands south of Cuba which he had visited on his second voyage, and then to the small island of Guanaja, or Bonacca, from which on the 30th of July, 1502, he saw, for the first time, the continent of North America. He then followed the coast of Central America and the coast of the Isthmus of Panama to the Gulf of Darien until the 1st of May, 1503, when he sailed for Hayti, but owing to the strong westerly current he brought up among the small islands on the south of Cuba where he had anchored the year before. Near the end of June he put into Jamaica, and his vessels being unseaworthy he remained there until June 28, 1504, when he was rescued and taken to Hayti. On the 12th of September he sailed for Spain and arrived at San Lucar November 7, 1504. He died at Valladolid on the 20th of May, 1506.

From this brief summary of Columbus' voyages to the New World we learn that he visited and named five islands of the Lucayos on his first voyage, but that he remained among them only fifteen days; all his other voyaging was along the coasts and to the islands which border the Caribbean Sea. He never returned to the Lucayos, nor are they often mentioned in the contemporaneous narrations. Within a few years after the death of Columbus, King Ferdinand authorized the transportation of laborers from them to Hayti, to work the mines there. In this way the whole population perished. In the Bahamas, at the present time, there are no descendants of the simple natives described by Columbus.

The chart which Columbus made of the Lucayos, the declarations in writing which signified his formal possession of Guanahani, the journal which he kept for "Their Highnesses," and all the original documents essential to authenticate this historical point, have disappeared.

The contemporaries and acquaintances of Columbus, Peter Martyr, Andres Bernaldes, G. F. de Oviedo, Marco A. Sabelico, Augustus Giustiniani, and his son Fernando, whose writings, or copies thereof, are preserved, give no information which will assist the student to determine the island upon which he first landed. There are four that have been pointed out and argued for most earnestly, which I shall enumerate. Beginning at the southeast the first is Grand Turk Island, in latitude 21° 31′ north, longitude 71° 08′ west from Greenwich. It is 5½ by 1¼ miles, has 6.87 square miles, is generally low, with an elevation at the highest part of 70 feet; bare of trees, and about one-third of the surface is salt and fresh water lagoons. This place is affirmed by *Don M. F. Navarrete Coleccion de los Viages y descubrimientos que hicieron por mar los Españoles desdes fines del siglo*, XV, Madrid, 1825, Tomo I, and supported by *Samuel Kettell, Personal Narrative of the First Voyage of Columbus to America*, Boston, 1827. *George Gibbs, Proceedings of the New York Historical Society*, 1846, Appendix; and *R. H. Major, Select Letters of Columbus*, edition of 1847, London.

The second island is that of Mariguana. The east end is latitude 22° 17′ north, longitude 72° 39′ west from Greenwich. It is 23½ miles long and from 2 to 6½ wide; has about 96 square miles, and is low, with the exception of a hill near the middle 101 feet high, and another at the east end 90 feet. There are neither lakes nor lagoons on the island. This is put forward by *Fr. Adolph de Varnhagen*, who published in Chili, in 1864, a work called *La Verdadera Guanahani de Colon*. He republished it in 1869 at Vienna.

The third is Watling's Island. The latitude of the southeast point is 23° 55′ north, longitude 74° 28′ west from Greenwich. Length north and south 13 miles, and breadth about 5 to 7. It has 60 square miles. Near the center is a hill of 140 feet. A lagoon of brackish water takes up one third of the island. *Juan Bautista Muñoz* first chose Watling in his *Historia del Nuevo Mundo*, Madrid, 1793, Tomo I. He is sustained by *Capt. A. B. Becher, Royal Navy*, author of *Land Fall of Columbus*, London, 1856. *O. Peschel, Geschichte der Entdeckungen*, Stuttgart and Augsburg, 1858; and *R. H. Major, Journal of the Royal Geographical Society*, vol. XLI, May 8, 1871, wherein he recants his former approval of Grand Turk and adopts that of Captain Becher.

The fourth island is that known as Cat, or San Salvador. The southeast end is latitude 24° 09′ north, longitude 75° 18′ west from Greenwich. Northwest and southeast it is 43 miles, and the breadth 2½ to 3½ miles. At the southeast end a part runs west-southwest 10 miles, with a width of 3½. There are 160 square miles in it. At the northwest end the hills rise to 400 feet, and are the highest land in the Bahamas. It has neither lakes nor lagoons. The principal writers who have adopted Cat are *Catesby, Natural History of Carolina*, 1731. *A New Collection of Voyages and*

Travels, J. Knox, London, 1767. An elaborate note in the *Second Volume of the French Translation of Navarrete, p.* 339, Paris, 1828; the author of this note is *Mr. De La Roquette. Revue nautique du premier voyage de Christophe Colomb au nouveau monde par M. le Baron de Montlezun, Nouvelles Annales des Voyages et des Sciences Geographiques Deuxième Série.* Tome X, Paris, 1828, and Tome XII, Paris, 1829. *Washington Irving, Life and Voyages of Christopher Columbus*, London, 1828, revised edition, New York, 1848; in the third volume of this edition, appendix, p. 380, Irving gives the authorship of his track to the late Commander Alexander Slidell Mackenzie, United States Navy. Baron Alexander von Humboldt argues, most ably, in favor of the route selected by Irving and Mackenzie, in *Examin critique de l'histoire de la geographie du nouveau continent*, 1837.

Irving and Humboldt, as well as some other writers, allege that Cat Island has the sanctity of tradition in favor of it. An impression to this effect certainly prevails, but as those who have adopted it do not give their authority, I can only offer to the reader that which freed my mind from its influence. The Spaniards were the discoverers of the New World; they made the first maps of the West Indies; for a long time they were the exclusive explorers there; they obtained, and have now, more of the lore of these regions than can be found among all other nations. If any tradition truly exists it ought to be found in Spain, in the writings of her historians. None of those I have cited mention it. On the contrary, Muñoz and Navarrete, who had access to the documents of Columbus and his contemporaries, and who each pointed out a landfall, differ; neither selecting Cat (*ante*, p. 350), which is proof that there is no tradition in relation it to in the country which alone could give it legitimate birth.

It is true that some maps can be referred to in support of a claim for Cat. But the identification of Guanahani, or San Salvador, with Cat is not earlier than the seventeenth century. Perhaps the first is on *Atlas Minor, by Blaeu, West Indies*, 1635, which is the same as a map published by *Joannes de Laet, at Leden*, 1625, titled, *Niewe Wereldt.* They are identical also in *Blaeu's Atlas*, Tome XII, *Amerique*, Amsterdam, 1667, and *Dorzieme, Continent l'Amerique*, Amsterdam, 1667. In the eighteenth century more maps were published, and the identity of Cat with San Salvador received additional support. See *Map of North America by John Senex, Charles Price, and John Maxwell*, 1710; *North America and West Indies, by Emanuel Bowen*, 1733?; *D'Anville, Map of* 1746; *The West India Atlas, by the late Thomas Jefferys*, 1775; *Laurie and Whittle*, 1794; and a *Spanish Chart of the Antilles, by Langara*, 1799.)

In Major's landfall (pp. 207–210) are collated the ancient and modern names of most of the Bahamas, ten of which he asserts can be identified. I cite only such as I wish to use in my argument:

He says that Guanahani is the present Watling; Guanima the present Cat or San Salvador; Mayaguana the present Mariguana; and Samana, the present Samana or Atwood Cay.

He considers that the identification of these four, as well as the other six, involves the whole question of the landfall, and he is so certain of it that he puts Senhor de Varnhagen "out of court" (p. 208), because his Mariguana appears on the old maps *with* Guanahani.

Major does not furnish the evidence to enable us to see that Guanahani is Watling. He refers to Herrera's map of 1601, with the expectation that we shall be as easily satisfied as he was. Looking at this map I notice three little islands marked triangula, and northwest of them is Guanahani.

On *Nicolas Vallard's Map of New Spain*, 1547, and the *Munich Collection*, plate x, and plate xiii, 1592, this Triango appears.

On *Anthony Jacobsz' Map of America and West Indies*, 1621, we find Triangulo.

On *Hesselgerritz's Dutch Chart*, about 1650, and *Sanson D'Abbiville's* map of 1656, there is Triangulo.

In *Otten's Atlas Minor*, Vol. IV, titled *Nova Tabula exhibens insulas, etc.*, there is a map which is the same as a map published by d'Anville in *Charlevoix's Histoire de l'isle Espagnole*, Paris, 1730. On these maps we find Triangolo *ou Watlins I.*

On *Sayer's Map*, November 1, 1792, and *Jeffery's Atlas*, 1794, there is *El triangulo, Watlands or Watling.*

These citations prove that the old maps, and especially Herrera's, to which Major calls attention, had two islands placed near each other which were called, respectively, Guanahani and triango, or Triangulo. It is the former that Major says is the present Watling; but from these maps it appears that *triango*, or *Triangulo*, is that now called Watling.

The earliest date I have found for Guanima [Cat] is a map in the Jomard collection styled *Mappe Monde Peinte sur parchmen par ordre Henri II Roi de France* (*I Partie*). M. D. Avezac makes the date of this 1532. Here are Guanima, Maynana [Mariguana], and one little island intermediate, to which are applied the *two names* of "Guanahani", "Samana." This is remarkable, as showing a connection between them at an early date.

A great part of the maps of the sixteenth and seventeenth centuries have Guanima and Mayaguana as outside islands, with Guanahani lying between; and inside of these is placed Samana. Triangulo or triango appears, but not so often. All this indicates that the information transmitted to the early map-makers included the fact that Guanahani or San Salvador was an island *distinct* from Guanima [Cat], Mayaguana [Mariguana], Triangulo [Watling], and Samana. This last is asserted to be the present Samana or Atwood Cay but I hope to prove, later, that it was the ancient name of the Crooked Island group, and thus save myself from being, as Major said of Varnhagen, "put out of court."

The valuable map of La Cosa, which I shall remark upon, fixed the position of Guanahani about the middle of the northeast side of the Bahamas. Herrera and others copy it. Such a situation is so mathematically conspicuous, and so easily followed, that we ought to find Guanahani or San Salvador retained here on later maps, in spite of the alterations involved in improved cartography. This has been the case. In the absence of determining data as to which one was the true San Salvador, this name has been applied, fortuitously, to several neighboring islands, but with the exception of Navarrete's chart, the *location* is where the companion of Columbus put it.

The old charts can be appealed to in corroboration of parts of this investigation, but consentaneity in respect to the first landfall will never be reached by their evidence. Fortunately a copy of Columbus's journal in the Bahamas has been preserved, but it has been construed so differently that all the authors of the four tracks referred to found their arguments upon this document.

About 1790, Navarrete, a civil officer of the marine department of Spain, found in the archives of the Duke del Infantado a manuscript narrative of the first voyage of Columbus, abridged from the original. It proved to be in the handwriting of Bishop Las Casas, a contemporary and companion of Columbus, who had visited the new world several times. He wrote a general history of the Indies, in three volumes, from the discovery in 1492 to 1520, which exists only in manuscript, but it has been, and is, accessible to scholars. Las Casas was engaged upon this history from 1527 to 1559, and he had before him the original journals of Columbus, his map of the first discovery, and many letters and documents, now lost. In the year 1825 the Spanish Government published this precious narrative, together with other valuable papers relating to Columbus. It is a matter of sincere regret that Las Casas abridged, in any degree, the "log-book" of such an eventful voyage, but we are thankful that he transcribed Columbus's words literally, from the landfall at Guanahani to the 29th of October, because it is this part only that is essential to prove the true landing-place.

Kettell has translated into English all of Las Casas's abridgement of Columbus's first voyage, and Irving, Major, and Captain Becher such parts as they considered necessary to their respective arguments. Here will be found the Spanish text from the first edition of Navarrete, 1825, vol. I, pp. 18–42, in parallel columns with the English by Mr. H. L. Thomas, translator of the United States State Department, at Washington. With respect to the disputed parts of the journal care has been taken to have a strict rendering of the Spanish.

Miercoles 10 *de Octubre.*

Navegó al Ouesudueste, anduvieron á diez millas por hora y á ratos doce y algun rato á siete, y entre dia y noche cincuenta y nueve leguas: contó á la gente cuarenta y cuatro leguas no mas. Aquí la gente ya no lo podia sufrir: quejabase del largo viage; pero el Almirante los esforzó lo mejor que pudo dándoles buena esperanza de los provechos que podrian haber. Y añadia que por demas era quejarse, pues que él habia venido á las Indias, y que así lo habia de proseguir hasta hallarlas con el ayuda de nuestro Señor.

Jueves 11 *de Octubre.*

Navegó al Ouesudueste, tuvieron mucha mar mas que en todo el viage habian tenido. Vieron pardelas y un junco verde junto á la nao. Vieron los de la carabela Pinta una caña y un palo, y tomaron otro palillo labrado á lo que parecia con hierro, y un pedazo de caña y otra yerba que nace en tierra, y una tablilla. Los de la carabela Niña tambien vieron otras señales de tierra y un palillo cargado descaramojos(¹). Con estas señales respiraron y alegráronse todos. Anduvieron en este dia hasta puesto el sol veinte y siete leguas.

Despues del sol puesto navegó á su primer camino al Oueste: andarian doce millas cada hora, y hasta dos horas despues de media noche andarian noventa millas, que son veinte y dos leguas y media. Y porque la carabela Pinta era mas velera é iba delante del Almirante, halló tierra y hizo las señas quel Almirante habia mandado. Esta tierra vido primero un marinero que se decia Rodrigo de Triana; puesto que el Almirante á las diez de la noche, estando en el castillo de popa, vido lumbre, aunque fue cosa tan cerrada que no quiso afirmar que fuese tierra; pero llamó á Pero Gutierrez, repostero destrados del Rey, é díjole, que parecia lumbre, que mirase él, y asi lo hizo y vídola: díjolo tambien á Rodrigo Sanchez de Segovia quél Rey y la Reina enviaban en el armada por veedor, el cual no vido nada porque no estaba en lugar dó la pudiese ver. Despues quel Almirante lo dijo se vido una vez ó dos, y era como una candelilla de cera que se alzaba y levantaba, lo cual á pocos pareciera ser indicio de tierra. Pero el Almirante tuvo por cierto estar junto á la tierra. Por lo cual cuando dijeron la *Salve*, que la acostumbran decir é

(¹) Por *de escaramujos.*

Wednesday October 10*th.*

He sailed west southwest, at the rate of ten miles an hour and occasionally twelve, and at other times seven, running between day and night fifty nine leagues: he told the men only forty four. Here the crew could stand it no longer, they complained of the long voyage, but the Admiral encouraged them as best he could giving them hopes of the profits that they might have. And he added that it was useless to murmur because he had come to [in quest of?] the Indies, and was so going to continue until he found them with God's help.

Thursday October 11*th.*

He sailed to the west-southwest, had a high sea, higher than hitherto. They saw pardelas(¹) and floating by the vessel a green rush. The men of the Pinta saw a reed and a stick, and got a small stick apparently cut or worked with an iron instrument, and a piece of cane and some other grass which grows on the land, and a small board. Those of the Caravel Niña also saw other indications of land and a little stick loaded with dog roses. In view of such signs they breathed more freely and grew cheerful. They ran until sunset of that day twenty seven leagues. After sunset he sailed on his first course to the West: they went about twelve miles an hour, and two hours after midnight they had run about ninety miles, that is twenty two and a half leagues. As the Caravel Pinta was a better sailer and had the lead, she made land and showed the signals ordered by the Admiral. The land was first seen by a sailor called Rodrigo de Triana:(²) as the Admiral at ten o'clock at night standing on the castle of the poop saw a light, but so indistinct that he did not dare to affirm that it was land; yet he called the attention of Pero Gutierrez, a King's butler to it, and told him that it seemed to be a light, and told him to look, he did so and saw it: he did the same with Rodrigo Sanchez de Segovia, whom the King and Queen had sent with the fleet as supervisor and purveyor, but

(¹) Pardelo—a name given by the Spanish to a bird of a gray color, or white and black. *Dominguez Dictionary*—Madrid 1878.

(²) It was first discovered by a mariner named Rodriguez Bermejo, resident of Triana, a suburb of Seville, but native of Alcala de la Guadaira; but the reward was afterwards adjudged to the Admiral, for having previously perceived the light. *W. Irving's Abridged Columbus.* New York, 1847. p. 60.

cantar á su manera todos los marineros y se hallan todos, rogó y amonestólos el Almirante que hiciesen buena guarda al castillo de proa, y mirasen bien por la tierra, y que al que le dijese primero que via tierra le daria luego un jubon de seda, sin las otras mercedes que los Reyes habian prometido, que eran diez mil maravedis de juro á quien primero la viese. A las dos horas despues de media noche pareció la tierra, de la cual estarian dos leguas. Amañaron(1) todas las velas, y quedaron con el treo(2) que es la vela grande sin bonetas, y pusiéronse á la corda(3) temporizando hasta el dia Viernes que llegaron á una isleta de los Lucayos, que se llamaba en lengua de indios *Guanahani*(4). Luego vieron gente desnuda, y el Almirante salió á tierra en la barca armada, y Martin Alonso Pinzon y Vicente Anes(5), su hermano, que era capitan de la Niña. Sacó el Almirante la bandera Real y los capitanes con dos banderas de la Cruz Verde, que llevaba el Almirante en todos los navíos por seña con una F y una Y: encima de cada letra su corona, una de un cabo de la ✠ y otra de otro. Puestos en tierra vieron árboles muy verdes y aguas muchas y frutas de diversas maneras. El Almirante llamó á los dos capitanes y á los demas que saltaron en tierra, y á Rodrigo Descovedo, Escribano de toda el armada, y á Rodrigo Sanchez de Segovia, y dijo que le diesen por fe y testimonio como él por ante todos tomaba, como de hecho tomó, posesion de la dicha isla por el Rey é por la Reina sus señores, haciendo las protestaciones que se requirian, como mas largo se contiene en los testimonios que allí se hicieron por escripto. Luego se ayuntó allí mucha gente de la isla. Esto que se sigue son palabras forma-

(1) *Amañaron* por *amainaron*.

(2) *Treo*, vela cuadrada que se ponia solo cuando habia mal tiempo para correr.

(3) *Ponerse á la corda*, es ponerse al pairo ó atravesado para no andar ni decaer del punto en que se está.

(4) Examinado detenidamente este diario, sus derrotas, recaladas, señales de las tierras, islas, costas y puertos, parece que esta primera isla que Colon descubrió y pisó, poniéndole por nombre *S. Salvador*, debe ser la que está situada mas al Norte de las turcas llamada *del Gran Turco*. Sus circumstancias conforman con la descripcion que Colon hace de ella. Su situacion es por el paralelo de 21°. 30′, al Norte de la medianía de la isla de Santo Domingo.

(5) Debe decir *Yañez*.

he, not being in a good position for seeing it, saw nothing. After the Admiral said this it was seen once or twice, and it was like a small wax candle that was being hoisted and raised, which would seem to few to be an indication of land. The Admiral however was quite convinced of the proximity of land. In consequence of that when they said the *Salve*, which they used to say and sing it in their way, all the sailors and all being present, the Admiral requested and admonished them to keep a sharp look out at the castle of the bow, and to look well for land, and said that he would give to him who first saw land a silk doublet, besides the other rewards that the King and Queen had promised, namely an annual pension of ten thousand maravedis(1) to him who should see it first. Two hours after midnight the land appeared, about two leagues off. They lowered all the sails, leaving only a storm square sail, which is the mainsail without bonnets, and lay to until Friday when they reached a small island of the Lucayos, called *Guanahani* by the natives. They soon saw people naked, and the Admiral went on shore in the armed boat, also Martin Alonso Pinzon and Vincente Anes,(2) his brother, who was commander of the Niña. The Admiral took the Royal standard and the captains with two banners of the Green Cross, which the Admiral carried on all the ships as a distinguishing flag having an F and a Y: each letter surmounted by its crown, one at one arm of the cross, and the other at the other arm. As soon as they had landed they saw trees of a brilliant green abundance of water and fruits of various kinds. The Admiral called the two captains and the rest who had come on shore, and Rodrigo Descovedo, the Notary of all the fleet, and Rodrigo Sanchez de Segovia, and he called them as witnesses to certify that he in presence of them all, was taking, as he in fact took possession of said island for the King and Queen his masters, making the declarations that were required as they will be found more fully in the attestations then taken down in writing. Soon after a large crowd of natives congregated there. What follows are the Admiral's own words in his book on the first voyage and discovery of these Indies. "In order to win the friendship and affection of that people, and be-

(1) One cent equals 2.7625 maravedis. *Irving's Columbus* revised edition 1848. Appendix p. 381.

(2) It ought to be Yañez. Navarrete.

les del Almirante, en su libro de su primera navegacion y descubrimiento de estas Indias. „Yo (dice él) porque nos tuviesen mucha amistad, porque conoscí que era gente que mejor se libraria y convertiria á nuestra Santa Fé con amor que no por fuerza; les dí á algunos de ellos unos bonetes colorados y unas cuentas de vidrio que se ponian al pescuezo, y otras cosas muchas de poco valor con que hobieron mucho placer y quedaron tanto nuestros que era maravilla. Los cuales despues venian á las barcas de los navíos adonde nós estabamos, nadando y nos traian papagoyos y hilo de algodon en ovillos y azagayas, y otras cosas muchas, y nos las trocaban por otras cosas que nós les dabamos, como cuentecillas de vidrio y cascabeles. En fin todo tomaban y daban de aquello que tenian de buena voluntad. Mas me pareció que era gente muy pobre de todo. Ellos andan todos desnudos como su madre los parió, y tambien las mugeres, aunque no vide mas de una farto moza, y todos los que yo ví eran todos mancebos, que ninguno vide de edad de mas de treinta años: muy bien hechos, de muy fermosos cuerpos, y muy buenas caras: los cabellos gruesos cuasi como sedas de cola de caballos, é cortos: los cabellos traen por encima de las cejas, salvo unos pocos de tras que traen largos, que jamas cortan: dellos se pintan de prieto, y ellos son de la color de los canarios, ni negros ni blancos, y dellos se pintan de blanco, y dellos de colorado, y dellos de lo que fallan, y dellos se pintan las caras, y dellos todo el cuerpo, y dellos solos los ojos, y dellos solo el nariz. Ellos no traen armas ni las cognocen, porque les amostré espadas y las tomaban por el filo, y se cortaban con ignorancia. No tienen algun fierro: sus azagayas son unas varas sin fierro, y algunas de ellas tienen al cabo un diente de pece, y otras de otras cosas. Ellos todos á una mano son de buena estatura de grandeza, y buenos gestos, bien hechos; yo vide algunos que tenian señales de feridas en sus cuerpos, y les hice señas que era aquello, y ellos me amostraron como allí venian gente de otras islas que estaban acerca y les querian tomar, y se defendian; y yo creí, é creo, que aquí vienen de tierra firme á tomarlos por captivos. Ellos deben ser buenos servidores y de buen ingenio, que veo que muy presto dicen todo lo que les decia, y creo que ligeramente se harian cristianos, que me pareció que ninguna secta tenian. Yo, placiendo á nuestro Señor, levaré de aquí al tiempo de mi partida seis á V. A. para que deprendan fablar.

cause I was convinced that their conversion to our Holy Faith would be better promoted through love than through force; I presented some of them with red caps and some strings of glass beads which they placed around their necks, and with other trifles of insignificant worth that delighted them and by which we have got a wonderful hold on their affections. They afterwards came to the boats of the vessels swimming, bringing us parrots cotton thread in balls and spears, and many other things, which they bartered for others we gave them, as glass beads and little bells. Finally they received every thing and gave whatever they had with good will. But I thought them to be a very poor people. All of them go about naked as when they came into the world, even the women, although I saw but one very young girl, all the rest being young men, none of them being over thirty years of age: their forms being very well proportioned, their bodies graceful and their features handsome: their hair is as coarse as the hair of a horse's tail and cut short: they wear their hair over their eye brows except a little behind which they wear long, and which they never cut: some of them paint themselves black, and they are of the color of the Canary islanders, neither black nor white, and some paint themselves white, and some red, and some with whatever they find, and some paint their faces, and some the whole body, and some their eyes only, and some their noses only. They do not carry arms and have no knowledge of them, for when I showed them the swords they took them by the edge, and through ignorance, cut themselves. They have no iron: their spears consist of staffs without iron, some of them having a fish's tooth at the end, and others other things. As a body they are of good size, good demeanor, and well formed; I saw some with scars on their bodies, and to my signs asking them what these meant, they answered in the same manner, that people from neighboring islands wanted to capture them, and they had defended themselves; and I did believe, and do believe, that they came from the main land to take them prisoners. They must be good servants and very intelligent, because I see that they repeat very quickly what I told them, and it is my conviction that they would easily become Christians, for they seem not to have any sect. If it please our Lord, I will take six of them from here to your Highnesses on my departure, that they may

Ninguna bestia de ninguna manera vide, salvo papagayos en esta isla." Todas son palabras del Almirante.

Sabado 13 de Octubre.

„Luego que amaneció vinieron á la playa muchos destos hombres, todos mancebos, como dicho tengo, y todos de buena estatura, gente muy fermosa: los cabellos no crespos, salvo corredios y gruesos, como sedas de caballo, y todos de la frente y cabeza muy ancha mas que otra generacion que fasta aquí haya visto, y los ojos muy fermosos y no pequeños, y ellos ninguno prieto, salvo de la color de los canarios, ni se debe esperar otra cosa, pues está Lesteoueste con la isla del Hierro([1]) en Canaria so una línea. Las piernas muy derechas, todos á una mano, y no barriga, salvo muy bien hecha. Ellos vinieron á la nao con almadias, que son hechas del pie de un árbol, como un barco luengo, y todo de un pedazo, y labrado muy á maravilla segun la tierra, y grandes en que en algunas venian cuarenta ó cuarenta y cinco hombres, y otras mas pequeñas, fasta haber dellas en que venia un solo hombre. Remaban con una pala como de fornero, y anda á maravilla; y si se le trastorna luego se echan todos á nadar, y la enderezan y vacian con calabazas que traen ellos. Traían ovillos de algodon filado y papagayos, y azagayas, y otras cositas que seria tedio de escrebir, y todo daban por cualquiera cosa que se los diese. Y yo estaba atento y trabajaba de saber si habia oro, y vide que algunos dellos traían un pedazuelo colgado en un agujero que tienen á la nariz, y por señas pude entender que yendo al Sur ó volviendo la isla por el Sur, que estaba allí un Rey que tenia grandes vasos dello, y tenia muy mucho. Trabajé que fuesen allá, y despues vide que no entendian en la ida. Determiné de aguardar fasta mañana en la tarde, y despues partir para el Sudueste, que segun muchos dellos me enseñaron decian que habia tierra al Sur y al Sudueste y al Norueste, y questas del Norueste les venian á combatir muchas veces, y asi ir al Sudueste á buscar el oro y piedras preciosas. Esta isla es bien grande y muy llana y de árboles muy verdes, y muchas aguas, y una laguna en medio muy grande, sin ninguna montaña, y toda ella verde, ques placer de mirarla; y esta gente farto mansa, y por la gana de haber de nuestras cosas, y teniendo que no se les ha de dar sin

([1]) La verdadera situacion de esta isla respecto á la del Hierro es O. 5° S. — E. 5° N.

learn to speak. I have seen here no beasts whatever, but parrots only." All these are the words of the Admiral.

Saturday October 13th.

"At dawn many of these men came down to the shore, all are, as already said, youths of good size and very handsome: their hair is not wooly, but loose and coarse like horse hair, they have broader heads and foreheads than I have ever seen in any other race of men, and the eyes very beautiful not small, none of them are black, but of the complexion of the inhabitants of the Canaries, as it is to be expected, for it is east [and] west with the island of Hierro in the Canaries in the same line. All without exception have very straight limbs, and no bellies, and very well formed. They came to the ship in canoes, made out of trunks of trees all in one piece, and wonderfully built according to the locality, in some of them forty or forty five men came, others were smaller, and in some but a single man came. They paddled with a peel like that of a baker, and make wonderful speed; and if it capsizes all begin to swim and set it right again, and bail out the water with calabashes which they carry. They brought balls of spun cotton parrots, spears and other little things which would be tedious to describe, and gave them away for any thing that was given to them. I examined them closely and tried to ascertain if there was any gold, and noticed that some carried a small piece of it hanging from a little hole in their nose, and by signs I was able to understand that by going to the south or going around the island to the southward, there was a king who had large gold vessels, and gold in abundance. I endeavored to persuade them to go there, and I afterwards saw that they had no wish to go. I determined to wait until tomorow evening, and then to sail for the southwest, for many of them told me that there was land to the south and to the southwest and to the northwest, and that those from the northwest came frequently to fight with them, and so go to the southwest to get gold and precious stones. This island is very large and very level and has very green trees, and abundance of water, and a very large lagoon in the middle, without any mountain, and all is covered with verdue, most pleasing to the eye; the people are remarkably gentle, and from the desire to get some of our things, and thinking that nothing will be given to them que den algo y no lo tienen, toman lo que pueden y se echan luego á nadar; mas todo lo que tienen lo dan por cualquiera cosa que les den; que fasta los pedazos de las escudillas, y de las tazas de vidrio rotas rescataban, fasta que ví dar diez y seis ovillos de algodon por tres ceotis(1) de Portugal, que es una blanca de Castilla, y en ellos habria mas de una arroba de algodon filado. Esto defendiera y no dejára tomar á nadie, salvo que yo lo mandára tomar todo para V. A. si hobiera en cantidad. Aquí nace en esta isla, mas por el poco tiempo no pude dar así del todo fé, y tambien aquí nace el oro que traen colgado á la nariz; mas por no perder tiempo quiero ir á ver si puedo topar á la isla de Cipango(2). Agora como fue noche todos se fueron á tierra con sus almadias."

Domingo 14 de Octubre.

,,En amaneciendo mandé aderezar el batel de la nao y las barcas de las carabelas, y fue al luengo de la isla, en el camino del Nornordeste, para ver la otra parte, que era de la otra parte del Leste que habia, y tambien para ver las poblaciones, y vide luego dos ó tres y la gente, que venian todos á la playa llamándonos y dando gracias á Dios; los unos nos traían agua, otros otras cosas de comer; otros, cuando veían que yo no curaba de ir á tierra, se echaban á la mar nadando y venian, y entendiamos que nos preguntaban si eramos venidos del cielo; y vino uno viejo en el batel dentro, y otros á voces grandes llamaban todos hombres y mugeres: venid á ver los hombres que vinieron del cielo: traedles de comer y de beber. Vinieron muchos y muchas mugeres, cada uno con algo, dando gracias á Dios, echándose al suelo, y levantaban las manos al cielo, y despues á voces nos llamaban que fuésemos á tierra: mas yo temia de ver una grande restinga de piedras que cerca toda aquella isla al rededor, y entre medias queda hondo y puerto para cuantas naos hay en toda la cristiandad, y la entrada dello muy angosta. Es verdad que dentro desta cinta

(1) Por *Ceuti ó cepti*, moneda de Ceuta que corria en Portugal.

(2) Marco Polo en el cap. cvi de la relacion de su viage asegura haber visto esta isla, de la cual hace una larga descripcion, y añade que estaba situada en alta mar, á distancia de 1500 millas del continente de la India. El Dr. Robertson dice que probablemente es el Japon. *Recherches hist. sur l'Inde ancienne, sec.* 3.

unless they give some thing, and having nothing they take what they can and swim off [to the ship]; but all that they have they give for any thing that is offered to them; so that they bought even pieces of crockery, and pieces of broken glass, and I saw sixteen balls of cotton given for three ceotis(1) of Portugal, which is equivalent to a blanca of Castile, and in them there must have been more than one arroba(2) of spun cotton. I forbad this and allowed no one to take any unless I ordered it to be taken for your Highnesses should it be found in abundance. It grows in the island, although on account of the shortness of time I could not assert it positively, and likewise the gold which they carry hanging in their noses is found here; but in order to lose no time I am now going to try if I can find the island of Cipango. At this moment it is dark and all went on shore in their canoes."

Sunday October 14.

"At dawn I ordered the boat of the ship and the boats of the Caravels to be got ready, and went along the island, in a north-northeasterly direction, to see the other side, which was on the other side of the east, and also to see the villages, and soon saw two or three and their inhabitants, coming to the shore calling us and praising God; some brought us water, some eatables; others, when they saw that I did not care to go on shore, plunged into the sea swimming and came, and we understood that they asked us if we had come down from heaven; and one old man got into the boat, while others in a loud voice called both men and women saying: come and see the men from heaven: bring them food and drink. A crowd of men and many women came, each bringing something, giving thanks to God, throwing themselves down, and lifting their hands to heaven, and entreating or beseeching us to land there: but I was afraid of a reef of rocks which entirely surrounds that island, although there is within it depth enough and ample harbor for all the vessels of christendom, but the entrance is very narrow. It is true that the interior of that belt contains some rocks, but the sea is there as still as the water in a well. And in order to see all this I moved this morning, that I might

(1) Copper coin of the value of half a maravedi—*Spanish Dictionary.*

(2) Equal to 25.353145 pounds. *Modern Metrology:* Lewis D'A. Jackson: London, p. 310.

hay algunas bajas, mas la mar no se mueve mas que dentro en un pozo. Y para ver todo esto me moví esta mañana, porque supiese dar de todo relacion á vuestras Altezas, y tambien á donde pudiera hacer fortaleza, y vide un pedazo de tierra que se hace como isla, aunque no lo es, en que habia seis casas, el cual se pudiera atajar en dos dias por isla; aunque yo no veo ser necesario, porque esta gente es muy simplice en armas, como verán vuestras Altezas de siete que yo hice tomar para le llevar y deprender nuestra fabla y volvellos, salvo que vuestras Altezas cuando mandaren puedenlos todos llevar á Castilla, ó tenellos en la misma isla captivos, porque con cincuenta hombres los terná todos sojuzgados, y les hará hacer todo lo que quisiere; y despues junto con la dicha isleta estan huertas de árboles las mas hermosas que yo ví, é tan verdes y con sus hojas como las de Castilla en el mes de Abril y de Mayo, y mucha agua. Yo miré todo aquel puerto, y despues me volví á la nao y dí la vela, y vide tantas islas que yo no sabia determinarme á cual iria primero, y aquellos hombres que yo tenia tomado me decian por señas que eran tantas y tantas que no habia número, y anombraron por su nombre mas de ciento([1]). Por ende yo miré por la mas grande([2]), y aquella determiné andar, y así hago y será lejos desta de *San Salvador*, cinco leguas y las otras dellas mas, dellas menos: todas son muy llanas, sin montañas y muy fértiles, y todas pobladas, y se hacen guerra la una á la otra, aunque estos son muy simplices y muy lindos cuerpos de hombres."

Lunes 15 de Octubre.

„Habia temporejado esta noche con temor de no llegar á tierra á sorgir antes de la mañana por no saber si la costa era limpia de bajas, y en amaneciendo cargar velas. Y como la isla fuese mas lejos de cinco leguas, antes será siete, y la marea me detuvo, seria medio dia cuando llegué á la dicha isla, y fallé que aquella haz, ques de la parte de la isla de *San Salvador*, se corre Norte Sur, y hay en ella cinco leguas, y la otra que yo seguí se corria Leste Oueste, y hay en ella mas de diez leguas. Y como desta isla vide otra mayor al Oueste,

([1]) La multitud de estas islas indica que deben ser las que forman *los Caicos, las Inaguas chica y grande, Mariguana*, y demas que se hallan al Oeste.

([2]) Esta isla grande debe ser la que llaman *Gran Caico*, y dista de la primera 6¼ leguas.

give an account of everything to your Highnesses, and also to see where a fort could be built, and found a piece of land like an island, although it is not one, with six houses on it, which in two days could easily be cut off and converted into an island; such a work however is not necessary in my opinion, because the people are totally unacquainted with arms, as your Highnesses will see by observing the seven whom I have caused to be taken in order to carry them to Castile to be taught our language, and to return them unless your Highnesses when they shall send orders may take them all to Castile, or keep them in the same island as captives, for with fifty men all can be kept in subjection, and made to do whatever you desire; and near by the said little island there are orchards of trees the most beautiful that I have seen, with leaves as fresh and green as those of Castile in April and May, and much water. I observed all that harbor, and afterwards I returned to the ship and set sail, and saw so many islands that I could not decide to which one I should go first, and the men I had taken told me by signs that they were innumerable, and named more than one hundred of them. In consequence I looked for the largest one and determined to make for it, and I am so doing, and it is probably distant five leagues from this of *San Salvador*, the others some more, some less: all are very level, without mountains and of great fertility, and all are inhabited, and they make war upon each other, although these are very simple hearted and very finely formed men."

Monday October 15th.

"I had been standing off and on this night fearing to approach the shore for anchorage before morning not knowing whether the coast would be clear of shoals, and intending to clew up at dawn. And as the island was over five leagues distant, rather seven, and the tide detained me, it was about noon when I reached the said island, and I found that that side, which is towards the island of *San Salvador* runs north [and] south, and is five leagues in length, and the other which I followed ran east [and] west, and contains over ten leagues. And as from this island I saw another larger one to the west, I clewed up the sails for I had gone all that day until night, because I could not yet have gone to the western cape, cargué las velas por andar todo aquel dia fasta la noche, porque aun no pudiera haber andado al cabo del Oueste, á la cual puse nombre la *isla de Santa María de la Concepcion*(1), y cuasi al poner del sol sorgí acerca del dicho cabo por saber si habia allí oro, porque estos que yo habia hecho tomar en la isla de S. Salvador me decian que ahí traian manillas de oro muy grandes á las piernas y á los brazos. Yo bien creí que todo lo que decian era burla para se fugir. Con todo, mi voluntad era de no pasar por ninguna isla de que no tomase posesion, puesto que tomado de una se puede decir de todas; y sorgí é estuve hasta hoy Martes que en amaneciendo fuí á tierra con las barcas armadas, y salí, y ellos que eran muchos así desnudos, y de la misma condicion de la otra isla de San Salvador, nos dejaron ir por la isla y nos daban lo que les pedia. Y porque el viento cargaba á la traviesa Sueste no me quise detener y partí para la nao, y una almadia grande estaba abordo de la carabela Niña, y uno de los hombres de la isla de San Salvador, que en ella era, se echó á la mar y se fue en ella, y la noche de antes á medio echado el otro(2)   y fue atrás la almadia, la cual fugió que jamas fue barca que le pudiese alcanzar, puesto que le teniamos grande avante. Con todo dió en tierra, y dejaron la almadia, y alguno de los de mi compañía salieron en tierra tras ellos, y todos fugeron como gallinas, y la almadia que habian dejado la llevamos abordo de la carabela Niña, adonde ya de otro cabo venia otra almadia pequeña con un hombre que venia á rescatar un ovillo de algodon, y se echaron algunos marineros á la mar porque él no queria entrar en la carabela, y le tomaron; y yo que estaba á la popa de la nao, que vide todo, envié por él, y le dí un bonete colorado y unas cuentas de vidrio verdes pequeñas que le puse al brazo, y dos cascabeles que le puse á las orejas, y le mandé volver su almadia que tambien tenia en la barca, y le envié á tierra; y dí luego la vela para ir á la otra isla grande que yo via al Oueste, y mandé largar tambien la otra almadia que traia la carabela Niña por popa, y vide des-

(1) Esta parece ser la que hoy se llama *Caico del Norte;* aunque con el nombre de *Santa María de la Concepcion* comprendió todo el grupo de las islas immediatas que se llaman *los Caicos,* como se nota mas adelante en el dia 16 de Octubre.

(2) Con la ininteligible escritura de esta palabra en el original, y el vacío ó hueco que sigue, queda obscuro el sentido del período. Acaso quiso decir: *y la noche de antes al medio se echó el otro á nado, y fue atrás la almadia, &c.*

to which(1) I gave the name of the *island of Santa María de la Concepcion,* and about sunset I anchored near said cape in order to learn whether there was gold there, because the men whom I had caused to be taken from San Salvador told me that they there wore very large rings of gold on their legs and arms. I well suspected that all they said was deceptive in order to get away from me. Nevertheless, it was my desire not to pass any island without taking possession of it, as one taken possession of the same may be said of all; and I anchored and remained until to day tuesday when at dawn I went on shore with the boats armed, and got out, and they who were many in number naked, and of the same disposition as those of the other island of San Salvador, allowed us to go over the island and gave us whatever we asked for. And because the wind was increasing across south east(2) I did not like to stay longer so I returned to the ship, and a large canoe was alongside the caravel Niña, and one of the men of the island of San Salvador, who was in it, jumped overboard and escaped in it, and in the middle of the preceding night the other(3)   and he went after the canoe, which fled so swiftly that there was never a boat that could overtake it, although we had a long start. Nevertheless it reached the land, and they left the canoe, and some of my men went on shore after them, and they all ran like hens, and the canoe they had left we took on board the caravel Niña, to which from another quarter another small canoe was coming with a man who came to barter a ball of cotton, and as he refused to go on board the caravel, some sailors plunged into the sea and took him; and

(1) The pronoun, which, is feminine in Spanish and cannot relate to cape which is masculine. It is therefore manifest that Columbus applied the name to the whole island.—H. L. T., translator.

(2) The phrase in the Spanish text is—*El viento cargaba á la traviesa Sueste.* I find so much diversity in regard to the meaning of *á la traviesa,* that I venture a nautical explanation, provided he was where I put him on the forenoon of the 16th of October—N. W. end of Crooked Island.—Here the flood tide ran east, on the 16th, from 9^h a. m. to $3^h\ 12^m$ p. m.—see p. 390—His ships were riding at single anchor, to a windward tide, with their heads to the westward; but as the *south east wind increased* there was the risk of "breaking shear," which the Admiral observed from the shore; hence his anxiety to be off.

(3) On account of the illegible writing of this word in the original and the blank space that follows, the meaning of the sentence remains in obscurity. Perhaps he meant: *and in the middle of the preceding night the other swam off, and went behind the canoe, &c. Casas.*

pues en tierra al tiempo de la llegada del otro á quien yo habia dado las cosas susodichas, y no le habia querido tomar el ovillo de algodon puesto quel me lo queria dar; y todos los otros se llegaron á él, y tenia á gran maravilla é bien le pareció que eramos buena gente, y que el otro que se habia fugido nos habia hecho algun daño y que por esto lo llevábamos, y á esta razon usé esto con él de le mandar alargar, y le dí las dichas cosas porque nos tuviesen en esta estima, porque otra vez cuando vuestras Altezas aquí tornen á enviar no hagan mala compañía; y todo lo que yo le dí no valia cuatro maravedís. Y así partí, que serian las diez horas, con el viento Sueste y tocaba de Sur para pasar á estotra isla, la cual es grandisima, y adonde todos estos hombres que yo traigo de la de San Salvador hacen señas que hay muy mucho oro, y que lo traen en los brazos en manillas, y á las piernas, y á las orejas, y al nariz, y al pescuezo. Y habia de esta isla de Santa María á esta otra nueve leguas Leste Oueste, y se corre toda esta parte de la isla Norueste Sueste, y se parece que bien habria en esta costa mas de veinte y ocho leguas(1) en esta faz, y es muy llana sin montaña ninguna, así como aquellas de San Salvador y de Santa María, y todas playas sin roquedos, salvo que á todas hay algunas peñas acerca de tierra debajo del agua, por donde es menester abrir el ojo cuando se quiere surgir é no surgir mucho acerca de tierra, aunque las aguas son siempre muy claras y se ve el fondo. Y desviado de tierra dos tiros de lombarda hay en todas estas Islas tanto fondo que no se puede llegar á él. Son estas Islas muy verdes y fértiles, y de aires muy dulces, y puede haber muchas cosas que yo no sé, porque no me quiero detener por calar y andar muchas Islas para fallar oro. Y pues estas dan así estas señas que lo traen á los brazos y á las piernas, y es oro porque les amostré algunos pedazos del que yo tengo, no puedo errar con el ayuda de nuestro Señor que yo no le falle adonde nace. Y estando á medio golfo destas dos islas es de saber de aquella de Santa María y de esta grande, á la cual pongo nombre la *Fernandina*(2), fallé un hombre solo en una almadia que se pasaba de la isla de Santa María á la Fernandina, y traia un poco de su pan, que sería tanto como el puño, y una calabaza de agua, y un pedazo de tierra bermeja

(1) Son solo 19 leguas.

(2) Conócese ahora con el nombre de *Inagua chica*.

I who from the poop of my ship saw all, sent for him, and I gave him a red cap put around his arm a string of small green glass beads, and two little bells on his ears, and ordered that his canoe which they also had on board of the vessel, should be returned to him, and thus I sent him on shore; and soon after I set sail for the other large island that appeared at the west, and I ordered that the other canoe that the Niña had astern should be turned adrift, when the man to whom I made the indicated presents and from whom I had refused the ball of cotton he offered to me reached the land; he was as I saw immediately surrounded by those on shore, and he thought it a great wonder and thought that we we were good people, and that the other man who had fled had probably been kept by us in consequence of some injury done us, and that was the reason why I gave him presents and ordered his release, my aim being to win thus the respect and esteem of all, and avoid their enmity to the future expeditions your Highnesses may send; and yet all I gave him was not worth four maravedis. And so I left, at about ten o'clock, with a south east wind inclining to the south for the other island, a very large one, where the San Salvador men I have with me assert by signs there exists much gold, and that they wear it in rings around their arms, and legs, and in their ears, and noses, and around their necks. And from this island of Santa Maria to the other one there are nine leagues east [and] west, and all this portion of the island runs north west [and] south east, and it appears that there are on this coast more than twenty eight leagues it is even, and devoid of mountains, like those of San Salvador and Santa Maria, and all its shores are free from reefs, except some sunken rocks near the land which require great watchfulness when one wants to anchor or makes it prudent to anchor some distance from land, although the water is remarkably limpid and the bottom can be seen. And at the distance of two lombard shots there is in all these islands so much bottom that it cannot be reached. These islands are very green and fertile, and have a balmy atmosphere, they probably contain many things which I do not know of, for I do not wish to stop but to reconnoitre many islands in search of gold. And since these thus give these signs that they wear it on their arms and legs, and it is real gold for I showed them some pieces of that which I have, I cannot fail God helping find-hecha en polvo y despues amasada, y unas hojas secas que debe ser cosa muy apreciada entre ellos, porque ya me trujeron en San Salvador dellas en presente, y traia un cestillo á su guisa en que tenia un ramalejo de cuentecillas de vidrio y dos blancas, por las cuales conoscí quel venia de la isla de San Salvador, y habia pasado á aquella de Santa María, y se pasaba á la Fernandina, el cual se llegó á la nao; yo le hice entrar, que así lo demandaba él, y le hice poner su almadia en la nao, y guardar todo lo que él traia; y le mandé dar de comer pan y miel, y de beber; y así le pasaré á la Fernandina, y le daré todo lo suyo, porque dé buenas nuevas de nos para á nuestro Señor aplaciendo, cuando vuestras Altezas envien acá, que aquellos que vinieren resciban honra, y nos den de todo lo que hobiere."

Martes 16 *de Octubre.*

„Partí de las *islas de Santa María de la Concepcion*, que seria ya cerca del medio dia, para la *isla Fernandina*, la cual amuestra ser grandísima al Oueste, y navegué todo aquel dia con calmeria; no pude llegar á tiempo de poder ver el fondo para surgir en limpio, porque es en esto mucho de haber gran diligencia por no perder las anclas; y así temporicé toda esta noche hasta el dia que vine á una poblacion, adonde yo surgí, é adonde habia venido aquel hombre que yo hallé ayer en aquella almadia á medio golfo, el cual habia dado tantas buenas nuevas de nos que toda esta noche no faltó almadias abordo de la naò, que nos traian agua y de lo que tenian. Yo á cada uno le mandaba dar algo, es á saber algunas contecillas, diez ó doce dellas de vidrio en un filo, y algunas sonajas de laton destas que valen en Castilla un maravedi cada una, y algunas agujetas, de que todo tenian en grandísima excelencia, y tambien los mandaba dar para que comiesen cuando venian en la nao miel de azúcar; y despues á horas de tercia envié el batel de la nao en tierra por agua, y ellos de muy buena gana le enseñaban á mi gente adonde estaba el agua, y ellos mismos traian

ing the place whence it is procured. And being in the gulf midway between these two islands namely that of Santa Maria and this large one, to which I give the name of la *Fernandina*, I found a man who was going from the island of Santa Maria to la Fernandina, he had a small piece of his bread, about the size of one's fist, a calabash of water, a lump of red earth reduced to powder and afterwards kneaded, and some dry leaves highly prized no doubt among them, for those of San Salvador offered some to me as a present,(1) and he carried a little basket in their fashion in which he had a small string of glass beads and two blancas, by which I knew that he came from the island of San Salvador, had passed to Santa Maria, and was now going to la Fernandina, and he came to the ship; I had him taken on board as he desired, and ordered that his canoe and all that he had, should be kept in the ship; and had him treated with bread honey, and drink; and I will take him to la Fernandina, giving him back what he has brought, in order that he may give good news concerning us so that God willing, when your Highnesses shall send here, those who shall come may receive honor, and that they may give us of all that they have."

Tuesday October 16th.

"About noon I left the *islands of Santa Maria de la Concepcion* for the *island of Fernandina*, which appears to be very large to the west, and I sailed all that day with calm weather; I could not arrive in time to see the bottom in order to get a clear anchorage, a thing requiring the greatest care in order not to lose the anchors; in consequence I waited until daylight when I anchored near a village, the man whom I found yesterday in his canoe in the gulf had come to that village, and so favorable was the account he had given of us that to night they have been constantly coming to the ship in their canoes, bringing us water and everything they have. I caused some things to be given to every one, such as small beads, ten or twelve of them of glass on a string, some brass [tin?] rattles like those that in Castile can be had for

(1) This was probably tobacco. When at Port Nuevitas del Principe, Cuba, November 6th, the two messengers he sent into the country returned and reported, among other things, that the natives, men and women, fumigated themselves by inhaling smoke from tubes—*tabacos*—made of dried leaves. This is the first record of smoking cigars. See Navarrete, 1st edition, p. 51. Note by Las Casas.

los barriles llenos al batel, y se folgaban mucho de nos hacer placer. Esta isla es grandísima y tengo determinado de la rodear, porque segun puedo entender en ella, ó cerca della, hay mina de oro. Esta isla está desviada de la de Santa María ocho leguas cuasi Leste Oueste; y este cabo adonde yo vine, y toda esta costa se corre Nornorueste y Sursueste, y vide bien veinte leguas de ella, mas ahí no acababa. Agora escribiendo esto dí la vela con el viento Sur para pujar á rodear toda la isla, y trabajar hasta que halle *Samaot*, que es la isla ó ciudad adonde es el oro, que así lo dicen todos estos que aquí vienen en la nao, y nos lo decian los de la isla de San Salvador y de Santa María. Esta gente es semejante á aquella de las dichas islas, y una fabla y unas costumbres, salvo questos ya me parecen algun tanto mas doméstica gente, y de tracto, y mas sotiles, porque veo que han traido algodon aquí á la nao y otras cositas que saben mejor refetar[1] el pagamento que no hacian los otros; y aun en esta isla vide paños de algodón fechos como mantillos, y la gente mas dispuesta, y las mugeres traen por delante su cuerpo una cosita de algodon que escasamente les cobija su natura. Ella es isla muy verde y llana y fertilísima, y no pongo duda que todo el año siembran panizo y cogen, y así todas otras cosas; y vide muchos árboles muy disformes de los nuestros, y dellos muchos que tenian los ramos de muchas maneras y todo en un pie, y un ramito es de una manera y otro de otra, y tan disforme que es la mayor maravilla del mundo cuanta es la diversidad de la una manera á la otra, verbi gracia, un ramo tenia las fojas á manera de cañas y otro de manera de lentisco; y así en un solo árbol de cinco ó seis de estas maneras; y todos tan diversos: ni estos son enjeridos, porque se pueda decir que el enjerto lo hace, antes son por los montes, ni cura dellos esta gente. No le conozco secta ninguna, y creo que muy presto se tornarian cristianos, porque ellos son de muy buen entender. Aquí son los peces tan disformes de los nuestros ques maravilla. Hay algunos hechos como gallos de las mas finas colores del mundo, azules, amarillos, colorados y de todas colores, y otros pintados de mil maneras; y las colores son tan finas que no hay hombre que no se maraville y no tome gran descanso á verlos. Tambien hay ballenas: bestias en tierra no vide

(1) Acaso *refertar* v. a. ant. contradecir, repugnar, resistir, reusar ó regatear.

one maravedi a piece, and some leather straps, all of which they held in the greatest estimation, and I also treated those who came to my ship with honey of sugar [molasses?]; and afterwards at nine o'clock a. m. I sent the ship's boat to the shore for water, and they willingly showed my men where the water was and they themselves brought the casks filled to the boat, and were very glad to be able to oblige us. This island is exceedingly large and I have determined to go around it, because as I can understand on it or near it, there is a mine of gold. This island lies at a distance from that of Santa Maria of eight leagues almost east [and] west; and this cape to which I have come, and all this coast, runs north-northwest and south-southeast, and I saw fully twenty leagues of it, but this was not the end. Soon after writing this I set sail with a south wind, intending to go around the whole island, and work until I should find *Samaot*, which is the island or city where the gold is, as all those say who have come with us in the ships, and as was before asserted by those of the island of San Salvador and Santa Maria. The people here are like those of the said islands, and speak the same language and have the same customs, but these look to me as somewhat more gentle, of better manners, and of keener intelligence, for I notice that in bartering cotton and other little things they know how to trade, which the others never did; and also on this island I saw cotton cloth made like mantles, and the people more intelligent, and the women wear in front a small piece of cotton stuff which scarcely covers what decency requires. The island is very green level and exceedingly fertile, and I doubt not that they sow and gather panizo(1) and all other things, at all seasons of the year; and I saw many trees whose shape was very different from ours, and many of them which had branches of many kinds although growing from one trunk, and one branch is of one kind and another of another kind, and so different that the diversity of the kinds is the greatest wonder of the world, for instance, one branch had leaves like those of cane and another like those of a mastic; and thus on a single tree

(1) Panicum—an ancient Latin name of the Italian millet *P. Italicum* (now *Setaria Italica*) thought to come from panis, bread; some species furnishing a kind of bread corn. *Gray's New Lessons and Manual of Botany*. Boston, 1868. p. 645.

ninguna de ninguna manera, salvo papagayos y lagartos; un mozo me dijo que vido una grande culebra. Ovejas ni cabras ni otra ninguna bestia vide; aunque yo he estado aquí muy poco, que es medio dia, mas si las hobiese no pudiera errar de ver alguna. El cerco desta isla escribiré despues que yo la hobiere rodeado."

Miercoles 17 de Octubre.

„A medio dia partí de la poblacion adonde yo estaba surgido, y adonde tomé agua para ir rodear esta isla Fernandina, y el viento era Sudueste y Sur; y como mi voluntad fuese de seguir esta costa desta isla adonde yo estaba al Sueste, porque así se corre toda Nornorueste y Sursueste, y queria llevar el dicho camino de Sur y Sueste, porque aquella parte todos estos indios que traigo y otro de quien hobe señas en esta parte del Sur á la isla á que ellos llaman *Samoet*, adonde es el oro; y Martin Alonso Pinzon, capitan de la carabela Pinta, en la cual yo mandé á tres de estos indios, vino á mí y me dijo que uno dellos muy certificadamente le habia dado á entender que por la parte del Nornorueste muy mas presto arrodearia la isla. Yo vide que el viento no me ayudaba por el camino que yo queria llevar, y era bueno por el otro: dí la vela al Nornorueste, y cuando fue acerca del cabo de la isla, á dos leguas, hallé un muy maravilloso puerto con una boca, aunque dos bocas se le puede decir, porque tiene un isleo en medio, y son ambas muy angostas, y dentro muy ancho para cien(1) navíos si fuera fondo y limpio, y fondo al entrada: parecióme razon del ver bien y sondear, y así surgí fuera dél, y fuí en él con todas las barcas de los navíos, y vimos que no habia fondo. Y porque pensé cuando yo

(1) En el original dice *parecian;* pero es error conocido.

there were five or six of these kinds; and all so different: nor can it be said that they have been grafted, because those trees grow wild in the field, and nobody cares for them.(1) I know no sect among them, and as they are of very good understanding, they would in my opinion soon become Christians. The fishes here are so different from ours that it is a wonder. Some look like cocks of the finest colors in the world, blue, yellow, red and all colors, and others variegated in a thousand fashions; their different hues being so exquisite that nobody can contemplate them without wondering, and feeling great delight in seeing them.(2) There are also whales here: but on shore I saw no beasts whatever, save parrots and lizzards; a young man told me that he had seen a large snake. No sheep nor goats nor any other beast did I see; although I have only stopped half a day I could not fail in seeing some, should there be any. When I shall have sailed around this island I will describe its coast."

Wednesday October 17th.

At midday I left the village where I had anchored and taken in water, in order to sail around this island of Fernandina, the wind was southwest and south; and as my wish was to follow the coast of the island where I was to the southeast, because it all runs to the north-northwest and south-southeast, and I desired to take the said route of south and south-east, because that part all these Indians whom I have on board and another from whom I received signs in this part of the south on the island which they call *Samoet*, [is] where the gold is; and Martin Alonso Pinzon, captain of the caravel Pinta, into which I sent three of these Indians, came to me and said that one of them had very positively given him to understand that I should round the island much the quickest by the north-northwest. I saw that the wind was not favorable to my intended course,

(1) The flora which Columbus saw has probably disappeared before the reckless firing and wasteful cultivation which characterizes the agriculture of the Bahamas. There are, however, now found there, besides the Epiphytes or air plants, many of a parasitic nature and two, Wild fig (*Ficus pedunculata*) and Scotch attorney (*clusea rosea*) which, springing from a chance seed lodged in the branches of trees throw their roots to the ground and join their foliage as if belonging to the same trunk.

(2) This vivid description applies to the fishes which are now found on the Bahama banks.

le vi que era boca de algun rio habia mandado llevar barriles para tomar agua, y en tierra hallé unos ocho ó diez hombres que luego vinieron á nos, y nos amostraron ahí cerca la poblacion, adonde yo envié la gente por agua, una parte con armas otros con barriles, y así la tomaron; y porque era lejuelos me detuve por espacio de dos horas. En este tiempo anduve así por aquellos árboles, que era la cosa mas fermosa de ver que otra que se haya visto; veyendo tanta verdura en tanto grado como en el mes de Mayo en el Andalucía, y los árboles todos estan tan disformes de los nuestros como el dia de la noche; y así las frutas, y así las yerbas y las piedras y todas las cosas. Verdad es que algunos árboles eran de la naturaleza de otros que hay en Castilla, por ende habia muy gran diferencia, y los otros árboles de otras maneras eran tantos que no hay persona que lo pueda decir ni asemejar á otros de Castilla. La gente toda era una con los otros ya dichos, de las mismas condiciones, y así desnudos y de la misma estatura, y daban de lo que tenian por cualquiera cosa que les diesen; y aquí vide que unos mozos de los navíos les trocaron azagayas por unos pedazuelos de escudillas rotas y de vidrio, y los otros que fueron por el agua me dijeron como habian estado en sus casas, y que eran de dentro muy barridas y limpias, y sus camas y paramentos de cosas que son como redes de algodon[1]: ellas las casas son todas á manera de alfaneques, y muy altas y buenas chimeneas[2]; mas no vide entre muchas poblaciones que yo vide ninguna que pasase de doce hasta quince casas. Aquí fallaron que las mugeres casadas traian bragas de algodon, las mozas no, sino salvo algunas que eran ya de edad de diez y ocho años. Y ahí habia perros mastines y branchetes, y ahí fallaron uno que habia al nariz un pedazo de oro que seria como la mitad de un castellano, en el cual vieron letras: reñí yo con ellos porque no se lo resgataron y dieron cuanto pedia, por ver que era y cuya esta moneda era; y ellos me respondieron que nunca se lo osó resgatar. Despues de tomada la agua volví á la nao, y dí la vela, y salí al Norueste tanto que yo descubrí toda aquella parte de la isla hasta la costa que se corre Leste Oueste, y despues todos estos indios tor-

(1) Llámanse *Hamacas*.

(2) Estas chimeneas no son para humeros, sino unas coronillas que tienen encima las casas de paja de los Indios. Por esto lo dice, puesto que dejan abierto por arriba algo para que salga el humo. *Casas*.

and was to the other: so I sailed to the north-north west, and when I was near the end of the island, two leagues off, I found a very marvellous port with an entrance, although it may be said that there are two entrances, because it has a rocky islet in the middle, and both are very narrow, but within it there is ample room for one hundred ships, if it had sufficient depth of water, and was clear, and had also a deep entrance: I thought it worth while to examine and sound it, and so I anchored outside of it, and went in with all the boats of the ships, and saw that there was not bottom. And because I thought when I saw it that it was the mouth of some river I had the casks sent on shore for water, and on shore I found eight or ten men who soon approached us, and showed us the village near by, to which I sent my men for water, some armed, and others with the casks, and thus they got it; and because it was rather far I was detained for the space of two hours. During this time I walked among those trees, which were the most beautiful things that were ever seen; so much verdure being visible and in as high a degree as in the month of May in Andalucia, and all these trees as different from ours as day is from night; the same was the case with the fruits, grass stones and all things. It is true that some trees were of the same family as others in Castile, however there was a very great difference, and the other trees of other kinds were so many that there is no person that can compare them to others in Castile. The people were all like those aforementioned, they have the same dispositions, go about naked and are of the same size, and gave of what they had for anything that was given to them; and here I saw that some young men of the vessels obtained spears from them for some little pieces of broken crockery and glass, the men I sent for water told us that the houses which they had entered were well swept and perfectly clean, and that their beds and coverings looked like cotton nets:(1) the houses are like tents, very high and have good chimneys;(2) but among the many villages which I saw none had over twelve or fifteen houses. Here they found that the married women wore cotton

(1) Which they called Hamacas. *Navarrete.* This is the first mention of the hammock.

(2) These are not chimneys for emitting smoke but are crowns on top of the straw huts, he called them chimneys because something is left open on top in order that the smoke may get out. *Casas.*

naron á decir que esta isla era mas pequeña que no la isla *Samoet*, y que seria bien volver atras por ser en ella mas presto. El viento allí luego mas calmó y comenzó á ventar Ouesnorueste, el cual era contrario para donde habiamos venido, y así tomé la vuelta y navegué toda esta noche pasada al Lestesueste, y cuando al Leste todo y cuando al Sueste; y esto para apartarme de la tierra porque hacia muy gran cerrazon y el tiempo muy cargado: el era poco y no me dejó llegar á tierra á surgir. Así que esta noche llovió muy fuerte despues de media noche hasta cuasi el dia, y aun está nublado para llover; y nos al cabo de la isla de la parte del Sueste adonde espero surgir fasta que aclarezca para ver las otras islas adonde tengo de ir; y así todos estos dias despues que en estas Indias estoy ha llovido poco ó mucho. Crean vuestras Altezas que es esta tierra la mejor é mas fertil, y temperada, y llana, y buena que haya en el mundo."

breeches, the young girls not, except a few who were already of the age of eighteen years. And they had there dogs mastines([1]) and branchetes,([2]) and here they found one wearing in his nose a piece of gold of the size of half a castillano,([3]) on which they saw letters: I scolded them for not having got it by giving whatever he asked, in order to see what it was and if coin whose coin it was; but they answered that he did not dare to barter it. After getting in water I returned to the ship, and set sail, and sailed to the northwest until I discovered all that part of the island as far as the coast which runs east [and] west, and afterwards these Indians again said that this island was smaller than the island of *Samoet*, and that it would be well to go back as we would thus reach it sooner. The wind then ceased and then sprang up from west-northwest, which was contrary to our course, and so I turned around and sailed all the past night to the east-southeast, and sometimes wholly east, and sometimes to the southeast; this I did in order to keep off the land for the atmosphere was very misty and the weather threatening: it [the wind] was light and did not permit me to reach the land in order to anchor. So that this night it rained very hard after midnight until almost day, and is still cloudy in order to rain; and we [are] at the southeast cape of the island where I hope to anchor until it gets clear in order to see the other islands where I have to go; ever since I came to these Indies it has been raining much or little. I beg your Highnesses to believe however that this land is the richest, the mildest in temperature, and the most level and wholesome in the world."

Jueves 18 *de Octubre.*

„Despues que aclaresció seguí el viento, y fuí en derredor de la isla cuanto pude, y surgí al tiempo que ya no era de navegar; mas no fuí en tierra, y en amaneciendo dí la vela."

Thursday October 18*th.*

"After it cleared up I followed the wind, and went around the island as much as I could, and I anchored when it was no longer possible to sail; but I did not go on shore, and at dawn I set sail."

Viernes 19 *de Octubre.*

„En amaneciendo levanté las anclas y envié la carabela Pinta al Leste y Sueste y la carabela Niña al Sursueste, y yo con la nao fuí al Sueste, y dado orden que llevasen aquella vuelta fasta medio dia, y despues que ambas se mudasen las derrotas y se recogieran para mí; y luego antes que andásemos tres horas vimos

Friday, October 19*th.*

"At dawn I weighed anchor and sent the caravel Pinta to the east and southeast and the caravel Niña to the south-southeast, and I

([1]) Mastines—mastiff.

([2]) Branchetes—probably a scenting dog.

([3]) One castillano of gold equal to $\$1.66\frac{66}{100}$. *Irving's Columbus*, revised edition. 1848. Note. Vol. II, p. 49.

una isla al Leste, sobre la cual descargamos, y llegamos á ella todos tres navíos antes de medio dia á la punta del Norte, adonde hace un isleo y una restinga de piedra fuera de él al Norte, y otro entre él y la isla grande; la cual anombraron estos hombres de *San Salvador*, que yo traigo, la isla *Saomete*, á la cual puse nombre la *Isabela*([1]). El viento era Norte, y quedaba el dicho isleo en derrota de la isla *Fernandina*, de adonde yo habia partido Leste oueste, y se corria despues la costa desde el isleo al Oueste, y habia en ella doce leguas fasta un cabo, á quien yo llamé el *Cabo hermoso*, que es de la parte del Oueste; y así es fermoso, redondo y muy fondo, sin bajas fuera de él, y al comienzo es de piedra y bajo, y mas adentro es playa de arena como cuasi la dicha costa es, y ahí surgí esta noche Viernes hasta la mañana. Esta costa toda, y la parte de la isla que yo ví, es toda cuasi playa, y la isla mas fermosa cosa que yo ví; que si las otras son muy hermosas, esta es mas: es de muchos árboles y muy verdes, y muy grandes; y esta tierra es mas alta que las otras islas falladas, y en ella algun altillo, no que se le pueda llamar montaña, mas cosa que afermosea lo otro, y parece de muchas aguas allá al medio de la isla; de esta parte al Nordeste hace una grande angla, y ha muchos arboledos, y muy espesos y muy grandes. Yo quise ir á surgir en ella para salir á tierra, y ver tanta fermosura; mas era el fondo bajo y no podia surgir salvo largo de tierra, y el viento era muy bueno para venir á este cabo, adonde yo surgí agora, al cual puse nombre *Cabo Fermoso*, porque así lo es; y así no surgí en aquella angla, y aun porque vide este cabo de allá tan verde y tan fermoso, así como todas las otras cosas y tierras destas islas que yo no sé adonde me vaya primero, ni me sé cansar los ojos de ver tan fermosas verduras y tan diversas de las nuestras, y aun creo que ha en ellas muchas yerbas y muchos árboles, que valen mucho en España para tinturas y para medicinas de especería, mas yo no los cognozco, de que llevo grande pena. Y llegando yo aquí á este cabo vino el olor tan bueno y suave de flores ó árboles de la tierrra que era la cosa mas dulce del mundo. De mañana antes que yo de aquí vaya iré en tierra á ver que es aquí en el cabo; no es la poblacion salvo allá mas adentro adonde di-

([1]) Parece que la *Isabela* corresponde á la isla que ahora se conoce con el nombre de *Inagua grande*, y los indios llamaban *Saometo*.

with the ship went to the southeast, having given orders that they should keep that course until midday, and then that both should change their course and return to me; and then before we had gone three hours we saw an island to the east, to which we directed our course, and all the three vessels reached it before midday at its northern extremity, where there is a rocky islet and a ridge of rocks outside it to the north, and another between it and the large island; which the men of *San Salvador*, that I brought with me, called *Saometo*, to which I gave the name of la *Isabela*. The wind was north, and the said islet lay from the island of *Fernandina*, whence I had come east [and] west, and the coast afterwards ran from the rocky islet to the westward, and there was in it twelve leagues as far as a cape, which I called *Cape Beautiful*, which is in the west; and so it is beautiful, round and [the water?] very deep and free from shoals, at first it is rocky and low, but farther in it is a sandy beach as it is along most of the coast, and it is here that I have to-night Friday, anchored until morning. This coast all, and the part of the island that I saw, is nearly all a beach, and the island the most beautiful thing I have seen; if the others are very beautiful this is still more so: it has many trees very green, and very large; and this land is higher than that of the other islands I have discovered, although it cannot be called mountainous, yet gentle hills enhance with their contrasts the beauty of the plain, and there appears to be much water in the middle of the island; northeast of this cape there is an extensive promontory, and there are many groves, very thick and very large. I wished to anchor off it in order to land, and visit so handsome a spot; but it was shallow and I could not anchor except far from land, and the wind was very favorble to come to this cape, where I have now anchored, and which I have called *Cape Beautiful*, because it is so; and so I did not anchor off that promontory, because I saw this cape so green and so beautiful, as are all the other things and lands of these islands so that I do not know to which to go first, nor do my eyes grow tired with looking at such beautiful verdure, so different from our own, and I even believe that among it there are many grasses or herbs, and many trees which would be of great value in Spain for dyes and medicines, but I do not know them, which I greatly regret. And con estos hombres que yo traigo, que está el Rey y que trae mucho oro; y yo de mañana quiero ir tanto avante que halle la poblacion, y vea ó haya lengua con este Rey, que segun estos dan las señas él señorea todas estas islas comarcanas, y va vestido, y trae sobre sí mucho oro; aunque no doy mucha fé á sus decires, así por no los entender yo bien, como en cognoscer quellos son tan pobres de oro que cualquiera poco que este Rey traiga les parece á ellos mucho. Este á quien yo digo *Cabo Fermoso* creo que es isla apartada de *Saometo*, y aun hay ya otra entremedias pequeña: yo no curo así de ver tanto por menudo, porque no lo podia facer en cincuenta años, porque quiero ver y descubrir lo mas que yo pudiere para volver á vuestras Altezas, á nuestro Señor aplaciendo, en Abril. Verdad es que fallando adonde haya oro ó especería en cantidad me deterné fasta que yo haya dello cuanto pudiere; y por esto no fago sino andar para ver de topar en ello."

when I reached this cape the odor came so good and sweet from flowers or trees on the land that it was the sweetest thing in the world. To-morrow before leaving here I will go on shore to see what there is on this cape: there is no population except farther inland where according to the information received from these men whom I have on board, their king lives and has much gold; I intend to proceed to-morrow until I find the population, and see or converse with this king, who, according to the signs made by these men is master of all these neighboring islands, and goes clothed, and wears much gold on his person; although I place little confidence in their assertions, both because I do not understand well and because I see that they are so poor in gold that any small quantity worn by this King would seem to them to be a great deal. I believe that this *Cape Beautiful* is a separate island from *Saometo*, and even that there is another small one between: for that reason I do not care to examine so much in detail, because I could not do it in fifty years, because I desire to see and discover the most that I can, in order to return to your Highnesses, God willing, in April. It is true that I will stop wherever I may find gold or spices in large quantities and get as much of each as possible; I am constantly sailing in order to find some."

Sabado 20 de Octubre.

„Hoy al sol salido levanté las anclas de donde yo estaba con la nao surgido en esta isla de *Saometo* al cabo del Sudueste, adonde yo puse nombre el *Cabo de la Laguna* y á la isla la *Isabela*, para navegar al Nordeste y al Leste de la parte del Sueste y Sur, adonde entendí de estos hombres que yo traigo que era la poblacion y el Rey de ella; y fallé todo tan bajo el fondo que no pude entrar ni navegar á ello, y vide que siguiendo el camino del Sudueste era muy gran rodeo, y por esto determiné de me volver por el camino que yo habia traido del Nornordeste de la parte del Oueste, y rodear esta isla para (1) el viento me fue tan escaso que yo no nunca pude haber la tierra al longo de la costa salvo en la noche; y por ques peligro (2) surgir en estas islas, salvo en el dia que se vea con el ojo adonde se echa el ancla, porque es todo manchas, una de limpio y otra de non, yo me

(1) Igual vacío en el original. Parece falta *reconocerla*.

(2) Así el original: parece ha de decir *peligroso*.

Saturday, October 20th.

"At sunrise I weighed anchor from the place where I was with the vessel anchored at this island of *Saometo* at the southwest cape, which I named the *Cape of the Lagoon* and I called the island la *Isabela*, in order to sail to the northeast and to the east towards the southeast and south, where I understood from these men whom I have with me that the population and their king were; and so I found the bottom so shallow that I could not enter or sail to it, and I saw that by following a southwestern route it would be a long way around, and consequently I determined to return by the course I had come from the north-northeast toward the west, and to go around this island in order (1) The wind, however, was so scant that I was never able to have the land along the coast except at night; and because it is dangerous to anchor among these islands, save in the day-time when

(1) A blank in the original, probably to reconnoiter it. Navarrete.

puse á temporejar á la vela toda esta noche del Domingo. Las carabelas surgieron porque se hallaron en tierra temprano, y pensaron que á sus señas, que eran costumbradas de hacer, iria á surgir; mas no quise."

Domingo 21 de Octubre.

„A las diez horas llegué aquí á este cabo del isleo, y surgí y asimismo las carabelas; y despues de haber comido fuí en tierra, adonde aquí no habia otra poblacion que una casa, en la cual no fallé á nadie que creo que con temor se habian fugido porque en ella estaban todos sus aderezos de casa. Yo no les dejé tocar nada, salvo que me salí con estos capitanes y gente á ver la isla; que si las otras ya vistas son muy fermosas y verdes y fértiles, esta es mucho mas y de grandes arboledos y muy verdes. Aquí es unas grandes lagunas, y sobre ellas y á la rueda es el arboledo en maravilla, y aquí y en toda la isla son todos verdes y las yerbas como en el Abril en el Andalucía; y el cantar de los pajaritos que parece que el hombre nunca se querria partir de aquí, y las manadas de los papagayos que ascurecen el sol; y aves y pajaritos de tantas maneras y tan diversas de las nuestras que es maravilla; y despues ha árboles de mil maneras, y todos de su manera fruto, y todos huelen que es maravilla, que yo estoy el mas penado del mundo de no los cognoscer, porque soy bien cierto que todos son cosa de valía, y de ellos traigo la demuestra, y asimismo de las yerbas. Andando así en cerco de una destas lagunas vide una sierpe(1), la cual matamos y traigo el cuero á vuestras Altezas. Ella como nos vido se echó en la laguna, y nos le seguimos dentro, porque no era muy fonda, fasta que con lanzas la matamos; es de siete palmos en largo; creo que destas semejantes hay aquí en esta laguna muchas. Aquí cognoscí del liñaloe, y mañana he determinado de hacer traer á la nao diez quintales, porque me dicen que vale mucho. Tambien andando en busca de muy buena agua fuimos á una poblacion aquí cerca, adonde estoy surto media legua; y la gente, della como nos sintieron dieron todos á fugir, y dejaron las casas, y escondieron su ropa y lo que tenian por el monte; yo no dejé tomar nada ni la valia de un alfiler. Despues se llegaron á nos unos hombres dellos, y uno se llegó del todo aquí:

(1) Yüana (*Iguana*) debió de ser esta. *Casas.*

one sees with the eye where the anchor is cast, because it is all spots, one clean the other not, I stood off and on all this night of Sunday. The caravels anchored because they reached the land early, and thought that I would do the same at sight of their customary signals; but I did not wish to."

Sunday October 21st.

"At ten o'clock I arrived here at this end of the rocky islet, and I anchored as did the caravels; and after taking my dinner I went on shore, I found there only a house, in which I found no person and I believe that they had fled through fear because all their household goods were there. I did not allow them to touch anything, except that I went with the captains and men to see the island; if the others appeared beautiful, green, and fertile, this one with its majestic and luxuriant forests surpasses them all. Here are some large lagoons, and around them are the trees so that it is a marvel, and here and throughout the island they are all green and the grass is like it is in April in Andalucia; and the songs of the little birds so that it seems as if a man could never leave here, and the flocks of parrots which darken the sun; and birds and little birds of so many kinds and so different from ours that it is a marvel; and then there are trees of a thousand kinds, all bearing fruit of their own kinds, and all smell so that it is a marvel, so that I felt the greatest regret in the world not to know them, because I am very certain that they are all things of value, and I bring the samples of them, and also of the grasses. While going around one of these lagoons I saw a serpent,(1) which we killed and I bring the skin to your Highnesses. When it saw us it plunged into the lagoon, and we followed it in, because it was not very deep, until we killed it with our lances; is of seven palmos (2) in length; I believe

(1) This should be Yüana (Iguana) Casas.

(2) *Library of Universal Knowledge.* N. Y. 1881. Vol. XI, p. 225. Spanish Palmo Major is given as 8.3450 inches, English. Spanish Palmo Minor is given as 2.7817 inches, English. Either of these dimensions might apply to the Iguana, but in Columbus's letter to the King and Queen concerning his fourth voyage, Navarrete, p. 450, he wrote of a harbor in Veragua, "bien que á la entrada no tenio salvo diez *palmos* de fondo." He used the same word, "palmos," for the depth of the harbor's entrance, as he used for the length of the Iguano. As neither of the above dimensions can express his meaning in both quotations I leave the original word, palmos.

yo dí unos cascabeles y unas cuentecillas de vidrio, y quedó muy contento y muy alegre, y porque la amistad creciese mas y los requiriese algo le hice pedir agua, y ellos despues que fuí en la nao vinieron luego á la playa con sus calabazas llenas y folgaron mucho de dárnosla, y yo les mandé dar otro ramalejo de cuentecillas de vidrio, y dijeron que de mañana vernian acá. Yo queria hinchir aquí toda la vasija de los navios de agua; por ende si el tiempo me da lugar luego me partiré á rodear esta isla fasta que yo haya lengua con este Rey, y ver si puedo haber dél el oro que oyo que trae, y despues partir para otra isla grande mucho, que creo que debe ser *Cipango*, segun las señas que me dan estos indios que yo traigo, á la cual ellos llaman *Colba*(1), en la cual dicen que ha naos y mareantes muchos y muy grandes, y de esta isla otra que llaman *Bosio*(2) que tambien dicen qués muy grande, y á las otras que son entremedio veré así de pasada, y segun yo fallare recaudo de oro ó especería determinaré lo que he de facer. Mas todavía tengo determinado de ir á la tierra firme y á la ciudad de *Guisay*, y dar las cartas de vuestras Altezas al *Gran Can*, y pedir respuesta y venir con ella."

Lunes 22 de Octubre.

„Toda esta noche y hoy estuve aquí aguardando si el Rey de aquí ó otras personas traerian oro ó otra cosa de sustancia, y vinieron muchos de esta gente, semejantes á los otros de las otras islas, así desnudos, y asi pintados dellos de blanco, dellos de colorado, dellos de prieto,

(1) Parece error en el original por *Cuba*, como se comprueba mas adelante.

(2) Acaso *Bohio*, como dice despues.

that there are many like this in this lagoon. Here I found the aloe tree, and as I have been told that it is very valuable I shall to-morrow, have ten quintals of it brought to the ship. While looking for good water we went to a village, distant half a league from my anchoring place; and the people fled at our approach, abandoning their houses, and hiding their wearing-apparel and what they had in the woods; and I did not allow them to take anything not even the value of a pin. Afterwards some of the men came to us, and one came quite up to us: I gave him some little bells and some glass beads, which satisfied and gladdened him very much, and in order that our friendship might increase and that I might ask something of them I asked for some water, which they after I had gone on board the ship brought to the beach with their calabashes filled, and were very much pleased to give it to us, I had them presented with another small string of glass beads, and they said they would come the next day. I wanted to have all the casks in the ship supplied with water; consequently the weather permitting I shall sail at once in order to go until I get an interview with this king, to see if I can get from him the gold which I hear that he wears, and afterwards to sail for another very large island, which I think must be *Cipango*, according to the signs given me by those Indians whom I have on board, and which they called *Colba*,(1) and where they say there are large ships and many merchants, and from it to another island named Bosio(2) which they also say is very large, taking a passing notice of others between, and shaping my future conduct in accordance with the quantities of gold or spices that I may find. I have also decided to go to the mainland to the city of *Guisay*, present there the letters of your Highnesses to the *Grand Khan*, ask for an answer and come away with it."

Monday October 22d.

"All last night and to day I have remained here expecting the king or other persons to come with gold or some other valuable things, many of these people came naked, like those of the other islands, painted some white, some red, some black, and so on in many ways. They

(1) It seems to be mistaken for Cuba in the original, as is shown further on. Casas.

(2) Perhaps Bohio, as he calls it afterwards. Casas.

y asi de muchas maneras. Traian azagayas y algunos ovillos de algodon á resgatar, el cual trocaban aquí con algunos marineros por pedazos de vidrio, de tazas quebradas, y por pedazos de escudillas de barro. Algunos dellos traian algunos pedazos de oro colgado al nariz, el cual de buena gana daban por un cascabel destos de pie de gavilano y por cuentecillas de vidrio: mas es tan poco, que no es nada: que es verdad que cualquiera poca cosa que se les dé ellos tambien tenian á gran maravilla nuestra venida, y creian que eramos venidos del cielo. Tomamos agua para los navíos en una laguna que aquí está acerca del *cabo del isleo*, que así la nombré; y en la dicha laguna Martin Alonso Pinzon, capitan de la Pinta, mató otra sierpe tal como la otra de ayer de siete palmos, y fice tomar aquí del linaloe cuanto se falló."

Martes 23 de Octubre.

„Quisiera hoy partir para la isla de *Cuba*, que creo que debe ser *Cipango* segun las señas que dan esta gente de la grandeza della y riqueza, y no me deterné mas aquí ni [1] esta isla al rededor para ir á la poblacion, como tenia determinado, para haber lengua con este Rey ó Señor, que es por no me detener mucho, pues veo que aquí no hay mina de oro, y al rodear de estas islas ha menester muchas maneras de viento, y no vienta así como los hombres querrian. Y pues es de andar adonde haya trato grande, digo que no es razon de se detener salvo ir á camino, y calar mucha tierra fasta topar en tierra muy provechosa, aunque mi entender es questa sea muy provechosa de especería; mas que yo no la cognozco que llevo la mayor pena del mundo, que veo mil maneras de árboles que tienen cada uno su manera de fruta, y verde agora como en España en el mes de Mayo y Junio, y mil maneras de yerbas, eso mesmo con flores, y de todo no se cognosció salvo este linaloe de que hoy mandé tambien traer á la nao mucho para llevar á vuestras Altezas. Y no he dado ni doy la vela para *Cuba*, porque no hay viento, salvo calma muerta y llueve mucho; y llovió ayer mucho sin hacer ningun frio, antes el dia hace calor, y las noches temperadas como en Mayo en España en el Andalucía."

[1] Igual vacío en el original.

brought spears and some balls of cotton to barter, which they exchanged here with some sailors for pieces of glass, broken cups, and pieces of earthenware. Some of these few wore pieces of gold in their noses, which they gladly gave away for a small bell such as is attached to the leg of a hawk: [1] but it is so little that it is nothing: it is true that for any little thing that was given them they marveled greatly at our coming, and thought that we had come down from heaven. We took water for the vessels from a lagoon which is near to the *Cape of the rocky island*, so named by me; and in the said lagoon Martin Alonso Pinzon, captain of the Pinta, killed another serpent like that of yesterday of seven palmos, I caused to be taken on board all the aloes that could be found."

Tuesday October 23d.

"I should like to sail to day for the island of *Cuba*, which from the description about its size and riches given by these people I infer to be Cipango, I will not stop here longer nor [2] around this island to go to the inhabited portion, as I had determined, in order to have an interview with this king or lord, this is in order not to stop much, because I see that there is no mine of gold here, and to go around these islands requires many different winds, and they do not blow as men would wish. And therefore the most important thing is to go where there is a great trade, I say that it is not right to stop, but to continue on one's course to examine many lands until one reaches some very profitable land, although my idea is that this is very rich in spices; but I grieve exceedingly that I have no knowledge of them, because I see a thousand kinds of trees having each one its own kind of fruit, and green now as in Spain in the month of May and June, and a thousand kinds of herbs, with flowers, of all of which none was known save this aloe of which I have had quantities brought on board the ship for your Highnesses. And I have not sailed nor do I sail for *Cuba*, because there is no wind, but a dead calm and much rain; yesterday it also rained much yet it was not cold, on the contrary it is warm during the day, and the nights are as mild as those of Andalucia in Spain in May."

[1] On the plains of Assyria and Babylonia the Arabs use hawks for hunting purposes, to the legs of which are, sometimes, fastened small bells. Layard's *Nineveh and Babylon*, p. 412.

[2] Blank space in the original. Navarrete.

Miercoles 24 de Octubre.

,,Esta noche á media noche levanté las anclas de la isla *Isabela* del *cabo del isleo*, ques de la parte del Norte á donde yo estaba posado para ir á la isla de *Cuba*, á donde oí desta gente que era muy grande y de gran trato, y habia en ella oro y especerías y naos grandes y mercaderes; y me amostró que al Ouesudueste iria á ella, y yo asi lo tengo, porque creo que si es así como por señas que me hicieron todos los indios de estas islas y aquellos que llevo yo en los navíos, porque por lengua no los entiendo, es la isla de *Cipango* de que se cuentan cosas maravillosas, y en las esperas que yo ví y en las pinturas de mapamundos es ella en esta comarca, y así navegué fasta el dia al Ouesudueste, y amaneciendo calmó el viento y llovió, y asi casi toda la noche; y estuve así con poco viento fasta que pasaba de medio dia y entonces tornó á ventar muy amoroso, y llevaba todas mis velas de la nao, maestra, y dos bonetas, y trinquete, y cebadera, y mezana, y vela de gavia, y el batel por popa; así anduve al camino fasta que anocheció y entonces me quedaba el *Cabo Verde* de la isla *Fernandina*, el cual es de la parte de Sur á la parte de Oueste, me quedaba al Norueste, y hacía de mí á él siete leguas. Y porque ventaba ya recio y no sabia yo cuanto camino hobiese fasta la dicha isla de *Cuba*, y por no la ir á demandar de noche, porque todas estas islas son muy fondas á no hallar fondo todo en derredor, salvo á tiro de dos lombardas, y esto es todo manchado un pedazo de roquedo y otro de arena, y por esto no se puede seguramente surgir salvo á vista de ojo, y por tanto acordé de amainar las velas todas, salvo el trinquete, y andar con él, y de á un rato crecia mucho el viento y hacía mucho camino de que dudaba, y era muy gran cerrazon, y llovía: mandé amainar el trinquete y no anduvimos esta noche dos leguas &c."

Wednesday October 24th.

"At midnight I weighed anchor from the island of *Isabela* the *cape of the rocky islet*, which is on the northern side where I was lying in order to go to the island of *Cuba*, which I heard from these people was very large, having much trade and that there was in it gold and spices and large ships and merchants; and they told me that I should go to it by the west-southwest, and so I think, because I believe that if it is as all the Indians of these islands and those whom I have on board told me by signs, because I do not understand their language, it is the island of *Cipango* of which marvellous things are related, and on the globes which I have seen and on the maps of the world it is in this region, and thus I sailed until day to the west-southwest, and at dawn the wind calmed and it rained, and so almost all night: and I remained with little wind until after midday and then the wind began to blow very lovely, and I carried all the sails of the ship, the mainsail, two bonnets, the foresail, and spritsail, and the mizzen, and the main-topsail, and the boat astern; thus I followed my course until nightfall and then *Cape Verde* of the island of *Fernandina*, which is towards the south towards the west, remained to the northwest of me, and there was from me to it seven leagues.[1] The wind was blowing hard and I knew not how far off the island of *Cuba* was, and in order not to approach it at night, because all these islands are so deep that no bottom can be found all around them, save at two lombard shots, and this is all spotted, one piece of rock another of sand, and consequently it is impossible to anchor safely except where you can see, and therefore I determined to lower all the sails, except the foresail, and to sail with that, and suddenly the wind grew very strong and I made much headway of which I was doubtful, and it was very misty, and rained: I had the foresail taken in and we did not go this night two leagues, &c."

Jueves 25 de Octubre.

Navegó despues del sol salido al Oueste Sudueste hasta las nueve horas, andarian cinco leguas: despues mudó el camino al Oueste: andaban ocho millas por hora hasta la una despues de medio dia, y de allí hasta las tres, y andarian cuarenta y cuatro millas. Entonces

Thursday October 25th.

He afterwards sailed from sunrise west-southwest until nine o'clock, making about five leagues: afterward he changed course to the west: they went eight miles an hour until one

(1) That is, Cape Verde, the southwest end of Fernandina, bore northwest seven leagues distant (22.3 nautical miles).

vieron tierra, y eran siete á ocho islas([1]), en luengo todas de Norte á Sur: distaban de ellas cinco leguas &c.

Viernes 26 de Octubre.

Estuvo de las dichas islas de la parte del Sur, era todo bajo cinco ó seis leguas, surgió por allí. Dijeron los indios que llevaba que habia dellas á *Cuba* andadura de dia y medio con sus almadias, que son navetas de un madero adonde no llevan vela. Estas son las canoas. Partió de allí para *Cuba*, porque por las señas que los indios le daban de la grandeza y del oro y perlas della pensaba que era ella, conviene á saber *Cipango.*

Sabado 27 de Octubre.

Levantó las anclas salido el sol de aquellas islas, que llamó *las islas de Arena* por el poco fondo que tenian de la parte del Sur hasta seis leguas. Anduvo ocho millas por hora hasta la una del dia al Sursudueste, y habrian andado cuarenta millas, y hasta la noche andarian veinte y ocho millas al mesmo camino, y antes de noche vieron tierra. Estuvieron la noche al reparo con mucha lluvia que llovió. Anduvieron el Sabado fasta el poner del sol diez y siete leguas al Sursudueste.

Domingo 28 de Octubre.

Fue de allí en demanda de la isla de *Cuba* al Sursudueste, á la tierra della mas cercana, y entró en un rio muy hermoso y muy sin peligro de bajas ni otros inconvenientes, y toda la costa que anduvo por allí era muy hondo y muy limpio fasta tierra: tenia la boca del rio doce brazas, y es bien ancha para barloventear; surgió dentro, diz que á tiro de lombarda. Dice el Almirante que nunca tan hermosa cosa vido, lleno de árboles todo cercado el rio, fermosos y verdes y diversos de los nuestros, con flores y con su fruto, cada uno de su manera. Aves muchas y pajaritos que cantaban muy dulcemente: habia gran cantidad de palmas de otra manera que las de Guinea y de las nuestras; de una estatura mediana y los pies sin aquella

([1]) Deben ser los Cayos orientales y meridionales del *Gran Banco de Bahama*, que despiden placer de sonda al Sur, y donde estuvo fondeado Colon el dia 26 de Octubre, partiendo desde allí para dar vista á *Cuba*; como en efecto la vió entrando el dia 28 en el *puerto de Nipe.*

o'clock p. m., and thence until three o'clock, and they made about forty-four miles. At that time they saw land, and there were seven or eight islands, all extending from north to south: distant from them five leagues, &c.

Friday October 26th.

He was on the southern side of said islands, all was shallow for five or six leagues, he anchored there. The Indians he had with him told him that to reach *Cuba* with their canoes from those islands would take them a day and half, these canoes are small vessels of one piece of wood and have no sail. These are the canoes. He sailed thence for *Cuba*, because from the signs which the Indians gave him of the size and of its gold and pearls he thought that was the one, that is to say *Cipango.*

Saturday October 27th.

At sunrise he weighed anchor from those islands, which he called *las islas de Arena* [Sand Islands] on account of the little bottom they had for six leagues to the south. He ran south-southwest at the rate of eight miles an hour until one o'clock in the afternoon, making about forty miles, and up to nightfall they had made about twenty-eight miles on the same course, and before night they saw the land. They were on the lookout during the night with much rain which it rained. They ran on Saturday until sunset seventeen leagues south-southwest.

Sunday October 28th.

He went thence in search of the island of *Cuba* to the south-southwest, to the land nearest to it [him?], and entered a very beautiful river very free from danger of shoals and other inconveniences, and all the coast that he passed there was very deep and very clear as far as the land: the mouth of the river had twelve fathoms, and is very wide in order to tack in; he anchored within, he said at the distance of a lombard shot. The Admiral says that he never saw such a beautiful thing, the banks of the river being covered with trees, which were beautiful and green and different from ours, with flowers and with their fruit, each one after its kind. Many birds and little birds which sang very sweetly: there was a great quantity of palms different from those of Guinea and from ours; of medium height and the feet without that shirt,([1]) and the leaves very large, with

([1]) He probably found a species of palm that was without the reticulum.

camisa, y las hojas muy grandes, con las cuales cobijan las casas; la tierra muy llana: saltó el Almirante en la barca y fue á tierra, y llegó á dos casas que creyó ser de pescadores y que con temor se huyeron, en una de las cuales halló un perro que nunca ladró, y en ambas casas halló redes de hilo de palma y cordeles, y anzuelo de cuerno, y fisgas de hueso y otros aparejos de pescar, y muchos huegos dentro, y creyó que en cada una casa se juntan muchas personas: mandó que no se tocase en cosa de todo ello, y así se hizo. La yerba era grande como en el Andalucía por Abril y Mayo. Halló verdolagas muchas y bledos. Tornóse á la barca y anduvo por el rio arriba un buen rato, y diz que era gran placer ver aquellas verduras y arboledas, y de las aves que no podia dejallas para se volver. Dice que es aquella isla la mas hermosa que ojos hayan visto, llena de muy buenos puertos y rios hondos, y la mar que parecia que nunca se debia de alzar porque la yerba de la playa llegaba hasta cuasi el agua, la cual no suele llegar donde la mar es brava: hasta entonces no habia experimentado en todas aquellas islas que la mar fuese brava. La isla, dice, ques llena de montañas muy hermosas, aunque no son muy grandes en longura salvo altas, y toda la otra tierra es alta de la manera de Sicilia: llena es de muchas aguas, segun pudo entender de los indios que consigo lleva, que tomó en la isla de *Guanahani*, los cuales le dicen por señas que hay diez rios grandes, y que con sus canoas no la pueden cercar en veinte dias. Cuando iba á tierra con los navíos salieron dos almadias ó canoas, y como vieron que los marineros entraban en la barca y remaban para ir á ver el fondo del rio para saber donde habian de surgir, huyeron las canoas. Decian los indios que en aquella isla habia minas de oro y perlas, y vido el Almirante lugar apto para ellas y almejas, ques señal dellas, y entendia el Almirante que allí venian naos del Gran Can, y grandes, y que de allí á tierra firme habia jornada de diez dias. Llamó el Almirante aquel rio y puerto de *San Salvador*(1).

(1) Conócese con el nombre de *Puerto ó Bahía de Nipe*, á seis leguas al S. S. E. de la punta de Mulas.

which they cover their houses; the land is very level: the Admiral jumped into the ship's boat and went on shore, and came to two houses which he thought to be those of fishermen and which ran away in fear, they found in one of them a dog which never barked, and in both houses he found nets of palm thread and cords, and horn fish-hooks, bone harpoons and other fishing-gear, and numerous sets within, and he believed that each house was occupied by many persons: he ordered that nothing in them should be touched, and nothing was. The grass was high as in Andalucia in April and May. He found much purslain and wild amaranth. He returned to the boat and went up the river for a good while, and he said that it was a great pleasure to see that verdure and those groves, and of the birds that he could not leave them in order to return. He says that that island is the most beautiful that eyes ever beheld, full of good ports and deep rivers, and it seemed to him that the sea must never be high there for the grass of the beach almost reached the water, which rarely happens where the sea is rough; until then he had not experienced a rough sea in all those islands. The island, he says, is full of very beautiful mountains, though they are not very long but lofty, and all the land is high like that of Sicily: full of much water, as he could understand from the Indians with him, whom he took from the island of *Guanahani*, who tell him that there are ten large rivers, and that with their canoes they cannot go around it in twenty days. When he went to the land with the vessels two canoes approached, and when they saw that the sailors entered the boat and rowed in order to go to see the bottom of the river in order to know where they were to anchor, the canoes fled. The Indians said that in that island there were mines of gold and pearls, and the Admiral saw place suitable for them and shell-fish, which is a sign of them, and the Admiral understood that ships of the Grand Khan came there, and large ones, and that from there to the main land was a run of ten days. The Admiral called that river and port *San Salvador*.

Next to this text in entirety, it is indispensable to every thorough discussion of the first landfall that the student should have before him a correct chart, since an imperfect one is inadequate to the settlement of a problem, the proof of which are certain brief courses. The chart in the appendix was prepared in the office of the U. S. Coast and Geodetic Survey, from the English Admiralty surveys of 1832–1836, and such Spanish charts as were available. The Bahamas, dependent upon the English surveys, are accurate. Some of the harbors, and perhaps part of the coast line of Cuba and Hayti, may be a little in error in longitude.

The five tracks from five different islands to Cuba are—

1st. Navarrete's from the Grand Turk.
2d. Irving's from Cat.
3d. Captain Becher's from Watling.
4th. Varnhagen's from Mariguana.
5th. G. V. Fox's from Samana, or Atwood Cay.

Although the authorities heretofore mentioned concurred on the first four islands, respectively, it is only those noted here that have laid down a continuous track from the first landfall they claimed for Columbus, to Cuba. With this authentic chart and Las Casas's copy of Columbus's journal, each of these tracks, and the arguments of their supporters, can be tried.

THE TRACK OF NAVARRETE.

Navarrete said, 1st: Columbus sighted the east side of the Grand Turk while steering a course W. by S. ¾ S. and from there he went around by the north, to the west side of the island.

ANSWER. The journal of October 11 says that at sunset—on that day the sun set at $5^h\ 41^m$ apparent time—Columbus steered west and made the land at 2 a. m. the next day. On the 13th Columbus wrote: "I determined to wait until to-morrow evening, and then to sail for the south-west." On the 14th he wrote that he went *with the boats* "along the island in a north-northeasterly direction, to see the other side," * * * "and afterwards *I returned to the ship*(1) and set sail."

Navarrete said, 2d: From the west side of the Grand Turk Columbus sailed W. by N. ½ N. 19 miles to the Caicos Islands which, together, formed the second, to which he gave the name of *Santa Maria de la Concepcion*. (*Navarrete*, p. 26, note I.)

ANSWER. Conceding that Columbus went to the north of west when he said, on the 13th, that he would sail "for the southwest," and admitting the probability that in 1492 the Caicos group was one island, yet it does not agree with the description of the second island he came to, of which he wrote on the 15th: "And I found that that side which is towards the island of San Salvador runs north [and] south, and is five leagues [15.9 nautical miles] in length, and the other which I followed ran east [and] west, and contains over ten leagues [31.8 nautical miles]. And as from this one I saw another larger one to the west, I clewed up the sails * * * and about sunset I anchored near said cape [the western cape]." The east side of the Caicos is north and south 13 miles, which corresponds with the journal; but the north shore is N. W. by W. ¼ W. 38 miles and then S. W. ¾ W. 38 miles. Or, if the N. E. side of the Caicos group be designated as the east and west side that Columbus followed, it agrees near enough in distance, but varies 2¾ points in direction; and if we assume the journal to be in error in giving "east [and] west," there is still the insurmountable fact that Columbus wrote three times on the 15th, and twice on the 16th, that the third island bore *west* from the second. A vessel anchored at the west cape of the N. E. side of the Caicos group has no land visible. The island of Mariguana is the nearest, and this is N. W. by W. ¼ W. 43 miles distant.

Navarrete said, 3d: From the second island Columbus sailed to the southward and westward to Little Inagua, the third island, which he named Fernandina. (*Navarrete*, p. 28, note I.)

ANSWER. If we take Navarrete's course as it is laid down on the chart, from the west cape of the N. E. side of the Caicos, the course and distance to Little Inagua are S. W. ¾ W. 60 miles. If we measure from the S. W. Caicos to Little Inagua—S. E. side—it is about W. S. W. 25 miles.

On the 15th of October Columbus was at the west cape of his second island and he wrote in regard to the third island, "I saw another larger one to the west * * * and so I departed at about ten o'clock with a S. E. wind, inclining to the south, for the other island, a very large one." * * * And when he came to the third island he said: "All this portion of the island runs N. W. [and] S. E., and it appears that there are on this coast more than 28 leagues [89.1 nautical miles]." On the 16th, after a more careful examination, he wrote: "And this cape to which I have come and all this coast runs N. N. W. and S. S. E. and I saw fully 20 leagues [63.6 nautical miles] of it, but this was not the end."

(1) *Italics* are by the writer.

This is the description of Ferdinand Island. It cannot be Little Inagua, as Navarrete asserts, because this is only 7½ miles east and west, and the same N. N. E. and S. S. W.

Navarrete said, 4th: From the third island, Little Inagua [Santa Maria], Columbus steered to the southward and westward to the fourth island, Great Inagua, which he named *Isabela*. (*Navarrete*, p. 33, note I.)

ANSWER. When Columbus left the third island on the 19th of October he wrote: "At dawn I weighed anchor and sent the caravel Pinta to the *east and southeast*, and the caravel Niña *to the S. S. E.*, and I with the ship *went to the S. E.* * * * And then before we had gone three hours we saw an island *to the east*,(¹) to which we directed our course, and all three vessels reached it before midday at its northern extremity, where there is a rocky islet. * * * And the said islet lay from the island of Fernandina, whence I had come, *east* [and] *west*."

Navarrete said, 5th: From the fourth island, Great Inagua [Isabella], Columbus steered N. by E. 11 miles—W. ½ N. 56 miles—W. by N. ¼ N. 61 miles—and S. by W. ½ W. 61 miles—to Port Nipe, in Cuba.

ANSWER. Such courses and distances cannot be found in Columbus' journal. He left the fourth island on the 24th of October and wrote: "At midnight(²) I weighed anchor from the island of Isabella, * * * in order to go to the island of Cuba. * * * And they told me that I should go to it by the W. S. W., and so I think. * * * And thus I sailed until day to the W. S. W., and at dawn the wind calmed. * * * And I remained with little wind until after midday and then the wind began to blow very lovely. * * * I followed my course until nightfall, and the Cabo Verde of the island of Fernandina bore N. W. 7 leagues [22.3 nautical miles]."(³)

On the 25th, still steering W. S. W., Columbus discovered "seven or eight islands, all extending from north to south, distant from them five leagues [15.9 nautical miles]." On the 26th the journal reads: "He was on the southern side of said islands, all was shallow for five or six leagues, he anchored there. * * * He sailed thence for Cuba." The journal says, October 27: "At sunrise he weighed anchor from those islands, which he called Sand islands, on account of the little bottom they had for six leagues [19 nautical miles] to the south." Navarrete wrote, in a note, pp. 39–40, that Columbus anchored on the 26th of October on the eastern and southern shoal of the "Grand Bank of Bahama," and left there for Cuba. Although Navarrete's track, on the chart, does not reach this bank, we must admit, from this note, that he intended it. But there is no part of "Columbus Bank" which bears W. S. W. from Great Inagua. Domingo Cay, the most southern part, is W. ½ N. from the most northeastern part of Great Inagua; and the south Ragged island, south of which he anchored, bears W. by N. ½ N. 155 miles from the N. E. end of Great Inagua, and N. W. by W. ¾ W. 133 miles from the S. W. end. The journal evidently omits some of the distances run from Isabella to the Sand Islands; but on the 24th Columbus gives the bearing and distance of the S. W. Cape of Fernandina, and this "departure" is put on the chart. Afterward he logs 16 leagues W. S. W., then he saw the Sand Islands 5 leagues distant, making a total of 21 leagues, 66.8 nautical miles. The true course and distance from his "departure" to South Ragged are W. S. W. 65 miles. This close agreement may be accidental; but if we omit all distances given, yet the courses found in the journal are irreconcilable with any from Great Inagua to the south-eastern Bahama Bank. In respect to Port Nipe, which Navarrete and Captain Becher adopt for Columbus's first anchoring-place in Cuba, see the discussion of Captain Becher's track.

By selecting Turk for the first landfall, an extreme S. E. island of the Bahamas, Navarrete confronts Juan de la Cosa and Antonio Herrera; for on their charts, which will be referred to later, Guanahani is an island situated *near the middle* of the N. E. side of the Bahama group.

THE TRACK OF VARNHAGEN.

Varnhagen said, 1st: Columbus made the island of Mariguana steering west; he rounded the east end and anchored on the northeast shore. Hence he steered W. ¼ N. 40 miles for Creek Point on Acklin Island; followed the north and south shore for 13 miles, and the east and west shore 29 miles, and so over to the south cape of Long Island.

(¹) *Italics* are by the writer.

(²) It was obviously the midnight which began this day.

(³) How could Little Inagua bear N. W. of him 22.3 miles?

ANSWER. Varnhagen, like Navarrete, ignores the assertion of Columbus of October 13: "I determined to wait until to-morrow evening and then to sail for the southwest." He has even omitted this weighty sentence from his *Geschichte des Zeitalters der Entdeckung*.

Conceding that he steered to the westward from Guanahani, yet Columbus said, on the 15th of October, that the second island he steered for was "over 5 leagues distant, rather 7 [22.3 nautical miles]" but Varnhagen's second island is 40 miles from the first. A difference of 79.4 per cent. in such a short run, *actually gone over*, is not possible with so experienced a navigator. In crossing the Atlantic, a distance of more than 3,000 miles, he overran his log 11½ per cent. only. In going from Mariguana to Acklin, Columbus went within 5 miles of two islands, each 70 feet high. According to Varnhagen, Columbus does not mention them. It is not characteristic of his journal to omit all notice of the first islands he came to in the New World. He wrote on the 15th of October: "Nevertheless it was my desire not to pass any island without taking possession of it, as one taken possession of the same may be said of all; and I anchored and remained until to-day."

Columbus did not go along the shore of the second island which runs north and south. He wrote on the 15th of October, "I found that that side which is towards the island of San Salvador runs north [and] south, and is five leagues in length, and *the other which I followed*(1) ran east [and] west."

Varnhagen said, 2d: Columbus went from the south cape, around Long Island and returned to the south cape.

ANSWER. On the 16th Columbus wrote: "This island is exceedingly large and I have determined to go around it * * * [again]. I set sail with a south wind intending to go around the whole island." * * *

On the 17th he wrote: "The wind then ceased, and then sprang up from the W. N. W., which was contrary to our course, and so I turned around and sailed all the past night. * * * And we [are] *at the S. E. cape of the island where I hope to anchor until it gets clear.*" In addition to these decisive words, there is the fact, shown by the chart, that between Exuma and Long Island the water is too shoal for such vessels as Columbus used. This will be spoken of again in discussing Irving's track.

Varnhagen said, 3d: Columbus sailed from the south cape of Long Island to the N. W. end of Crooked Island, then across the "Columbus bank" to Port Gibara, in Cuba.

ANSWER. This part of Varnhagen's track comes near to Captain Becher's and the writer's, and therefore need not be considered here except in regard to the harbor of Gibara. In the journal of October 28th we read: "He went thence in search of the island of Cuba, * * * and entered a very beautiful river * * * the mouth of the river had *twelve fathoms*."(2) The port of Gibara is a small basin, exposed to northerly winds, and has *three fathoms*, only, at the entrance.

WASHINGTON IRVING'S TRACK.

The track of Washington Irving is laid down from his description of the "Route of Columbus in his first voyage." (*Irving's Columbus*, revised edition, vol. iii, appendix, pp. 366–380.)

Irving wrote, 1st: "From Guanahani Columbus saw so many islands that he was at a loss which next to visit. * * * He determined to go to the largest in sight. * * * The island thus selected, it is presumed, was the present island of Conception; and that the others were that singular belt of small islands known as La Cardena (or the chain) stretching past the island of San Salvador in a S. E. and N. W. direction; the nearest of the group being nearer than Concepcion, while the rest are more distant. * * * We know that in all this neighborhood the current sets strongly to the W. N. W.; *and since Columbus had the current against him he must have been sailing in an opposite direction, or to the E. S. E.* * * * Hence it is rendered certain that Columbus did not sail westward in going from San Salvador to Conception; for from the opposition of the wind, as there could be no other cause, he could not sail toward that quarter. * * * Conception situated E. S. E. from San Salvador, and at a corresponding distance of 5 leagues [15.9 nautical miles]."

(1) *Italics* are by the writer.

(2) E. F. Qualtrough, Master U. S. Navy. *Sailors' Handy Book*, p. 192, makes the old Spanish braza equal 5.432 English feet. *Italics* are by the writer.

ANSWER. Columbus wrote, on the 14th of October: "I returned to the ship and set sail and saw so many islands that I could not decide to which one I should go first." Mr. Gibbs made personal observation from the southeast point of Cat island and wrote: "No land can be seen from the highest hills, nor from the mast-head of a vessel lying at Winding Bay or Columbus Point, where he is said to have landed.(1)

The island of Conception is $2\frac{3}{4}$ miles long, $1\frac{3}{4}$ broad, and 90 feet high. Near by, on the east side, is Booby Cay, one-third of a mile across and 130 feet high. The reef surrounding both is 8 by 5 miles. It is possible that in 1492 an island might have been there of these dimensions.

On the 15th of October Columbus described the second island thus: "I found that that side which is toward the island of San Salvador runs north [and] south, and is five leagues [15.9 nautical miles] in length, and the other which I followed ran east [and] west, and contains over ten leagues"—31.8 nautical miles. La Cardena (the chain of islands stretching away to the northward and westward from Great Exuma) is, in the highest part, 36 miles from Cat island, 48 from Columbus Point, and 50 from Conception, and certainly invisible from each.

The currents in this neighborhood are spoken of by Capt. E. Barnet in the *West India Pilot*, 3d edition, 1876, p. 431, thus: "In the neighborhood of Conception Island it is said generally to run strong to the N. W. Some observations tend to show that after northers or on the increase of the moon, as it approaches to change, there is a similar set to the southward. There is, however, no certainty in the case, and consequently more than ordinary attention is required when navigating among the West India islands."

There is no foundation that Columbus had "the current against him," except his remark of the 13th of October, "the tide detained me." On the eve of leaving Guanahani he wrote, "I determined to wait until tomorrow evening, and then to sail for the southwest." There is no mention in the journal of "the opposition of the wind." Columbus does not give its direction until the 15th, when he was at the second island, then he records it as being S. E. Conception lies S. S.E. $\frac{1}{4}$ E., 19 miles from the southeast point of Cat.

Irving wrote, 2d: "Leaving Conception on the 16th of October Columbus steered for a very large island seen to the westward nine leagues [28.6 nautical miles] off, and which extended itself 28 leagues [89 nautical miles] in a southeast and northwest direction. * * * He named it Fernandina. At noon he made sail again, with a view to run round it and reach another island called Samoet; but the wind being at S. E. by S. the course he wished to steer, the natives signified that it would be easier to sail around the island by running to the N. W. with a fair wind. He therefore bore up to the N. W., and having run two leagues [6.4 nautical miles] found a marvelous port with a narrow entrance. * * * Sailing out of this harbor by the opposite entrance at the northwest, he discovered that part of the island which runs east and west. The natives signified to him that this island was smaller than Samoet, and that it would be better to return towards the latter. It had now become calm, but shortly after there sprung up a breeze from the W. N. W., which was ahead for the course they had been steering; so they bore up and stood to the E. S. E. in order to get an offing; for the weather threatened a storm, which however dissipated itself in rain. The next day, being the 18th of October, they anchored opposite the extremity of Fernandina. The whole of this description answers most accurately to the island of Exuma. * * * The identity of the island here described with Exuma is irresistibly forced upon the mind."

ANSWER. In calling Exuma Fernandina, and anchoring Columbus "opposite the extremity," it is evident that Irving included in this name Little Exuma, which lies to the southward and eastward of Great Exuma, and Hog Cay lying farther east. These might have formed one island in 1492, for the narrow channel between Great and Little Exuma is now almost fordable at low water. On this chart Great Exuma and Hog Cay only are noted. The land between is Little Exuma.

From Conception Irving takes Columbus to a position, whence, by steering at least 6.4 miles N. W., he came to, entered, and passed through "a marvellous port" (Great Exuma harbor). It is obvious that the opposite of northwest, measured 6.4 miles from the southeast entrance of this harbor, would put a ship on shore; therefore the track on this chart is laid down close to the land, without regard to the course it makes.

(1) Proceedings of the New York Historical Society, 1846. Appendix.

From Conception to the turning-point of Irving, 6.4 miles to the eastward of Great Exuma harbor, the course and distance are S. W. ½ S., 35 miles. While on his way from the second island to the third—Conception to Fernandina—October 15th, Columbus wrote: "And from this island of Santa Maria to the other one there are 9 leagues [28.6 nautical miles] east [and] west." On the 16th, after arriving at Fernandina, he wrote: "This island lies at a distance from that of Santa Maria 8 leagues [25.5 nautical miles] almost east [and] west."

He could not have entered and sailed out of this marvellous port by the opposite entrance, because on the 17th of October he said: "I found a very marvellous port. * * * Within it there is ample room for 100 ships if it had sufficient depth of water and was clear, and also had a deep entrance. I thought it worth while to examine and sound it, and so I anchored outside of it, and went in with all the boats of the ships and saw there was not bottom." Neither could he have discovered that part of Exuma which runs east and west, because no part of it does. Nor could he have anchored opposite the extremity of Fernandina, because there is not sufficient depth of water.

Irving wrote, 3d: "On the 19th of October the ships left Fernandina steering S. E., with the wind at north. Sailing three hours on this course they discovered Samoet to the east, and steered for it, arriving at its north point before noon. Here they found a little island surrounded by rocks, with another reef of rocks lying between it and Samoet. To Samoet Columbus gave the name of Isabella, and to the point of it opposite the little island, that of Cabo del Isleo; the cape of the S. W. point of Samoet Columbus called Cabo de Laguna, and off this last his ships were brought to anchor. The island lay in the direction from Fernandina to Isabella, east and west. The coast from the small island lay westerly 12 leagues [38.2 nautical miles] to a cape which Columbus called Formosa, from its beauty; this he believed to be an island apart from Samoet or Isabella, with another between them. Leaving Cabo Laguna, where he remained until the 20th of October, Columbus steered to the N. E. toward Cabo del Isleo, but meeting with shoals inside the small island, he did not come to anchor until the day following. * * * The island of Isabella, or Samoet, agrees so accurately in its description with Isla Larga [Long Island], which lies east of Exuma, that it is only necessary to read it with the chart unfolded to become convinced of its identity."

ANSWER. This is the description of that part of the Bahamas which the *West India Pilot*, vol. ii, p. 444, describes thus: "The west side of Long Island is only navigable for boats and very small coasters, who manage to pick their way across to the Jumento cays." The blank space on this chart from Exuma to Long Island was purposely left so by the English surveyors, because it is unnavigable. There is no ground for believing that the water was deeper in 1492, for the wasting of these islands and cays tends to the opposite result.

Irving makes Columbus leave Exuma [Fernandina] in search of Samoet, which, he says, is Long Island. Now when Columbus was at Conception he had Long Island plainly in sight, for it is only 14 miles from there. In fact, to go from Conception to Exuma, an island he could not see, he had to bend his course to the northward and westward to avoid an island that was visible at his start and for which he was searching.

Irving wrote, 4th: "Having resolved to visit the island which the natives called Cuba, and described as bearing W. S. W. from Isabella, Columbus left Cabo del Isleo at midnight, the commencement of the 24th of October, and shaped his course accordingly to the W. S. W. * * * and in the evening Cape Verd, S. W. point of Fernandina [Exuma], bore N. W. distant 7 leagues [22.3 nautical miles]. * * * At 3 p. m. of the 25th land was discovered, consisting of 7 or 8 keys, lying north and south, and distant 5 leagues [15.9 nautical miles] from the ship. Here he anchored the next day, south of these islands, which he called Islas de Arena. * * * This sum of 30 leagues [95.5 nautical miles] is about three less than the distance from the S. W. point of Fernandina or Exuma, whence Columbus took his departure, to the group of the Mucarras, which lie east of Cayo Lobo on the grand bank of Bahama, and which correspond to the description of Columbus. * * * The course from Exuma to the Mucarras is about S. W. by W. * * * At sunrise Columbus set sail from the isles Arenas or Mucarras for an island called Cuba, steering S. S. W. At dark, having made 17 leagues [54.1 nautical miles] on that course, he saw the land and hove his ship to until morning. On the 28th he made sail again at S. S. W. and entered a beautiful river with a fine harbor, which he named San Salvador. * * * This port of San Salvador we take to be the one now known as Caravelas Grandes."

ANSWER. Columbus wrote on the 24th of October: "At midnight I weighed anchor from the island of Isabela the cape of the rocky islet, which is on the northern side where I was lying in order to go to the island of Cuba." On the 19th, when he had anchored at this rocky islet, he wrote: "The coast afterwards ran from the rocky islet to the westward, and there was in it twelve leagues as far as a cape, which I called Cape Beautiful, which is in the west." These extracts point out that the rocky islet from which Columbus sailed for Cuba had land stretching from it to the westward, which terminated in a beautiful cape. Muñoz, Irving, and also M. le Baron de Montlezen, make this position to be the northwest end of Long Island.(1) But thence no land runs to the westward, nor could Columbus's vessels go to Cuba from there, because of shallow water.

The bearing and distance which Columbus gives on the 24th of October, "S. W. cape of Fernandina N. W. 7 leagues [22.3 nautical miles]" Irving reckons from the southeast end of Exuma. This is marked on the chart "departure." The course to it from the rocky islet—northwest end of Long Island—is S. by E. When Columbus left the cape of the rocky islet, on the 24th of October, he wrote: "And thus I sailed until day to the W. S. W." A course from the northwest end of Long Island to Irving's "departure" passes over the shallow water spoken of, and goes through the solid land which stretches from Long Island.

From this departure, Irving makes Columbus go straight to the Mucarras Reef. A glance at the chart shows the impossibility of such a course. It runs through cays, among "rocky heads," and over that very shoal part of the Bahama bank upon which the experienced seaman hesitates to venture even with a good pilot and a correct chart.

Columbus's journal does not speak of any shoal water from the cape of the rocky islet to the "*islas de Arena.*" When *he arrived there* it reads: "He was on the southern side of said islands, all was shallow for five or six leagues [15.8 to 19.1 nautical miles], he anchored there." According to the chart, there is no shallow water south of the Mucarras; the deep water of the old Bahama channel runs close to it.

From Mucarras to the port of Caravelas Grandes it is S. S. W. ½, W. 28 miles only. Irving admits that Columbus ran on the 27th 17 leagues—54.1 nautical miles—and, on the 28th, more on the same course. Fifty-four miles from the Mucarras, in a south-southwest direction, is 26 miles *into the island of Cuba.* The port of Caravelas Grandes has 6 feet of water at the entrance and the tide rises 3½ feet. The journal of October 28th reads: "The mouth of the river had twelve fathoms." Even if this is a clerical error it is certain that the flag-ship of Columbus could not enter so shallow a port. (See Appendix E.)

All that Muñoz wrote in regard to the identity of Watling and Guanahani and the track of Columbus in the Bahamas is this, in volume 1—the only one published, owing to his death—pp. 85–86: "In my opinion, Guanahani is Watlin. He landed on the S. W. point. He took the boats and reconnoitered by way of the N. N. E. the western coast, and having doubled the northern point, he turned around by the eastern coast, which is the largest side and is estimated at having more than 15 leagues(2) [47.7 nautical miles]."

Page 87: "Having stayed three days at San Salvador, he sailed to a smaller island which he had descried, at the distance of 7 leagues [22.3 nautical miles]; without stopping there, he steered for another and larger one, which seemed to lie at a distance of about 10 leagues [31.8 nautical miles] to the west. Here he cast anchor and took possession of the land, calling it Santa Maria de la Concepcion. * * * Hence continuing 8 leagues [25.4 nautical miles] in a westerly direction, he came upon an island which was considerably larger, level, pleasant, and having a beautiful beach. I think it is the island which is called Gato [Cat], which he called Fernandina."

Page 88: "Having turned the prows to the S. E., the fleet passed an island superior to those which they had seen, both in extent and pleasant appearance; it rose higher above the surface of the sea; the soil was not so uniform as in the others, but varied, with some hills; it abounded in water, many lagoons, and most beautiful meadows and groves. He took possession

(1) According to Irving's text, *ante*, 3d, Columbus's track on this chart, on the west side of Long Island, should be extended to the "north point."

(2) To row around Watling island, the distance is 39 nautical miles; around Cat, it is 100.

and changed its former name Samoeto to Isabela. It is probably that which is now called Long Island."

Page 90: "He steered to the south, in quest of the large land which was mentioned by all the people of the Lucayos islands under the name of Cuba. They referred to it with expressions and gestures which seemed to our men to signify abundance of gold and pearls, great nations, powerful kings, many ships, seamen, and merchants. Having compared these circumstances with the place where the map of Toscanelli represented the extreme portion of India and its adjacent islands, Columbus and the Pinzons suspected that this Cuba was the famous Cipango. They sighted it on the 27th of October, at nightfall, on the northern coast. At dawn on the following day they saw, in taking their first view, a most beautiful country, very remarkable; beautiful rising grounds and mountains, wide-stretching meadow lands, and rivers of considerable volume. In one of these the fleet anchored," &c.

Muñoz, probably, had no authentic chart when he wrote the above. The east side of Watling is only twelve miles long. If Columbus went from Watling *to* a smaller island, without stopping at the latter, it was either Conception or Rum Cay. From neither could he have sailed to the west 31.8 miles and then taken possession of any land except—with some allowance—the northwest part of Long Island. From here he could not continue in a *westerly* direction 25.4 miles and arrive at Cat, because this lies about *north by west* from that. After leaving Cat, he turns his prows to the southeast, returns, and takes possession of the island he left a few days before. As Muñoz means that Columbus went to Cuba, steering south from the northwest end of Long Island, see the discussion of Irving's track (*ante*, p. 379).

CAPTAIN BECHER'S TRACK.

Captain A. B. Becher, Royal Navy, published in London, in 1856, an octavo of 376 pages, called the *Landfall of Columbus on his first voyage to America.* In the preface he wrote: "The work has cost several years of close application at frequent intervals of rest from the duties of the Hydrographical Office of the Admiralty." In 1856 the accurate Admiralty charts used in this discussion had been published. The office in which Captain Becher served possessed more knowledge about the Bahamas than is known elsewhere, and his position gave him exceptional advantages in seeking information. With such facts it might be expected that his conclusions should be generally accepted.

Captain Becher first makes Columbus approach Watling steering S. W., and he anchors him on the northeast side, about four miles east-southeast of the northeast end, in a position from which his boats must have rowed northwest "to see the other side." He also takes the squadron around Watling by the north.

ANSWER. The journal of October 11 reads: "He sailed to the west-southwest. * * * After sunset he sailed on his first course to the west; they went about 12 miles an hour [9.6 nautical miles], and two hours after midnight they had run about 90 miles, that is, 22½ leagues [71.6 nautical miles]. * * * Two hours after midnight the land appeared about two leagues off [6.4 nautical miles]." Columbus wrote on the 14th: "At dawn I ordered the boat of the ship and the boats of the caravels to be got ready, and went along the island, in a north-northeasterly direction, to see the other side, which was on the other side of the east, and also to see the villages." After he had examined the island in the boats on the 14th, he wrote: "And afterward I returned to the ship and set sail."

Captain Becher writes, 2d (page 345, note, appendix): "Rum Cay is the name of the small island first steered for by Columbus after leaving Guanahani, and on which he not only did not consider it worth while to land, but even not to bestow a name."

Pages 111, 112: "The distance of Rum Cay corresponds with that given by Columbus, but he was mistaken in respect of its size, and no doubt baffled and deceived from the effects of the current. Yet no sooner does he gain it than, attracted by another large island to the westward, without waiting to land on this, 'the first island steered for,' he continues his course toward that, making all the sail he can, so as to reach it before night."

Page 116: "But with respect to the size of Rum Cay, it is evidently erroneously stated in the journal; perhaps from accident, arising from the blotted and rotten condition of the papers. But Columbus, seeing it was an unimportant island, and that a much larger one was before him, hastens off to it, and could not, therefore, say anything for certain about Rum Cay. If he really meant the length of its side next to Guanahani and that lying east and west to be as he gives them, they are greatly in error. But this requires confirmation; and it might be asked how he could have determined the former? All this must have been mere guesswork, for he could not get to the southward, being prevented by the current."

ANSWER. Rum Cay is only 4½ miles north and south, and 9½ east and west. If the reef around it is included, it would measure 8 miles north and south and 12½ east and west. Columbus wrote of the second island, on the 15th of October: "And I found that that side, which is toward the island of San Salvador, runs north [and] south, and is five leagues [15.9 nautical miles] in length, and the other which I followed ran east [and] west, and contains over ten leagues [31.8 nautical miles]. And as from this island I saw another larger one to the west, I clewed up the sails for I had gone all that day until night, because I could not yet have gone to the western cape, to which I gave the name of the island of Santa Maria de la Concepcion, and about sunset I anchored near said cape in order to learn whether there was gold there."

Columbus said, in his letter to Luis de Santangel (Navarrate, p. 167): "To the first island that I found I gave the name of San Salvador. * * * To the second island I gave the name of Santa Maria de Concepcion; the third I called Fernandina; the fourth, Isabela; the fifth, Juana," &c. These extracts from Columbus and Captain Becher are contradictory. Captain Becher's strain at an agreement is at the expense of Columbus, and his surmises show the insurmountable obstacle of selecting Rum Cay for the second island. The substance of Columbus' journal is this: he sailed over $31\frac{8}{10}$ miles along a shore of the second island, which ran east and west; then he saw a larger island to the west; he took in sail; he named the second island and he anchored at the west cape of it, and the next day he went on shore there.

Captain Becher, Appendix, p. 345, note xxix, translates "Cargue las velas"—*crowds all sail;* the true meaning is, *I clewed up the sails.* On p. 118 Captain Becher again recognizes the perplexity of his situation, for after saying that Columbus did not bestow a name on the second island he writes: "But why should 'Rum Cay' be thus left nameless?" And thereupon he proposes this tampering with the names given by Columbus (p. 118). "The long appellation of Santa Maria de la Concepcion is, therefore, divided between Rum Cay and Long Island; the name Concepcion being assigned to the former, and to the latter, Long Island, Santa Maria, or St. Mary." On page 376 he recalls this extraordinary division, and suggests that the whole of Long Island should be called Concepcion, and the northwest cape, Santa Maria. Captain Becher asks how Columbus could have determined the length of the side of the island next to Guanahani, as the current prevented his going to the southward, and he remarks that it must have been mere "guesswork." On the 15th of October Columbus speaks of being late in arriving at the second island, because "the tide detained me." He says nothing about the "current" preventing his course to the south. Of the two sides of the island he saw, he chose to follow the one running east and west, without giving any reason therefor. His estimate of the length of the side he did not follow *was* "guesswork." Navigators of the present day necessarily enter upon their log-books a great deal of guesswork, especially in regard to new lands, and they will continue to do so.

Captain Becher writes, 3*d* (p. 118): "Columbus passed along the northern shore of Rum Cay without landing on it, and continued to the west under all the sail he could set for Cape Santa Maria de la Concepcion." * * *

Pages 120, 121. "Columbus is now approaching that portion of his discoveries where he has been least understood, and yet where his journal is by no means deficient in clearness and perspicuity; still his actual proceedings, and their localities, seemed to have escaped the penetration of all who have attempted to connect them. But here in fact, he was deceived himself, believing that he was alluding to one island when he was really speaking of two, thereby baffling investigation without intending to do so, and puzzling effectually the ingenuity of all geographers. Among other reasons, such as the state of the wind, &c., for not delaying his stay at Cape Santa Maria, is the appearance of another large island in the west. He, therefore, makes sail for it, about 10 a.m., with a S. E. wind, borrowing, as seamen term it (that is edging) toward the south, that he might look down along the western shore of the island, as he would open it when rounding Cape Santa Maria."

Pages 121–122: "The wind, however, does not allow of his making much progress to the south. It falls in light airs, comes more from the southward against him, so that his course becomes more westerly, and he approaches the southern portion of the Exuma Islands." * * *

Page 122. "And before he arrives at it, while it is yet before him, he gives it the name of Fernandina, not having given any name even to that of Cape Santa Maria."

Page 126: "The 17th of October, the Admiral is at anchor off the island called Great Exuma. * * * The course which Columbus pursued from Guanahani to Concepcion (considered here to be Rum Cay, although not named by the Admiral), and from thence to Cape Santa Maria de Concepcion (believed here also to be the north extreme of Long Island), and from this to Exuma, which is agreed on as being Fernandina, appears on the accompanying chart."

ANSWER. On the 15th of October Columbus was at the western cape of an island which he called Santa Maria de la Concepcion, considered by Captain Becher to be the north end of Long Island. Then, and on that date, Columbus wrote: "From this island I saw another larger one to the west." * * * "And soon after I set sail for the other large island that appeared at the west." * * * "And so I left, at about ten o'clock, with a southeast wind inclining to the south for the other island." * * * "And from this island of Santa Maria to the other one there are nine leagues [28.6 nautical miles] east and west."

On the 16th he wrote: "About noon I left the *islands of Santa Maria de la Concepcion* for the *island of Fernandina*, which appears to be very large to the west, and I sailed all that day with calm weather." On the same date, having arrived at Fernandina, he writes: "This island lies at a distance from that of Santa Maria of eight leagues [25.5 nautical miles] almost east [and] west."

Assuming that the masthead lookout of the flag-ship was 60 feet above the sea, the range of visibility for the horizon is 8.85 nautical miles. There is no part of Great Exuma over 100 feet high, the range of visibility of which is 11.42 nautical miles, total 20.27 miles.(1) The land which bears west from the north end of Long Island is the northwest end of Exuma, distant 38 miles, and it is, of course, invisible. The entrance of Exuma harbor, to which Captain Becher takes Columbus (pp. 132–133), is S. W. by W. 24 miles from Cape Santa Maria, and the island about 2 miles farther. At the distance of 26 miles it is below the horizon, but sometimes, especially at nightfall, clouds form which make a strong resemblance to land.

Had Columbus meant to go from Santa Maria to the southward and westward, he might believe that he saw land there. But he did not sail in that direction; he did not "edge" to the south; he did not "look along the western shore"; he reiterates that he saw land *to the west*, and he went there. Captain Becher easily satisfies himself in respect to the views he holds in contradiction to Columbus, by saying that he "deceived himself"; was baffling investigation, and "puzzling effectually the ingenuity of all geographers."

Captain Becher writes 4th, pages 132–133, that Columbus sailed from Exuma harbor, "where he had now obtained water, * * * about noon of Wednesday, the 17th of October," and "the ships all make sail on a north-northwest course."

Pages 134–135: "When they were about two leagues from the cape, or extreme of the island, he observes what he supposes to be the mouth of a river, and is induced to anchor his ships off it. * * * Instead of a river they find what would be a harbor large enough to contain all the ships of Christendom (a favorite expression of Columbus), if it were not deficient in depth, a no less essential quality, indeed, than superficial extent for the formation of a harbor. It is described as having two entrances formed by an island, yet very narrow and with little water in them. The harbor, from this description, seems to correspond with a part of the shore of the island about ten miles to the N. W. of the former harbor (Exuma), but is really nothing more than the low shelving shore of the island covered to the depth of a few feet by the sea."

Page 137: "After staying a couple of hours at this anchorage and obtaining water, the boats return to their ships, and Columbus continues his north-northwest course along the island. The

(1) From the table of distances at which objects can be seen at sea in nautical miles, as used by the U. S. Light House Board.

wind meanwhile seems to have died away, and the ships no sooner arrive off the extreme of the island than they are becalmed; not, however, very long, for soon afterwards it springs up again from the west-northwest, which, as Columbus observes in his journal, was fair for where they had come from, * * * on which he claps his helm up and stands away to the eastward."

ANSWER. When Columbus left Santa Maria for Fernandina, on the 16th of October, he wrote: "I could not arrive in time to see the bottom in order to get a clear anchorage, a thing requiring the greatest care in order not to lose the anchors; in consequence I waited until daylight when I anchored near a village." * * * "And this cape to which I have come, and all this coast runs northwest and southeast." October 17th he wrote: "At midday I left the village where I had anchored and taken in water, in order to sail around this island of Fernandina. * * * I sailed to the north-northwest, and when I was near the end of the island, two leagues off [6.4 nautical miles], I found a very marvellous port with an entrance, although it may be said that there are two entrances, because it has a rocky islet in the middle, and both are very narrow, but within it there is ample room for one hundred ships if it had sufficient depth of water and was clear, and also had a deep entrance: I thought it worth while to examine and sound it, and so I anchored outside of it, and went in with all the boats of the ships, and saw that there was not bottom. And because I thought when I saw it that it was the mouth of some river I had the casks sent on shore for water. * * * After getting in water I returned to the ship, and set sail, and sailed to the northwest until I discovered all that part of the island as far as the coast which runs east [and] west."

Captain Becher anchors Columbus off Exuma harbor, where his vessels take in some water. He does not say which entrance, but from his track it appears to be the southeast one. The series of connected harbors formed by Elizabeth and Stocking islands and the adjacent cays, on the northeast side of Exuma, are the best in the Bahamas. They are from $\frac{1}{4}$ to $\frac{1}{2}$ a mile wide, and have two entrances, $7\frac{1}{2}$ miles apart. The southeast one has 18 feet at low water and the northwest one 21 feet. The tide rises $2\frac{1}{2}$ feet. Beginning at the southeast is Elizabeth harbor, with from 21 to 23 feet; Stocking with 16; Conch 15 to 24, and at the northwest Exuma with 31. These harbors are generally known by the name of "Exuma," and they will be so called in this paper. Captain Becher had the Admiralty plans, and the description of each, in his office, and therefore knew that Exuma could not be the "marvellous port" which Columbus examined and found too shoal. Hitherto Columbus had been casting anchor on the reefs surrounding the islands, and his anxiety therefrom found expression in his journal of the 15th and 16th of October. Can anyone be made to comprehend, that when he had "voyaged the unreal, vast, unbounded deep," and arrived off a series of sheltered harbors, *he did not go in and anchor;* did not even mention them in his journal; but sailed away from these, which had sufficient depth, to the northwest 10 miles, where he found a "marvellous port which had ample room for 100 ships"—not "all the ships of Christendom," as Captain Becher translates it—*but was too shallow;* and that this "marvellous port" described so minutely by Columbus—because a harbor deep enough for his vessels to enter was the necessity of his situation—Captain Becher dismisses by saying that it corresponds "with a part of the shore about ten miles to the northwest of the former harbor [Exuma], but is really nothing more than the low shelving shore of the island covered to the depth of a few feet by the sea."

If Columbus's track had been along the shore of Exuma, as laid down by Captain Becher, he could not have found a port with *insufficient water* to enter; he would have discovered those excellent harbors ample for his needs, which may be seen on the British Admiralty charts—"Special plans of the Bahama Bank" and "Harbors of Great Exuma, number 390"—and he would certainly have anchored therein.

Captain Becher writes, 5th (pp. 137–140): "But trouble is at hand. Columbus says, he had experienced rain every day more or less since he had been among the islands. He was now to endure the discomforts of a heavy gale, the first he had met with in the New World. * * * The breeze before which the Admiral bore up soon freshens, and he runs before it to the E. S. E., making good this course, steering sometimes east and sometimes southeast, the first part of it to keep off the land, the courses being altered as necessary. The first part of these courses would take him from his position where he bore up towards and well clear of Cape Santa Maria; and with the southeast course his ships would bound along before the gale at no great distance from the outer shore of Long Island (the wind drawing northerly as he proceeded), while he was under the impression, from the direction in which the southeast part of Exuma Island lies, which he had seen, that the southern part of Long Island was that same Fernandina he had left on the previous day. The deception would be completed in the mind of Columbus, first, by the direction in which Exuma lies, being the same as the southern part of Long Island; and, next, by losing sight of this island when obscured at intervals of the storm and by the darkness of the night, in which he was either lying by or running to the southward; for the journal tells us that, as the weather permitted, the ships continued running before the wind towards the southeast point of the island, which having reached they passed round it sufficiently to find shelter, and soon found a smooth anchorage. This mistake of the Admiral in believing that he was now at anchor off the southeast end of Exuma, which he had named Fernandina, when he was really off Long Island, is thus quite admissible. He had undergone the ordeal of a gale accompanied by heavy rain, and in the obscurity of this and the darkness of night he must frequently have lost sight of the land, anxious as he was to keep it on board, and at the same time fearful of getting too near it. His conclusion was formed on fair grounds, but under circumstances which rendered him very liable to be deceived as he was; for he was now at anchor snugly sheltered from the sea with his fleet under the southeast end of Long Island, or, as he supposed, Fernandina, to which island the name Santa Maria has been assigned, as given by himself to the northwest cape of it, that of Fernandina being left for Exuma, on which island it was undoubtedly bestowed by the Admiral."

ANSWER. The substance of these extracts is, that from the northwest end of Great Exuma Columbus made good an E. S. E. course to clear Cape Santa Maria, before a wind which freshened into a gale; that during the night of October 17–18 there *was* a heavy gale accompanied by rain; that the ships rounded the cape and "bound along before the gale at no great distance from the outer shore of Long Island;" that sometimes the land was obscured by the storm and the darkness of the night; and that finally he arrived safe at the southeast end of the island, but, for reasons given, he believed he was at anchor at the southeast end of Exuma.

Columbus, under date of October 17, but obviously written on the 18th, said: "And so I turned around and sailed all the past night to the east-southeast, and sometimes wholly east and sometimes to the southeast; this I did in order to keep off the land for the atmosphere was very misty and the weather threatening: it [the wind] *was light* and did not permit me to reach the land in order to anchor. So that this night it rained very hard after midnight until almost day, and is still cloudy in order to rain; and we [are] at the southeast cape of the island where I hope to anchor until it gets clear in order to see the other islands where I have to go." On the 18th, continuing these remarks, he wrote, "After it cleared up I followed the wind, and went around the island as much as I could, and I anchored when it was no longer possible to sail."

From the northwest end of Great Exuma to the northwest end of Long Island it is east 38 miles, hence about S. E. by S. ¼ S. 57 to the southeast cape and 5 more to the south end; total 100 miles. The sun rose October 17 at 6^h 20^m and set at 5^h 40^m apparent time; twilight lasted 1^h 19^m, so that the darkness of that night was very little more than 10 hours. It is essential to Captain Becher's case that the vessels of Columbus shall be gotten to the south cape of Long Island, but he cannot take them the shortest way, between Long Island and Exuma, as Irving did, because the surveys made since he examined the subject show this to be impossible. Therefore he seeks to extricate himself from the dilemma by inventing a storm for the night of October 17–18.

There is not a word in the journal to authorize Captain Becher's assertion in regard to the weather of this night. Kettell's translation, p. 51, is this: "The weather being cloudy and thick it rained violently from midnight till near day, and the sky still remains cloudy." Major, journal of the Royal Geographical Society, volume xli, p. 200: "There was little wind and it did not allow me to put in to anchor. So it rained very heavily from midnight till near daybreak." Irving, revised edition, Life of Columbus, volume iii, appendix: "For the weather threatened a storm, which, however, dissipated itself in rain." Columbus says of the wind, "el era poco," *it was light.* All his other words, and his actions, show the truth of this. He was among islands which he had observed were surrounded by reefs, and at "two lombard shots" no bottom; he had felt the influence of the tides, and now, at night, with thick weather, *but light winds*, his anxiety "to reach the land in order to anchor," and thus maintain his position rather than drift, was what might be expected of a prudent and skilful seaman.

If Columbus had "made good" a course E. S. E. from the northwest end of Exuma he would have run on shore about 12 miles south of the northwest end of Long Island. Little Exuma, considered by Captain Becher to be also Exuma—and so allowed in this discussion—lies west-northwest and east-southeast, while the south part of Long Island is north-northwest and south-southeast.

In Captain Becher's track from Rum Cay to Exuma he anchors Columbus, on the evening of October 15, at the northwest end of Long Island. The next morning the Admiral went on shore, but returned and sailed on or before noon. During this short visit he had no opportunity to inspect the shore line of the island, neither could he possibly know the direction of that part which lay beyond the range of visibility from his masthead, a distance only of 8.85 miles (*ante*, p. 382).

Although at this time Columbus had been but four days among the Bahamas, he noted in his journal the dangers of the navigation and the care which he took to shun them.

Captain Becher ought to have reached the conviction that such a seaman and navigator as Columbus would not start his squadron from the northwest end of Great Exuma and steer between Rum Cay and Conception on the one side, and Long Island on the other, and then coast the whole length of the latter 60 miles, 50 *of which were unknown to him, in a dark night, during a gale of wind, in thick rainy weather, and so near the coral reefs circling the island that he saw the latter in the intervals of the storm.*

This night had about ten hours of darkness (*ante*, p. 384), and the distance run along Captain Becher's track is 100 nautical miles, equal to 10 nautical, or about 12 Italian miles, every hour, an unprecedented speed. This might be conceded, but in no circumstances such as Captain Becher mentions should a seaman attempt to steer for and then haul around Long Island, except there was a light on the northwest end. Neither would a seaman *coast the shore of unknown land during darkness and storm*, no matter what the urgency might be. The fruit of blundering seamanship like this can be found in the record of shipwrecks along the Bahama reefs.(1)

In navigating among such islands a commander is sometimes compelled to take the present risk in order to escape an impending disaster. But Captain Becher laid no such stress upon Columbus. He "bounds him along" the reef of this coral island and into the unknown darkness, as if it was as easy to do as to write about. He makes him straddle a strange island during a stormy night, and anchor witlessly at the end of the wrong one in the morning.

The circumstances in which St. Paul's ship approached an unknown island during a storm and darkness were different from those which Columbus found in the Bahamas, but the narrative of St. Luke, in the twenty-seventh chapter of the Acts, is instructive, because it shows an excellent piece of seamanship performed at land under great strain, by which, although the ship was lost, all hands were saved.(2) These ancient seamen had not learned to "bound along" the shores of unknown lands in a stormy night. Their thoughts at such a time were bent upon saving, not risking.

Captain Becher writes, 6th: That on the 19th of October Columbus went from the south end of Long Island to the northwest end of Crooked and remained on the west side of that and Fortune, until the 24th, when he sailed to the W. S. W., and on the 25th anchored, according to Captain Becher's chart, on the edge of "Columbus Bank," 19 miles E. ¾ N. from the South Ragged. Hence, on the 27th, he left for Cuba, steering S. S. W., and on the 28th brought his vessels to in the harbor of Nipe.

Page 131: Captain Becher speaks of the efforts which Irving and Humboldt made to establish Cat Island as the first landfall, in this way: "In reality they are so many proofs of the want of that patient and discriminate perusal of the journal which it really required."

Of his own work to the Crooked Island, he writes (pp. 154–155): "Thus far, then, among the islands which Columbus first discovered, he has here been traced by means of the courses he has given, the corresponding distances and relative positions of those islands from each other on the

(1) "The number of wrecks reported in 1858-'64 was 313, of which 259 were total losses."—*Report on the Bahamas for the year* 1864, by Governor R. W. Rawson.

(2) "*Voyage and Shipwreck of St. Paul*", by James Smith London, 4th edition. Revised and corrected by Walter E. Smith, 1880, pp. 134–135.

chart, and the descriptions which he has left recorded concerning them with a degree of precision that places his position at any time beyond a doubt."

Pages 165–167: After arriving in Cuba he writes: "Señor Navarrete has recorded his opinion that this harbor is that now known as the port of Nipe. Following the Admiral to it, as has now been done, it cannot be any other. His track to it from the bank on which he anchored, the description which he has given of it, and the *deep channel* into it of twelve fathoms that no other near it possesses, clearly proves that Navarrete was right here when he declared that the port of San Salvador of Columbus in Cuba is in reality the port of Nipe. * * * It was necessary, in order to prove the identity of the landfall, to accompany Columbus from one island to another to compare as he went along his journal with the chart. * * * By the route through which the Admiral has been traced, his statements agree with the chart. The islands mentioned by him can be *no other than* those here pointed out. The track of the Admiral has been so clearly designated by himself, in direction at least, if not by the very compass point, as well as the distances he gives, which (with slight exceptions, to be attributed to blotted paper) so fairly correspond with those of the chart that the whole result deduced is at once conclusive and satisfactory. * * * A chain of evidence is completed from which there can be no appeal, and which establishes the real landfall beyond the reach of controversy."

Finally, speaking of Columbus's journal, Captain Becher writes (p. 174): "That it is not *conformable to the ancient opinion of Cat Island being the landfall*, but undoubtedly shows that Watling Island *was* that landfall, and in reality the island on which Columbus first landed in the new world. * * * If the island be now unquestionably pointed out. * * * If his earliest footsteps in the new world * * * have now for the first time been successfully traced, the difficult task is amply rewarded by the harmony now established between the correct chart and the journal of Columbus, and in having finally set at rest the question of *the landfall*."

ANSWER. From the south end of Long Island to Crooked and Fortune islands, hence toward the Sand Islands, Captain Becher's track is near to mine and will be referred to subsequently. Columbus did not anchor 19 miles E. ¾ N. of the Sand Islands (Ragged). His journal of October 26 reads: "He was on the *southern side* (1) of said islands; all was shallow for 5 or 6 leagues [15.9 to 19.1 nautical miles]. *He anchored there*."(1)

I believe he did not go to port Nipe for the following reasons: From the mouth to one mile inside are these soundings in mid-channel, 39 fathoms, 35, 17, 28, 33, 17 and 18. See a Spanish plan published by the British Admiralty, October 25, 1826; corrected to 1855. The journal of October 28 reads: "The mouth of the river had 12 fathoms."

The course from the southern side of Sand Islands to port Nipe, is S. ¾ E. If the "two points of westerly variation," *supposed* by Captain Becher, be applied to the S. S. W. course steered by Columbus from the Sand Islands to Cuba, he would not have fetched it by three-quarters of a point, and there is a westerly current also to overcome.

The entrance to port Nipe looks east; it cannot be seen on a southerly course until one gets to it. A seaman would not run into a lee bight unless he was pressed, or acquainted with the land and knew of a harbor at the bottom. Columbus was probably running before the N. E. trades which made this bight a lee shore. His journal tells us that he went "to the land nearest to it" [him]. Such would be the act of a discoverer now. There are two harbors west of Nipe that come nearer to the words of Columbus's journal: Naranjo, with 13 fathoms at the entrance, and Padre with 14. Captain Becher might better have taken either.

The British Admiralty have begun to adopt the conjectures of Captain Becher on their charts, even to dividing the name of "Santa Maria de la Concepcion," which was given by Columbus. It must have come to pass from the positiveness of his assertions and not on account of his argumentation.

This method of applying Columbus's words in detail to refute each of the alleged tracks, and the study that I gave to the subject in the winter of 1878–'79 in the Bahamas, which had been familiar cruising ground to me, has resulted in the selection of Samana or Atwood Cay for the first landing-place. It is a little island 8.8 miles east and west; 1.6 extreme breadth, and averaging 1.2 north and south. It has 8.6 square miles. The east end is in latitude 23° 05′ N.; longitude 73°

(1) *Italics* are by the writer.

37′ west of Greenwich. The reef on which it lies is 15 by 2½ miles. On the southeast this reef stretches half a mile from the land, on the east four miles, on the west two, along the north shore one-quarter to one-half of a mile, and on the southwest scarcely one-quarter. Turk is smaller than Samana, and Cat very much larger. The selection of two so unlike in size shows that dimension has not been considered essential in choosing an island for the first landfall.[1]

When Columbus discovered Guanahani, the journal called it a "little island." After landing he speaks of it as "bien grande," "very large," which some translate, *tolerably*, or *pretty large*. November 20, 1492, Navarrete, first edition (p. 61), the journal refers to Isabela, a larger island than Guanahani, as a "little island," and the 5th of January following (p. 125), San Salvador is again called a "little island."

The Bahamas have an area of about 37,000 square miles, 6 per cent. of which may be land enumerated as 36 islands, 687 cays, and 2,414 rocks. The submarine bank upon which these rest underlies Florida also. But this peninsula is wave-formed upon living corals, whose growth and gradual stretch toward the south has been made known by Agassiz.

I had an unsuccessful search for a similar story of the Bahamas, to learn whether there were any probable changes within so recent a period as four hundred years.

The common mind can see that all the rock there is coral, none of which is in position. The surface, the caves, the chinks, and the numerous pot-holes are compact limestone, often quite crystalline, while beneath it is oolitic, either friable or hard enough to be used for buildings. The hills are sand-blown, not upheaved. On a majority of the maps of the sixteenth century there were islands on Mouchoir, and on Silver Banks, where now are rocks "awash"; and the Dutch and the Severn Shoals, which lay to the east, have disappeared.

It is difficult to resist the impression that the shoal banks, and the reefs of the Bahamas, were formerly covered with land; and that for a geological age waste has been going on, and, perhaps, subsidence. The coral polyp seems to be doing only desultory work, and that mostly on the northeast or Atlantic side of the islands; everywhere else it has abandoned the field to the erosive action of the waves.

Columbus said that Guanahani had abundance of water and a very large lagoon in the middle of it. He used the word *laguna*—lagoon, not *lago*—lake. His arrival in the Bahamas was at the height of the rainy season. *Governor Rawson's Report on the Bahamas*, 1864, p. 92, Appendix 4, gives the annual rainfall at Nassau for ten years, 1855–'64, as 64 inches. From May 1 to November 1 is the wet season, during which 44.7 inches fall; the other six months 19.3 only. The most is in October, 8.5 inches. Andros, the largest island, 1,600 square miles, is the only one that has a stream of water. The subdivision of the land into so many islands and cays, the absence of mountains, the showery characteristic of the rainfall, the porosity of the rock, and the great heat reflected from the white coral, are the chief causes for the want of running water. During the rainy season the "abundance of water" collects in the low places, making ponds and lagoons that afterward are soaked up by the rock and evaporated by the sun. Turk and Watling have lagoons of a more permanent condition, because they are maintained from the ocean by permeation. The lagoon which Columbus found at Guanahani had certainly undrinkable water, or he would have gotten some for his vessels, instead of putting it off until he reached the third island. There is nothing in the journal to indicate that the lagoon at Guanahani was aught but the flooding of the low grounds by excessive rains; and even if it was one communicating with the ocean, its absence now may be referred to the effect of those agencies which are working incessantly to reshape the soft structure of the Bahamas.

Samana has a range of hills on the southwest side about 100 feet high, and on the northeast another, lower. Between them, and also along the north shore, the land is low, and during the

[1] I am indebted to T. J. McLain, esq., United States consul at Nassau, for the following information given to him by the captains of this port, who visit Samana or Atwood Cay. The sub-sketch on this chart is substantially correct: Good water is obtained only by sinking wells. The two cays to the east are covered with guano; white boobies hold the larger one, and black boobies the other; neither intermingle. The island is now uninhabited, but arrow heads and stone hatchets are sometimes found; and in places there are piles of stone supposed to have been made by the aborigines. Most of the growth is scrubby, with a few scattered trees. The Nassau vessels enter an opening through the reef on the south side of the island and find a very comfortable little harbor with from 2 to 2½ fathoms of water. From here they send their boats on shore to "strip" guano, and cut satin, dye woods, and bark.

season of rains there is a row of ponds parallel to the shore. On the south side a conspicuous white bluff looks to the southward and eastward. The two cays, lying respectively half a mile and 3 miles east of the island, and possibly the outer breaker, which is four miles, all might have been connected with each other, and with the island, four hundred years ago. In that event the most convenient place for Columbus to anchor in the strong N. E. trade-wind, was where I have put an anchor on the sub-sketch of Samana.

He did not note the direction of the wind while running for, nor when at Guanahani. I feel confident that it was the N. E. trade, since he gives the speed of the vessels from sunset ($5^h\ 41^m$) until 2 a. m. the next morning—October 11–12—as 22½ leagues—79½ nautical miles—which is at the rate of 9½ miles per hour, an unusual speed for his vessel, and plainly indicating that he was running with a strong quartering wind under all sail, and having fine weather. The "trades" generally freshen near the islands, but they are always in the eastern quarter. In the Bahamas they break up and are very light at east and southeast, but frequently blow strong when they get to the southward and westward, and the circuit ends with heavy squalls from the northward and westward; afterward north and northeast winds and fine weather prevail.

Columbus had none of the strong winds from a western quarter, because he was steering west. If the weather had not been fine he could not have seen the light at 10 p. m.—"like a small wax candle."(1) Neither could he have discovered the land at 2 a. m., 2 leagues—6.4 miles distant. *Varnhagen* (note I, p. 16) says the "moon shown bright, and a sailor saw by its light a white point; fired his lombard; called out land." I am greatly indebted to Professor William Harkness, United States Navy, of the Naval Observatory at Washington, for the moon's place. It was full October 5, O. S., 1492, at $10^h\ 58^m$ p. m., Greenwich mean time. It rose the 11th of October at 11 p. m., and at 2 a. m., when the land was sighted, it was 39° high, latitude 5° S., longitude 106° 03′. Those who were admonished by the admiral to keep a sharp lookout from the forecastle were, of course, looking ahead—west—and the moon, then nearly at the third quarter, was partly behind them and shone directly upon the white bluff. This was most favorable for seeing the land at night, and it is a memorable fact that Columbus first saw the New World through the light of the moon.

In the journal of the 14th of October the Admiral wrote that he "went along the island, in a north-northeasterly direction, to see the other side, which was on the other side of the east." The same date he said that in going along in the boats he "found a piece of land, like an island, although it was not one, with six houses on it, which in two days could easily be cut off and converted into an island." The first quotation is the language of a seaman who had anchored under a jutting point of land which stretched to the eastward and was in sight; he could see one side as far as the east end, but he desired to see the *other side of the east end.* Columbus was at anchor on an open coast; each vessel had but one boat, see Appendix E, and he took all the boats for his exploration of the 14th. For this reason, according to the usage of the sea, he ought not to withdraw far from his ships. The second quotation confirms the first, as to his being in the neighborhood of a peninsula. Both agree well with the east end of Samana. The point of land that Columbus said could easily be cut off has been separated already by the erosion of the waves. See sub-sketch of Samana.

It seems a weighty objection to Samana, that this name appears on the noted map of Juan de la Cosa, *together with* Guanahani. La Cosa was the companion of Columbus—seaman, chart-maker, pilot, master, and he made six voyages to the New World. It is said of him in ***Disquisiciones Nauticus, por el Capitan de Nario, Cesareo Fernandez Duro***, Madrid, 1876, Tom. I, p. 59: "In the first voyage of Christopher Columbus, La Cosa went as master of his vessel, the same on which that officer served until it was wrecked in the Antilles: on the second he went likewise on board the caravel Niña styling himself master of chart-making, and in returning from this latter he was obliged to undertake in the port of Santa Maria the long and minute labor of making the chart which was finished in the year 1500." In 1832 Baron de Humboldt and M. Valcknaer, found in the library of Baron de Walckenaer, an illuminated map skilfully drawn on an ox-hide. It measured 5 feet 9 inches by 3 feet 2 inches, was in good preservation, and bore the signature of La Cosa, and the

(1) Columbus met at Guanahani with canoes which held 45 men. The natives went in them as far as Cuba; they were fishermen and sailors, and the light of October 11 might have been in a canoe. Irving puts it on Watling; but Columbus was steering west, and if a line is drawn east, from the southeast point of Cat, Irving's landfall, it will go through the reefs north of Watling.

date 1500. A *fac-simile* was printed without notes, in Paris, from 1854–'60, for *Jomard's* work, titled *Les monuments de la géographie*, &c. Copies are in the principal libraries of the United States. This map has sustained the scrutiny and disputation of nearly a half a century, and the belief widens that it is the genuine work of Juan de la Cosa (1). The most suggestive figure thereon is Guanahani, since it has the same relative situation that Samana holds on modern maps: *both are little, narrow, east-and-west, outlying islands*, such as cannot be found elsewhere in the neighborhood. If La Cosa went with Columbus on the first voyage, he lay three days at Guanahani, and because he was "master of chart-making," his sketch of the first island should be true in respect to comparative size and exceptional position. A line drawn on the Appendix Chart, from the east end of Cuba, north a little easterly, to Samana, touches only Acklin, one of the Crooked island group. A similar line drawn on La Cosa's map, reaches Guanahani by passing through one large roundish island marked Samana. Therefore, according to La Cosa, Samana was an *interior* island, *much larger* than Guanahani, *unlike* it in shape, situated near and in a southerly direction from it, about where Crooked and Acklin now are; whereas Samana on the present charts is applied to the little east-and-west island lying *outside* of the Crooked group. These facts and the disappearance of Guanahani from modern maps, led me to suspect and search for proofs of a transfer of this strange name of Samana.

Map of New Spain by Nicolaus Vallard, of Dieppe, 1547: [reproduction by J. G. Kohl, in the library of the Department of State.] "Gamana" [Samana] is an interior island.

Theatrum Orbis Terrarum: Abraham Ortelius, Antwerp, 1572. Guanahany is an outside island and southwest of it, among others, is Samana.

Karte von Thomas Hood, *die Ostküste von Nordamerika bis zur Landenge von Panama*, 1592. Plate XIII. *Atlas zur Entdeckungsgeschichte Amerikas. Aus Handschriften der k. Hof- und Staats-Bibliothek etc.* Munich. Samana an interior and Guanahani an exterior island.

Descripcion de las Indias occidentales de Antonio Herrera, &c., Madrid, 1726—30, vol. 1, pp. 6–7: Here is a map of the Bahamas of the date of 1601, on which Guanahani is an exterior island, and to the southward and westward is Samana, an interior one.

Karte der Ostküste von Amerika von Neubraunschweig bis zum Amazonenstrome. Plate X of *Atlas zur Entdeckungsgesch. Am.* Munich. "Samano" [Samana] an interior island.

Carte du Mexique et de la Floride par Guillaume Del'Isle. Paris 1703. Samana, an interior island.

Map of North America, by John Senex, Charles Price, John Maxwell, geographers, 1710: The present group of Crooked and Acklin is marked "Samana or Krooked." Guanahani is a separate island.

An Accurate Map of North America. * * * *Also all the West India Islands*, by Eman. Bowen, Geographer to His Majesty; and John Gibson, engraver. 1733? I Samana, Crooked, Fortune, and Acklin's form one group. Outside of these is *Atwood's Key.* This map is in vol. i *Old Maps of America*, No. 20. Library of Congress.

Atlas Historique, par Henri-Abrah. Chatelain, 7 vols. Amsterdam: In vol. vi (1738) the present place of Crooked group is marked "I Samana."

d'Anville's Maps of 1731, 1746, *and* 1794: The present Crooked group is marked "Samana ou Krooked." Guanahani is a separate island.

G. Delisle and P. Buache. *Map of the Bahamas.* 1740. In a volume of maps, Library of Congress. I Croqued, Fortune, and Acklin are strung along northwest and southeast. To the northeast of Croqued is a small island marked "I Nova." It is near the present place of Samana. I have not met this name before. On page 80 of this volume is a map in which Samana appears as one of the Crooked Island group.

Bellin. 1750. Authority J. Carson Brevoort, esq.: "Samana appears to be the northeast part of Crooked I."

Homann, Johannes Baptista, *Atlas Geographicus Major.* 2 vols. Nuremberg, 1759. Vol. i, p. 147. The present place of Crooked group is marked *Samana I.*

The West-India Atlas, by the late Thomas Jefferys, Geographer to the King. MDCCLXXV.

(1) In *Stephens's Historical and Geographical Notes*, referred to farther on, the reader will find the objections to La Cosa's map satisfactorily answered.

Chart 8. The present Samana is marked "*el Terrigo or* Atwood's Key, *the Samana of the French*." To the southwest is "*Samana or* Crooked Island."

Tour through the British West Indies, 1802–3, Dan'l McKinnen, London, 1804. p. 149: "Samana, spell Sumana, ancient Indian name of French charts; probably the original name of Crooked island."

These citations might be increased, but are they not enough to prove that the name of Samana has been shifted from an interior to an exterior island, from the present Crooked group to the present Atwood Cay, thus surmounting a scholarly obstacle in the way of selecting Samana for the first landing-place. Columbus does not use this name. It appears first on La Cosa's map, for the island spoken of above, and also for the name of a bay on the northeast part of Hayti, which retains it now, but Columbus called it *Golfo de las Flechas: Navarrete*, vol. i, p. 139. An inquiry in regard to this name would be worth pursuing, but it does not belong to a discussion of the first landfall. On the 13th of October, the day before the Admiral left Guanahani, he wrote: "I determined to wait until to-morrow evening, and then to sail for the southwest." This is all the information the journal gives in respect to the course steered *from* the first island. The inference is that he went as he said he should go, because he understood that *gold could be gotten in that direction*. But the proof shall be supplied by the subsequent agreements between the journal and the physical facts.

After he had left Guanahani he saw so many islands that he was undecided which to sail for first, but he determined to make for the largest. A vessel that leaves the east part of Samana and steers to the southward with some westing comes into view of the hills of Plana Cays, Acklin, and Crooked, on bearings from south-southeast to west by south, and to a stranger these hills would appear like so many islands. After Columbus anchored at the second island he wrote that it was five leagues, rather seven—15.9 or 22.3 nautical miles—from the first. The northeast end of Acklin bears S. W. by S. ¼ S., 23 nautical miles from the east part of Samana. For this discussion I consider Acklin and Crooked to be one island, under the name of Crooked. The channel which separates them is of modern origin, no doubt. It has the appearance of having been made by erosion; it is so shallow that it can be waded across, even at high water, and it is invisible to a passing vessel. See chart and sub-sketch.

Columbus wrote that the second island had a north-and-south side 15.9, and one east and west over 31.8 miles long. Crooked has a north-and-south side 13, and another which runs west by north and east by south 29 miles. A navigator of to-day could not come nearer to the truth, in describing the island in like circumstances; but Columbus kept his time with a sand-glass, and reckoned his speed by the eye. I wish the reader to take heed that it is the *second island, and no other*, of which the journal records the length and trend of two separate sides; and that *Crooked is the only one in the Bahamas* which conforms to this description.

A seeming objection to Crooked arises from the language in the journal of the 15th of October, that the side of the second island toward San Salvador ran north and south, whereas the side of Crooked which is in the direction of Samana runs east and west. Columbus could not note this fact *at* the first island, because Crooked is not visible from his anchorage there. After leaving Guanahani he saw many islands, and made for the largest. As he stood off and on all night, and the tide detained him on the 15th till about noon, he might have noted the side he then came to. This is the understanding of R. H. Major, who, in the *Journal of the Royal Geographical Society*, vol. xli, p. 198, translates the passage thus: "I found that the face of it, on the side toward San Salvador [or rather, I would suggest, on the side approached by the ships in coming from San Salvador], ran north and south five leagues, and the other side which I coasted ran east and west ten leagues."

From the data kindly supplied by the officers of the Naval Observatory in Washington, I learn that the moon crossed the meridian of Crooked Island on the 14th of October, 1492, at $6^h\ 36^m$ a. m., Civil time. The British Admiralty Tide Tables for 1881 give VII o'clock for the "Establishment of the Port" at Crooked. *Therefore it was high water there on the 14th of October at* $1^h\ 36^m$ p. m.; low at $7^h\ 48^m$, high at 2 a. m. on the 15th; low at $8^h\ 12^m$ and high at $2^h\ 24^m$ p. m. The sun set at $5^h\ 40^m$ and twilight lasted about $1^h\ 19^m$. The journal does not give the wind *at* Guanahani, nor until the 16th, at the second island, when it is entered as S. E. I believe I have proved on p. 388 that Columbus made the land on the 12th of October with a strong N. E. trade; and the invariable circuit of winds alluded to on that page would give light easterly ones, sometime from the 12th to the 16th. During the regular "trades" the current between Samana and Crooked flows W. N. W. a knot an hour; but at other times the set and drift are uncertain. On the north side of Crooked the flood *tide* runs always to the eastward and the ebb contrarily. When Columbus neared the second island he estimated it to be 15.9 miles from the first; but the next day he called it 22.3. In the mean time he was detained by the *tide* so that he did not reach it again until about noon. Captain Becher (pp. 111–345) said that this detention was "set of the current"; but Columbus used the word *maréa*, not *corriénte;* the former signifies *tide*, flux and reflux; the latter *current*, progressive motion of the water; a distinction held in both languages and especially among seamen, and one of importance here.

These facts, in connection with the journal, enable me to offer a reasonable theory as to the movements of his vessels on the 14th and 15th of October. He left the south side of the east part of Samana on the 14th, undoubtedly after noon; and steered to the southward and westward, with light easterly winds, for Crooked. Midway he found the usual westerly current, and on the other side he ran into a stronger one setting in the same direction; but this was the *ebb tide* which flowed west, along the north shore of Crooked, from $1^h 36^m$ to $7^h 48^m$ p. m. He did not reach the land in time to see his anchoring-ground before dark, and the night was moonless. In consequence, he began, about sunset ($5^h 40^m$), to stand off and on; that is, he beat to the eastward to overcome this westerly set and keep his place until morning, when he intended to run in and anchor. At $7^h 48^m$ p. m. the tide turned and flowed east until 2 a. m. on the 15th. So that in the darkness of the night he had, unknowingly, six hours and twelve minutes of current, *contrary* to that for which he was allowing. In this way he got so far to the eastward that it was noon before he reached the island again; when he coasted the north shore and near sunset anchored at the west end. On the following day, the 16th, he wrote his journal of the 15th, by which time he had observed the distinction between the currents and tides in the neighborhood of Crooked, and he noted the one which caused his detention.

The second island of Columbus has been such a stumbling-block to investigators that many of them assert that he sighted it, but passed on without stopping. See translation from Munoz, *ante*, p. 379, and discussion with Captain Becher, *ante*, p. 380 and on. Major (p. 198) wrote: "Here I beg to call your attention to the fact that Columbus neither lands upon nor gives any name to the first island which he reaches after leaving Guanahani, a fact which argues its unimportance and sanctions our assuming it to be Rum Cay." The weight of these authorities makes it necessary for me to try to answer them before I go on. The following paragraph from the Spanish text of the journal is the authority upon which Major and Captain Becher found their assertion that Columbus did not land upon the second island (Navarrete, 1st edition, p. 25, October 15, and *ante*, p. 358): "*Y como desta isla vide otra mayor al Oueste, cargué las velas por andar todo aquel dia fasta la noche, porque aun no pudiera haber andado al cabo del Oueste.*" Major's translation (p. 198) is: "And as from this island I saw another larger one to the west, I started for the purpose of sailing the whole of that day until night, for otherwise I could not have reached the westernmost cape." Captain Becher (p. 109) renders it: "And as from this island I saw another larger one to the westward, I made sail, continuing on until night; for as yet I had not arrived at the western cape." Mr. Thomas's translation, which I have adopted, is: "And as from this island I saw another larger one to the west, *I clewed up the sails*, for I had gone all that day until night, because I could not yet have gone to the western cape." The essential difference is with, *cargué las velas*. Major makes it, "I started"; Captain Becher, "I made sail"; and Thomas, "I clewed up the sails." In *Diccionario Maritimo Español*, etc., *por D. José de Lorenzo, D. Gonzalo de Murga y D. Martin Ferreiro, Empleados en la Direccion de Hidrografiá*, Madrid, 1864, the definition agrees with that given by Mr. Thomas. So of all other Spanish dictionaries which I can find. I have also submitted the phrase to Spanish officers with like result. The signification is, to clew up, or brail up; that is, take in sail. A similar expression occurs in the first part of the journal of October 15: "I had been standing off and on this night fearing to approach the shore for anchorage before morning not knowing whether the coast would be clear of shoals, and intending to clew up—*cargar velas*—at dawn." If he had been hove to all night he might have written "I will make sail in the morning"; but as he was standing off and on, the two clauses—"Fearing to approach the shore for anchorage before morning," and "Intending to clew up at dawn", are connected, and the meaning of *cargar velas* in the latter is obviously to take in, not to make sail.

The proof that he stopped at the second island does not depend upon the signification of any one phrase, but upon the concord existing between the journal and the cartographic facts. Columbus promised in his Prologue (see Appendix D) that he would mark "each night my progress during the day and each day the run made during the night." But it can be readily understood that he had no regular time for writing his journal among the Bahamas, where the navigation is difficult and where the Indians thronged upon him as coming from heaven. This appears upon reading the remarks under October 11, the day before seeing Guanahani. All the journal of that day—with the exception of the first forty-seven lines—refers to transactions which took place on the 12th, a date omitted from the journal. From the closing paragraph of the 13th it seems that most of his Guanahani log was written near sunset of that day. He says: "At this moment it is dark and all went on shore in their canoes." The 14th was written in the afternoon, during the leisure which came to him from being at sea, clear of the land and the inhabitants. He wrote then: "I looked for the largest one and determined to make for it, *and I am so doing.*" (1) It is important that I should call attention to the fact that all the journal of the 15th was certainly written on the 16th. He entered no remarks on the 15th. Under this date, which was Monday, he wrote: "I anchored and remained until *to-day Tuesday* (1) when at dawn I went on shore with the boats armed." Same date, farther on, 15th, he writes: "And soon after I set sail for the other large island." He could not have done so except on the 16th, the day he wrote this. His story in the journal of the 15th is certainly the experience of the 16th. For example: near the close of the remarks of the 15th he writes: "And being in the Gulf midway between these two islands namely that of Santa Maria and this large one, to which I give the name of la Fernandina." No one can fail to see that this circumstance, and those immediately preceding it, belong to the 16th, although found under date of the 15th. His journal of the 16th begins with the statement that he left Santa Maria for Fernandina about noon, an assertion repeated twice on the 15th, but which could not have been put into execution until the 16th. A study of the journal of the 15th and 16th shows that his first leisure was the afternoon of the 16th, in the calm weather between the two islands, and *then* he wrote the journal of the 15th. That of the 16th was not written until the 17th, for he writes under the former date about sending the ship's boat on shore for water at 9 a. m.—certainly on the 17th. A little later in the journal of the 16th he says: "Soon after writing this I set sail with a south wind." As he did not arrive at the island to which this refers until the morning of the 17th, see first part of the journal of this day, it is obvious that it was of the 17th—not the 16th—that he was speaking. The student who is attentive to the journal will notice that Columbus wrote it when he could find time—to all appearance at one sitting, as a very busy sailor would do. This led him to set down often the matter of several days under one date, and he seems not to have overhauled his log to see whether it was at variance with itself.

Remembering, then, that all the things done on the 15th were recorded on the 16th—after he had left the second island—they might be put into a concise and truthful statement as follows: Columbus explored Guanahani in the boats before noon of the 14th, and sailed after noon to the southward and westward, the direction of the gold. Many islands coming shortly into sight, he made for the largest, but did not reach it in time to see the anchoring-ground before dark. The wind being light from the eastward, and a strong current running west, he decided to stand off and on, or beat to the eastward, to hold his position during the night, that he might anchor in the morning *at that part of the island which he had seen before dark.* The next forenoon, the 15th, he found himself so far to the eastward that it was noon before he got back. He observed two sides of the island, one north and south, five leagues; the other, east and west, over ten. He approached the first, but as it was a lee-shore he followed the other all the afternoon, arriving at the western cape about sunset, whence he saw another large island to the west. Not wishing to be under weigh again at night, among the tides and currents, and the wind having canted to the southward and eastward, which gave him a weather shore to anchor under, he clewed up his sails and came to. On the morning of the next day, the 16th, he went on shore to explore the island, but, as the wind increased from the S. E., and his ships were riding to a weather tide, they were liable to be set

(1) *Italics* by the writer.

across it and foul their anchors: *ante*, p. 359, note 2. The Admiral observing this from the shore, returned and weighed anchor before or at noon, for the island in the west.

Major, p. 198 (*ante*, p. 390), and Captain Becher, pp. 108–112 (*ante*, p. 380), admit, what is obvious in the journal, that Columbus steered for the second island on the afternoon of the 14th, stood off and on during the night, and the following day he was detained by the tide or current until noon, when he reached this second island, and *then* he followed that side of it which ran east and west over ten leagues, and came to anchor at sunset, $5^h\ 40^m$.

My interpretation is that he did not go beyond this second island on the 15th, but that he anchored about sunset at the west cape of the side he had followed. This would make his run 10 leagues—31.8 nautical miles—in $5^h\ 40^m$, equal to 5.6 miles each hour. Major and Captain Becher say that, in addition to coasting this side, he kept on eight leagues—25.5 nautical miles—farther, where he came to anchor at sunset, making a sum of 18 leagues—57.3 nautical miles—in $5^h\ 40^m$, which gives a speed of 10.1 nautical, or 12.7 Italian, miles for every hour—greater than is recorded anywhere for his vessels. He must have had a gale of wind all the afternoon of the 15th to have been driven at such extraordinary speed; but there is no mention of it in the journal. His log across the Atlantic was 105½ nautical miles a day, equal to 4.4 miles every hour. The best day's run was October 4, 200.5 nautical miles, an average of 8.4 each hour.

Columbus wrote on the 14th of October, in respect to the second island: "I looked for the largest one and determined to make for it, and I am so doing." On the 15th—written on the 16th and relating solely to past events—he said: "It was about noon when I reached the said island." * * * "The other [side] which I followed ran east [and] west, and contains over ten leagues. And as from this island I saw another larger one to the west, I clewed up the sails for I had gone all that day until night [noon to sunset], because I could not yet [otherwise] have gone to the western cape, to which I gave the name of Santa Maria de la Concepcion, and about sunset I anchored near said cape in order to learn whether there was gold there." This is the island of which Columbus wrote, in his letter to Santangel (*ante*, p. 381): "To the second island I gave the name of Santa Maria de Concepcion." It lay in the direction of the gold; it was the largest in sight; the Guanahani Indians reported, "That they there wore very large rings of gold on their legs and arms." Columbus wrote that one island taken possession of, the same may be said of all; but it was his desire not to pass any without taking possession, and he did not. After sailing from this island he wrote: "And being in the gulf midway between these two islands namely that of Santa Maria and this large one, to which I gave the name of *Fernandina*," he found a man in a canoe who had come "from the island of San Salvador, had passed to Santa Maria, and was now going to la Fernandina," the very sequence he was doing. All who are mindful of these facts from the journal of the 14th, 15th, and 16th of October, may group them better than this to suit their own mind, but in every aspect they will outweigh the assertion that he did not stop at that second island which he made for on the 14th, and strove for on the 15th.

Columbus anchored at the northwest cape of Crooked (Santa Maria), at sunset, October 15, and remained until the following forenoon. He wrote: "And as from this island I saw another larger one to the west, I clewed up the sails." It would appear from this paragraph that the island referred to came into view when he reached the west cape, near sunset. Writing of what took place the following forenoon, he said: "I set sail for the other large island that appeared at the west." He begins the 16th with, "About noon I left the *islands of Santa Maria de la Concepcion* for the *island of Fernandina*, which appears to bevery large to the west." Long Island lies 25 miles west of Crooked, and the range of hills upon it, marked 150 feet high, are two miles farther. The distance of visibility for 150 feet is 14 miles, and for Columbus's lookout, of 60 feet, it is 8.8 miles; total, 22.8 miles. In consequence Long Island cannot be seen from Crooked.

I have alluded, on page 387, to probable physical changes among the Bahamas in the past, but I shall not appeal to these here. Seamen understand very well that, in favorable circumstances, the appearance of land is very striking over coral islands which are below the range of visibility from the observer. This is especially noticeable in the Bahamas, because all the necessary conditions are there: low islands of white coral; not enough trees or undergrowth to hinder radiation; a high degree of heat, and the air loaded with moisture. When a fall of temperature happens this is precipitated into a cloud cap which often covers the island like a blanket, and outlines it. It is this and the blending of cloud and land that makes the latter appear, frequently, to be above the horizon when truly below it. (1)

Columbus sailed from the northwest end of Crooked, October 16, either at 10 a. m. or noon, for he gives both times, toward the island which appeared in the west. Calm weather retarded him until daylight of the 17th, when he anchored at a cape of an island, which he named Fernandina. Here, he said, the coast ran north-northwest and south-southeast. On the way over he estimated the distance from the second to the third island at nine leagues. After he had arrived he called it eight leagues—25.5 nautical miles. A course from Crooked W. ¼ N. 25 miles strikes a cape of Long Island where the coast line runs as given by Columbus. See chart and the sub-sketch of Long Island, the latter on a larger scale, which shows the cape and trend of land more distinctly. The appearance of Long Island (Fernandina) from Crooked (Santa Maria), the course and distance between them, the southeast cape and the trend of the coast of Long Island (Fernandina), all conform accurately to the facts and we need not linger upon them.

At noon of the 17th of October, Columbus sailed from this southeast cape, steering along the shore to the N. N. W., "the wind being S. W. and S." When he was near the end of the island "two leagues off" he found a marvellous port with two entrances formed by a rocky islet in the middle. Both were narrow, but within was ample room for 100 ships, if there had been sufficient depth free from obstructions, with a deep entrance. He was so much impressed with this marvellous port that he anchored outside of it and went in with all the boats and sounded it and saw that it was too shoal. This was the first opening into the land that he had met with and he thought it betokened a fresh-water river, therefore he took in the water casks. His former visit to a tropical country was to Guinea (Africa) where all the openings into the shore are made by fresh-water streams.

The wind was off the land, and he remained in this harbor with the boats, getting water, for two hours, when he returned to the vessels and sailed. Columbus wrote that the entrance of this marvellous port was two leagues from the end of the island. The reader will observe how often the journal uses leagues and miles in such a way that an interchange of them was possible on the Admiral's part and very probable with the copyist.(2) If the two leagues of the journal were a clerical error for two Italian miles, it corresponds with the chart. See sub-sketch of Clarence Harbor, where the southeast entrance is two Italian miles (1.6 nautical miles) from Booby Cay, the visible extremity of the island; and the course to the latter is N. W. He wrote that he sailed on this course until he discovered that part of the island which ran east and west; and afterward the Indians persuaded him to go back, and because the wind ceased and then sprang up from the W. N. W., which was contrary to his course, he turned around. This and the subsequent courses point out that he was following this east-and-west shore on a likely course of W. N. W. when the wind came out ahead. After turning around he sailed all night, E. S. E., sometimes E. and also S. E. to clear the land. He wrote that the atmosphere was very misty and the weather threatening, but that the wind was *light* and it did not permit him to reach the land to anchor, and that it rained hard after midnight until almost day. He adds, "We [are] at the southeast cape of the island where I hope to anchor until it gets clear." He closes the journal of the 17th with general remarks, which was his frequent habit. It is evident that he wrote this paragraph, and the last observations of the 17th, on the morning of the 18th, at the southeast cape of the island, where, as he was exposed to rainy weather and light winds, he desired to anchor.

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(1) Since I navigated among the Bahamas a light-house has been built at the N. W. end of Crooked, and I wrote to T. J. McLain, esq., United States consul at Nassau, asking him to inquire from officials merely whether Long Island could be seen from it. This is his answer: "I saw Capt. W. H. Stuart, who has commanded the light-house yacht Richmond for many years, and who is a most trustworthy person. He agreed to look up the matter and get me reliable information. The Richmond returned lately from a trip to the windward light-houses, and the captain called to-day to report. He says he inquired particularly of both the keepers at Bird Rock Tower, and of Mr. Aranha, who is clerk of the board of works at that station, and the three united in saying that Long Island is *not* visible from Bird Rock light-house, that they have never seen it, even on the clearest day. A gentleman residing near there says he has seen smoke on it in a clear day. And all four say that they have frequently seen clouds settle over Long Island in still weather *like a stretch of land.* [*Italics* by G. V. F.] Captain Stuart says that all his own observations confirm the foregoing statements."

(2) *Navarrete*, vol. i, p. 101, December 21, 1492: On this day he was at the present bay of Acul on the north side of Hayti, and the journal reads: "The distance from the entrance to the bottom of it [Acul] is about five leagues." This is a clerical error for five miles, because the bay of Acul is 25,800 feet deep, equal to 5⅓ Italian miles.

These words imply that he was at the cape from which he had sailed the day before. In other words, that he had retraced his steps as he was advised to do, and getting back to a familiar anchorage, with unfavorable conditions for coasting such shores, he wished to anchor and wait for clear weather.

On page 392 I have asked the student to take heed in adapting the dates in Columbus's journal. The caution is necessary here. The log of the 18th of October opens with a clause which belongs to the remarks quoted above; for he says: "After it cleared up I followed the wind"; the last of this date is, "At dawn I set sail." It is enough to read the journal of the 19th, which was written in the evening of this day, *after arriving* at the rocky islet, to see that getting under way at dawn of the 18th referred to the same act done at dawn of the 19th. What he did on the 18th is not obscure; shifting tides and inconstant winds hindered him from following the coast to a favorable anchorage. This appears from his remark on the 18th, I "went around the island as much as I could, and I anchored when it was no longer possible to sail."

We find recorded in the journal certain physical characteristics concerning the second island which belong to Crooked only; and in like manner is the third island established. This is so important that I briefly recapitulate. Columbus anchored at a cape of the third where the coast line was north-northwest and south-southeast. He followed it N. N. W. until he came to a marvellous port, two leagues [miles?] from the end. He sounded it in the boats and found it capacious, but shallow. He sailed N. W. until he opened that part of the shore which ran east and west; he steered along it W. N. W. till the approach of night and the advice of the Indians caused him to turn about.

A sailor describing the strange things seen in new lands is likely to put into his story some of the warmth of his vocation, but he does not do this in his log. When he enters the course steered, the depth of water, the trend of the coast, and the speed of his vessel, these are facts which his daily duty calls for, and the safety of his ship may turn upon the accuracy of the record. Columbus's description of the shore-lines and harbor of the third island relate to physical facts which he observed. They are his log, and they cannot be ignored. It is essential, therefore, that a third island shall be found answering to this description. The sub-sketch on the chart shows at a glance that the southeast part of Long Island is the only land and water that will fit. See narrative of Captain Becher 17th and 18th of October, *ante*, for the entanglement arising from using another island for the track of these two days.

There is an element of time here which is important as it limits the ground passed over on the afternoon of the 17th. The Admiral left the southeast cape at noon and turned around while heading W. N. W., and then he steered an opposite course during the night, to clear the land. It is fair to select sunset, $5^h\ 40^m$, as the time of his turning. As long as he could see the land and reefs he might keep on, but *not after dark*. He would choose the day only to explore new shores. In the night he might retrace his steps steering well off, or anchor, or heave to, or stand off and on, nothing else. The distance from the southeast cape past the shallow port and around to the end of the east-and-west side is 22 nautical miles. As he stopped at the above port two hours, he was under way only $3^h\ 40^m$. This gives a speed of 6 miles an hour, which is fully as much as his vessels were likely to do. Any track which is longer, or which requires more speed than this, must be very liable to error.

If Columbus turned at sunset on the 17th and returned to the southeast cape at "almost day" of the 18th he sailed in a night which had ten hours of darkness, the distance he went over in $3^h\ 40^m$ of day. This is not strange. In addition to the various courses steered to clear the land, he says, of this night, that the atmosphere was misty and the weather threatening, but *the wind light.* The fact that he followed this shore at all during such a moonless night is proof that he had gone along it the day previous and learned the direction of the shores, so that he retraced his steps without much hazard *provided he steered well off.* This he could do; for in coasting the island the afternoon before he must have observed that there was no land on the other side to pick him up.

Columbus is now at anchor on the southwest side of the south end of the third, or Long Island (Fernandina). He sailed from here at dawn on the 19th. Sunrise was at $6^h\ 21^m$, twilight $1^h\ 19^m$, dawn at $5^h\ 2^m$. The flag-ship steered S. E., the Pinta E. and S. E., and the Niña S. S. E. Three hours had not elapsed when they saw an island to the east for which all the vessels headed, and before mid-day they arrived at the northern extremity, where there is a rocky islet. I take this to be the north end of Fortune Island. See chart and sub-sketch of Crooked Island anchorages. The Admiral gives no distances in sailing across. If he was fairly under way at 5^h 30^m and anchored at 11^h 30^m, the time was 6 hours, half of which he steered S. E. and half E., making E. S. E. if each three hours was equal speed. From the south end of Long Island to the north end of Fortune the course and distance are E. by S. ¾ S. 32 nautical miles. This gives a little more than 5.3 miles an hour, which is fair sailing for his vessels. Columbus wrote on the evening of the 19th that this rocky islet "lay from the island of Fernandina, whence I had come east [and] west, and the coast afterwards ran from the rocky islet to the westward, and there was in it twelve leagues." If the last clause is an error for 12 Italian miles, it agrees with the chart, as the coast inclines from here two points to the west and measures 10.5 nautical miles, or 13.2 Italian miles.

Long Island is invisible from the rocky islet, and the line between them is not east and west. In steering from Fernandina Columbus spread his vessels from an E. to a S. S. E. course, to get hold of the land; then he drew them together on one course and afterward anchored. A bearing entered at this time with reference to an island no longer in sight, and from which they had arrived by steering several courses, might easily be 1¾ points in error.

Fortune is the fourth island of Columbus's visitation, the one he named after that manful and lovable queen, *Isabela*, who sent him on his way when kings and councils rejected him. It will be noticed that the journal makes the third island lie west of the second, and the fourth east of the third. This brings the second and fourth adjacent to each other, as they are found upon the chart. If a landsman thinks that the Admiral ought to have known that the land now north of him was the same which lay south on the evening of the 15th, it can be answered truly, that one of the most perplexing things in the vocation of the sea is the recognition of lands or islands that have no conspicuous marks. Light-houses, beacons, and pilotage grew out of this difficulty. Columbus sees the *opposite side* of Crooked, after an interval during which he was harassed by navigating the shores of the third island. He comes in sight of it for the second time, while steering a course opposite to that which he steered at first; and of all islands to distinguish, one from the other, or the different sides, the Bahamas are the most puzzling, owing to their similarity. *Irving*, vol. i, p. 433, wrote of the Admiral: "On his second voyage returning from Cuba, he coasted the southern side of his favorite island of Haiti without recognizing it until a cacique came off and addressed him by his title and used several words of Castilian. The news spread joy throughout the ships." The mountains of Haiti are 9,000 feet high and are easily recognized now, for we know their height and have excellent maps; but Columbus was making discoveries where the islands seemed to be innumerable; he was not surveying, nor had he any instruments by which he could lay down accurately the relative bearings of the lands.

The first part of the journal of October 20 remarks upon the failure of the vessels to get to the eastward of Isabella, either by the northeast or south, on account of shallow water. This agrees with the present cartography of Fortune Island. My position here derives strength from a statement in the journal of November 20. *Navarrete*, p. 61: On this day the Admiral was 25 leagues—79.6 nautical miles—N. E. ¾ N. from Puerto del Principe, admitted to be the present Cuban port of Tanamo. The appendix chart has the 20th of November laid down at 75 miles only, arising from the use of 3 as a multiplier for leagues, instead of 3.1818. The Admiral said that on this day he was 12 leagues—38.2 nautical miles—from Isabella. From here to Fortune Island, which I call Isabella, the distance is 36 miles; but to Great Inagua, Navarrete's Isabella, there are 60 miles; to Long Island, Irving's Isabella, 67, and to Crooked, selected by Captain Becher, 53. The journal adds that he could have anchored at Isabella, but did not wish to, for fear that the Indians he had brought from Guanahani might escape, as the distance between these two islands was but eight leagues—25.5 nautical miles. Fortune is 36 miles from Samana; Crooked and Watling, the Isabella and Guanahani of Captain Becher, are 68 miles apart; Grand Turk and Great Inagua, the Isabella of Navarrete, are 101.

At the beginning of October 24 Columbus sailed from the rocky islet, at the north end of Fortune, on a predetermined W. S. W. course. The day was characterized by rain, calms, little wind, and then a "lovely" breeze. At nightfall, 5^h 36^m, the southwest cape of Fernandina (Long Island) bore N. W. distant 22.3 miles. This is known at sea as "departure." The night of the 24th–25th he had strong winds with rain, and being on unknown ground he first reduced, then took in all sail. He said he had made much headway, of which he was doubtful, but he estimated that he did not go this night two leagues. The direction of the wind is not noted. He says that it grew strong suddenly, with mist and rain. Such wind and weather are well known among the Bahamas; they are the sudden rain squalls which are common from the northward and westward (*ante*, p. 388.) At sunrise on the 25th he made sail at W. S. W., but at 9 a. m. he steered west—no doubt to make the former course good, which he had lost somewhat in the night, by drifting under bare poles.

At 3 p. m. the Admiral saw land. "There were seven or eight islands, all extending from north to south; distant from them five leagues," 15.9 nautical miles. He anchored on the 26th of October in the shallow water south of these, which he called Sand Islands. The course and distant from the rocky islet to the south sand island are W. S. W. 82 miles. The same from the "departure"—night-fall of October 24th—W. S. W. 65 miles. The journal gives the following distances between "departure" and Sand Islands: Night of the 24th–25th, *not* two leagues. Five leagues to 9 a. m. on the 25th. From 9 to 3 p. m., 44 miles, and then 5 leagues to the Sand Islands. Ten leagues, 44 Italian miles, are 66.8 nautical miles. This accord between the log and the truth, on the largest run the Admiral made in the Bahamas, is not accidental. In the journal of the 23d–24th, we see that he is disappointed with the poverty of the land and people, and his ardent temperament seizes upon what the Indians called Cuba, to signify that land of gold and spices and large ships for which he had sailed from Spain—Cipango (Japan). He carefully notes the direction to it, pointed out by the natives, who would be most likely to indicate the way their canoes went, touching at intermediate land. He believes this course is W. S. W., and to make it good he would put forward all his skill.

About 60 miles N. N. E. of the northeast coast of Cuba, a line of cays and islands extend N. N. W. ½ W. and S. S. E. ½ E. for 21 miles. The principal ones are eight: Nurse, Bonavista, Racoon, Double Breasted, Maycock, Hog, Great Ragged, and Little Ragged. From the southernmost a coral bank stretches 28 miles south, and 30 east, having from 4 to 11 fathoms of water, interspersed with rocky heads and shoal spots. This is known as the "Columbus Bank"; it terminates the Great Bahama Bank on the southeast. Here, then, is the fifth island, or islands, visited by Columbus; and it should be noted that this string of islands, and the bank of shallow water stretching from them, described so correctly in the journal, *cannot be found anywhere else in the Bahamas.*

He left this anchorage Saturday, October 27th at sunrise ($6^h\ 23^m$) and steered S. S. W. for Cuba. By sunset ($5^h\ 37^m$) he had made 17 leagues—54.1 nautical miles—about 4.8 knots an hour. He saw the land before dark, but kept off "on the look-out during the night with much rain." Sunday he resumed his course S. S. W., striving to reach the nearest land. Arriving there he entered a beautiful river which had 12 fathoms at the mouth. The courses "logged" from the Sand Islands are S. S. W., and the distance 54.1 miles, which was made by sunset Saturday. In the night he probably held his position. Sunday he again steered S. S. W., but as the time of anchoring is not given, we do not know how much more was made on this course. It is certain, only, that the distance from the Sand Islands to this Cuban port was *more* than the run to Saturday night, 54.1 miles. If he anchored early Sunday, which is probable from the soundings and explorations he made on this day, it did not exceed it but little.

Columbus designated this beautiful river and port with his favorite title, *San Salvador.* This name has not been preserved, and each investigator points out his own choice. I select Port Padre. The course and distance on this chart, from the Sand Islands, are S. W. ¼ S. 63 miles. Some authorities place Padre ten miles farther west, in which case it would be S. W. ¼ S. 71 miles' The currents here are thus spoken of in the *West India Pilot*, vol. i, p. 6: "Sometime the current on the north coast of Cuba as far west as Matanzas runs one to four knots to the westward." The vessels of Columbus were under its influence from Saturday afternoon until he entered the river, and as I allow no variation to the compass (see Appendix C), his true course should be as much to the west of S. S. W. as the current drifted him. Port Naranjo answers the description of the journal as well as Padre, but it is S. ¾ W. 62 miles from South Ragged, and a vessel could not, of course, get to it steering S. S. W. with a westerly current. I choose Padre because it is the only port west of Naranjo that has depth of water enough at the mouth to satisfy the journal, and in other respects is free of objections. See Sheet II, *Harbors and anchorages on the north coast of Cuba, from a Spanish plan*, U. S. Hydrographical Office, 1876, which gives the soundings of Port Padre. Outside are 8½ fathoms; at the entrance, 14; then 8, 6, 10, and 9, through to the harbor.

As a matter of interest, I have laid down a track for the vessels of Columbus from Padre west, as far as Boca de Guajaba, where he probably turned. He then coasted the northeast shore of Cuba, crossed to Hayti, and followed the north side to the present bay of Samana, where his first voyage in the New World ended. This track coincides, sometimes, with the track of Navarrete, but both are liable to be inaccurate, owing to the imperfection of the charts of the north coast line of Cuba and Hayti.

Washington Irving lays so much stress upon Herrera's description of the voyage of Ponce de Leon through the Bahamas that I am constrained to examine its merit at the hazard of making this paper wearisome to the reader. The translation from Herrera is in his *Columbus*, revised edition, vol. i, pp. 378–379: "Leaving Aguada in Porto Rico they steered to the N. W. by N. and in five days arrived at an island called El Viejo in latitude 22° 30′ N. The next day they arrived at a small island of the Lucayos called Caycos. On the eighth day they anchored at another island called Yaguna in 24°, on the eighth day out from Porto Rico. Thence they passed to the island of Manuega, in 24° 30′, and on the eleventh day they reached Guanahani, which is in 25° 40′ N. This island of Guanahani was the first discovered by Columbus on his first voyage and which he called San Salvador."

Irving remarks upon this that the latitudes are placed too high, but that the substance is conclusively in favor of Cat Island. He says Ponce de Leon's first island, El Viejo, must have been Turk's Island. This agrees with the old maps. The second he thinks was one of the Caycos. There can be no doubt of it. The third, he says, was probably Mariguana. But Herrera gives the third as Yaguna; and by the old maps this appears to be the present Inagua. Irving calls the fourth island Crooked; Herrera's fourth is Manuega, considered by scholars to be that now known as Mariguana. The fifth island Irving says is Isla Larga (Long Island), and lastly Guanahani. This would make Guanahani the sixth, but the narrative above gives only five islands touched at.

It seems more reasonable to believe that Ponce de Leon left Aguado and steered N. 49° 18′ W. (287 miles) to El Viejo (Grand Turk). The next day he ran over to one of the southerly Caycos cays some 30 miles to the southward and westward. He arrived on the eighth day at Yaguna (probably Little Inagua), 75 miles to the westward of his last place. Thence he steered to the northward 55 miles to Manuega (Mariguana), the fourth island since leaving Porto Rico. From Mariguana his next stopping-place is Guanahani. Herrera writes that on the eighth day out Ponce de Leon was at Yaguna (Little Inagua), and on the 11th at Guanahani, having touched at Manuega (Mariguana) on the way. This gives three days from Yaguna (Little Inagua) to Guanahani, including one anchorage at Manuega (Mariguana). The distance is 108 miles from Little Inagua to Samana, touching at Mariguana. The same to Watling is 176, and to Cat 213.

Ponce de Leon was five days from Porto Rico to Grand Turk, 287 miles, equal to 57.4 miles a day, on a straight course, clear of the land and within the "trades". If we use this distance to measure his run from Little Inagua to Guanahani—and we have no other—then these two islands were three days apart, 172.2 miles. But he stopped at Manuega (Mariguana) on the way, so we can only reduce this distance by guess. But the less the distance the greater the probability that Guanahani was, in the opinions of the contemporaries of Columbus, an island *not far from Manuega* (Mariguana). If Ponce de Leon left Little Inagua, touched at Mariguana, and then anchored at Samana (Guanahani), the sequence is apparent and the distance, 108 miles in three days, including one stop, is fair. But to Cat, 213 miles in the same time, would be greater speed than in any other part of the voyage, and there are several large intervening islands where he was likely to anchor, as he did between Aguado and Manuega (Mariguana).

Herrera was the official historiographer of the Indies in the sixteenth century, and he had exclusive access to the original documents of Columbus and other explorers. He is a good witness, therefore, to cite against the assertions in favor of Grand Turk and Mariguana. If Ponce de Leon sailed *from* each of these islands *to* Guanahani, neither can be the first landfall of Columbus in the view of this historian.

CONCLUSION.

There is a common belief that the first landing-place is settled by one or another of the authors cited here. Nevertheless, I trust to have shown, paragraph by paragraph, wherein their several tracks are contrary to the journal, inconsistent with the true cartography of the neighborhood, and to the discredit, measurably, both of Columbus and of Las Casas. The obscurity and the carelessness which appear in part of the diary through the Bahamas offer no obstacle to this demonstration, provided that they do not extend to the "log" or nautical part.

Columbus went to sea when he was fourteen years of age, and served there almost continuously for twenty-three years. The strain of a sea-faring life, from so tender an age, is not conducive to literary exactness. Still, for the very reason of this sea experience, the "log" should be correct. This is composed of the courses steered, distances sailed over, bearings of islands from one another, trend of shores, &c. The recording of these is the daily business of seamen, and here the entries were by Columbus himself, chiefly to enable him on his return to Spain to construct that nautical map which is promised in the prologue of the first voyage.

In crossing the Atlantic the Admiral understated to the crew each day's run, so that they should not know how far they had gone into an unknown ocean. Las Casas was aware of this counterfeit "log," but his abridgment is from that one which Columbus kept for his own use.

If the complicated courses and distances in this were originally wrong, or if the copy of them is false, it is obvious that they cannot be "plotted" upon a correct chart. Conversely if they *are* made to conform to a succession of islands among which he is known to have sailed, it is evident that this is a genuine transcript of the authentic "log" of Columbus, and, reciprocally, that we have the true track, the beginning of which is the eventful landfall of October 12, 1492.

The student or critical reader, and the seaman, will have to determine whether the writer has established this conformity. The public, probably, desires to have the question settled, but it will hardly take any interest in a discussion that has no practical bearing, and which for its elucidation leans so much upon the jargon of the sea.

It is not flattering to the English or Spanish speaking peoples, that the four hundredth anniversary of this great event draws nigh, and is likely to catch us still floundering, touching the first landing-place.

SUMMARY.

First. There is no objection to Samana in respect to size, position, or shape. That it is a little island, lying east and west, is in its favor. The erosion at the east end by which islets have been formed, recalls the assertion of Columbus that there it could be cut off in two days and made into an island. The Nassau vessels still find a snug anchorage here during the N. E. trades. These blew half a gale of wind at the time of the land-fall; yet Navarrete, Varnhagen, and Captain Becher anchored the squadron on the windward sides of the coral reefs of their respective islands, a "*lee shore.*" (See the chart.) The absence of permanent lagoons at Samana I have tried to explain on p. 387.

Second. The course from Samana to Crooked is to the southwest, which is the direction that the Admiral said he should steer "to-morrow evening." The distance given by him corresponds with the chart.

Third. The second island, Santa Maria, is described as having two sides which made a right angle, and the length of each is given. This points directly to Crooked and Acklin. Both form one island, so fitted to the words of the journal as cannot be done with any other land of the Bahamas.

Fourth. The course and distance from Crooked to Long Island is that which the Admiral gives from Santa Maria to Fernandina.

Fifth. Long Island, the third, is accurately described. The trend of the shores "north-northwest and south-southeast"; the "marvellous port" and "the coast which runs east [and] west," can nowhere be found except at the southeast part of Long Island.

Sixth. The journal is obscure in regard to the fourth island. The best way to find it, is to "plot" the courses *forward* from the third island, and the courses and distances *backward* from the fifth. These lead to Fortune for the fourth.

Seventh. The Ragged Islands are the fifth. These he named *las islas de Arena*—Sand Islands. They lie W. S. W. from the fourth, and this is the course the Admiral adhered to. He did not "log" all the run made between these islands; in consequence the "log" falls short of the true distance, as it ought to. These "seven or eight islands, all extending from north to south," and having shoal water "six leagues to the south" of them are seen on the chart at a glance.

Eighth. The course and distance from these to Port Padre, in Cuba, is reasonable. The westerly current, the depth of water at the entrance of Padre, and the general description, are free of difficulties. The true distance is greater than the "logged" because Columbus again omits part of his run. It would be awkward if the true distances from the fourth to the fifth islands, and from the latter to Padre, *had fallen short* of the "log," since it would make the unexplainable situation which occurs in Irving's course and distance from Mucaras Reef to Boca de Caravela (*ante*, p. 379).

From end to end of the Samana track there are but three discrepancies. At the third island (*ante*, p. 364) two leagues ought to be two miles. At the fourth island (*ante*, p. 366) twelve leagues ought to be twelve miles. The bearing between the third and fourth islands is not quite as the chart has it, nor does it agree with the courses he steered (*ante*, p. 366). These three are fairly explained, and I think that no others can be mustered to disturb the concord between this track and the journal. (1)

In this paper I mention only the publications containing what was indispensable to the discussion. The student who is eager to sift the matter further will derive much aid by searching among the following:

Bartlett, John Russell. *Bibliographical notices of rare and curious books relating to America*, printed in the XVth and XVIth Centuries (1482–1601) in the library of the late John Carter Brown, of Providence, R. I. Providence, printed for private distribution, 1875.

Harrisse, Henry. *Bibliotheca Americana Vetustissima:* a description of works relating to America, published between 1492–1551. New York, 1866.

——— [*idem:* containing additions.] Paris, 1872.

Rich, Obadiah. *A catalogue of books, relating principally to America*, arranged under the years in which they were printed. London, 1832.

——— *Bibliotheca Americana Nova;* or a catalogue of books in various languages, relating to America, printed since the year 1700. Parts I, 1701–1800, and II, 1801–1844. London, 1846.

——— *Bibliotheca Americana Vetus:* Books relating to America, 1493–1700 [also] Supplement. London, 1846.

Stevens, Henry. *Historical and geographical notes on the earliest discoveries in America:* 1453–1530 [with] fac-similes of many of the earliest maps and charts of America. New Haven and London, 1869.

Winsor, Justin. *Columbus; a bibliographical note from the catalogue of the Ticknor collection.* Boston Public Library, Bulletin No. 10, 1876.

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(1) La Cosa's map preserves the name of Guanahani instead of San Salvador. It is evident that this sturdy old seaman was heedful of the fixed names. There are obvious and strong reasons for saving enchorial names from obliteration. In this case *Guanahani* is the oldest American name we have. It is all that remains from the wreck which the white man made of this gentle race. If ever there shall be any agreement upon Samana, for the first landing-place, I hope that the name of *Guanahani* may be restored to it.

APPENDIX A.

Age of Columbus.

The range of years ascribed to his birth is from 1435–'36 to 1446–'47.

For 1435–'36 are *Bonnefoux, Irving, Bernaldez, Napione, Navarrete, Humboldt,* and *Luigi Colombo.*

For 1441, *Charlevoix.*

For 1445, *Cladera and Bossi.*

For 1446, *Muñoz.*

For 1447, *Sportorno and Robertson.*

For 1446–'47, see *Select Letters of Columbus*, 2d edition, by R. H. Major, introduction, pp. xxxii–xxxiv.

If he was born in 1435 his age was fifty-seven when he discovered the New World; if in 1447 he was forty-five.

Without attempting an investigation of the question, I refer to the following exploit of Columbus as bearing upon it (Irving's revised edition of *Columbus*, vol. i, pp. 28–29):

"The first account of his being engaged in a naval expedition was one fitted in 1459 by John of Anjou, Duke of Calabria, to make a descent upon Naples to recover that kingdom for his father. It lasted [this struggle] four years [until 1463]. During this expedition Columbus was detached on a perilous cruise to cut out a galley from the harbor of Tunis. Columbus himself relates that when he arrived off San Pedro, in Sardinia, he heard that there were two ships and a carrack with the galley, by which information the crew refused to go on, and determined to go to Marseilles for re-enforcements. Columbus apparently acquiesced, but altering the compass-card he so deceived them as to arrive off Tunis instead of Marseilles."

Columbus wrote to King Ferdinand (Major, introduction, p. xxxvi): "It happened to me that King René (whom God has taken to himself) sent me to Tunis to capture the galley Fernandina," &c. If the king sent him on this hazardous and independent enterprise during the last year of the expedition to Naples—1463—he was only sixteen years of age, if born in 1447. The naval profession will not admit that any authority, either ancient or modern, would intrust to a boy of sixteen the execution of a deed likely to put to the proof the ability of an able and efficient seaman.

If we take 1435–'36 for the year of his birth—and there the weight of authority lies—he was twenty-seven to twenty-eight when he went to Tunis, and fifty-six to fifty-seven when he landed on Guanahani. It is more reasonable to believe that he was fifty to fifty-one, rather than thirty-nine to forty, when he offered his plan to the king and queen of Spain; and under all the circumstances of his tedious solicitation, that he could not have been fewer than fifty-six to fifty-seven years of age when he saw the New World.

APPENDIX B.

Mile and League of Columbus.

In *Navarrete*, 1st edition, vol. i, p. 258, Columbus wrote: "56⅔ miles to an equinoctial degree."

Page 300, fourth voyage: "The world is not so large as the common opinion makes it, one degree of the equinoctial line measuring only 56⅔ miles."

Page 3, August 3, 1492: "Steered southward until sunset under a strong sea-breeze, making 60 miles, which are 15 leagues."

On pp. 3–4 is this note of Navarrete: "Columbus used Italian miles, which are shorter than the Spanish, thus four of the former and three of the latter make a league."

I notice that writers multiply the leagues of Columbus by 3 and call the product a geographical mile. My search for accuracy, and to see where the multiplier 3 was obtained, is not conclusive. Rear-Admiral John Rodgers, superintendent of the United States Naval Observatory, after giving the subject some investigation, is of opinion that the ancient Roman or Italian mile was 1,614 English yards. An article in the *Penny Cyclopedia* (Mile and League) written by Augustus De Morgan, late professor of mathematics in University College, London, calls the ancient Italian mile 1,614 English yards. Humboldt discusses the subject of leagues, miles, and degrees in his *History of the New Continent* (note, vol. ii, p. 216) without bringing their length to any undisputed measure. So with Pigafetta (*Treatise on Navigation*, p. 216).

Martin Cortes, *Breve Compendio de la Sphera, &c.*, Seville, 1551, English translations, 1561, folio xix, has this table:

4 grains of barley make a finger.
4 fingers a hand or palm.
4 hands a foot.
5 feet a geometrical passus.
2 steps make a passus.
125 passus a furlong, or stadium (old English furlongs long)(1).
8 furlongs one mile.
1 mile is 1,000 passus.
3 miles one league; in Germany longer leagues;
France, 15 leagues to one degree;
Spain, $16\frac{2}{3}$ leagues *and* $17\frac{1}{2}$ *for a degree of the Great Circle.*
Pedro de Medina, *Arte de Navega*, Valladolid, 1545, prefers 4 miles to a league.
Pigafetta says, "shore leagues 3 miles; nautical, 4."

On the 9th of December, 1492, Columbus was at the present Bay of Acul, Hayti. The journal reads (*Navarrete*, vol. i, p. 84): *Este puerto tiene en la boca mil pasos, ques un cuarto de legua*— "The harbor here is about a thousand paces, or a quarter of a league wide at the mouth." It is evident that with Las Casas 4,000 "pasos" was a nautical league. By using the table above and the note below, this league is found to be 20000.64 English feet.

Since the Italian mile of Admiral Rodgers and Professor De Morgan is 1,614 yards, or 4,842 feet, and Columbus called four of these a league, this was 19,368 English feet, which differs 632.64 feet only from that derived from Las Casas's remark and Martin Cortes's table.

In the computations of this paper I call the mile of Columbus 1,614 yards or 4,842 English feet, and his league 6,456 yards or 19,368 English feet. For the geographical or nautical mile or knot, I have adopted Clarke's estimate of one minute of arc on the equator, rejecting a small decimal. This is 2,029 yards or 6,087 English feet. Wherever I have omitted to designate the kind of mile this is the one meant. I have tried to prove these measures by comparing them with some of the distances given in the journal, but the result is unsatisfactory. Allowing 3 leagues departure from St. Sebastian (Gomera), he sailed, according to his log, 1,111 leagues to Guanahani, = 1178.33 of Clarke's leagues, or 3,535 nautical miles, 3,458 on a straight course. Cat Island is the farthest landing ascribed to him. It is 3,141 miles from Gomera, an overrun of 317 miles. The Grand Turk is the nearest, 2,834 miles; a difference of 624.

In Dr. Chanca's narrative of the second voyage of Columbus (*Navarrete*, vol. i, p. 200), the distance sailed from Ferro to the first land, Dominica, is called 800 leagues, 2545.5 nautical miles. The true distance is 2,529. He remarks that it is 300 more between Ferro and Cadiz, equal to 954.6 nautical miles, but the true distance is 774.

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(1) *Modern Metrology*, by Jackson, London:

Page 41. "The present value of the English furlong adapted to the English statue mile—a modern arrangement—is 132 paces, but as the old London mile of 1,000 paces was the local form of the Roman mile, its former value was 125 paces."

Page 66. "Old London mile = 1,000 paces = 5,000 feet = .9470 mile"—of 5,280 feet. This would make the old London mile 5000.16 English feet.

December 5, 1492, the journal has 120 leagues—381.8 miles—for the distance he coasted Cuba. From Boca de Guajaba, where he probably turned, to Cape Maysi, the coast line is 244 miles. In giving a summary of his first voyage to Luis de Santangel, Navarrete, vol. i, p. 168, Columbus wrote that he followed the coast of Cuba for 107 leagues—340.5 miles—and the coast of la Española for 178 "grandes leguas." If these are like the other leagues they equal 566.3 miles. The true distance, along the coast-line of Hayti, between St. Nicolas Mole and Samana Bay, is 286 miles. Andres Bernaldes, *Mass. Hist. Col.*, vol. viii, 3d series, p. 6, said that Columbus went 88 leagues—280 miles—in a straight line from west to east, along Hayti. The navigator of these shores still finds the same currents and baffling winds; but he is spared such errors of distance, because of the perfection of chronometers and of nautical instruments.

Columbus was very correct in estimating the short runs. He called it ten leagues from Navidad to Isabella, on the north side of Hayti. This is the true distance. Considering the guess-work in the distances among the Bahamas, he was surprisingly accurate, as I have shown in the discussion.

Taking the mile of Columbus at 4,842 feet, his estimate of the circumference of the globe was 16227.3 nautical miles. Clarke's circumference, at the equator, is 21,600 nautical miles, each 6087.11 English feet. The earth was larger around by 33 per cent. than Columbus believed.

APPENDIX C.

VARIATION OF THE COMPASS IN 1492.

In Captain Becher's *Landfall of Columbus*, Appendix, p. 331, is this: "In laying down the track of Columbus from the Crooked Island group, named in the chart the Fragrant Isles, from the journal of the Admiral, it becomes evident from his courses and distances, run as far as Cuba, that it was necessary to allow a considerable amount of variation. In his first voyage he mentioned in his journal that he found above a point of westerly variation, on a meridian a hundred leagues west of the Azores, and in his third voyage, when he is on the coast of Paria, he also mentions having found, to the surprise of the pilots, above a point and a half. And now that his courses and distances run to an anchorage in the bank specified as being at the distance of five leagues from the Arena isles, and from thence to Cuba, it may be safely said that the variation which he found there in 1492 amounted to little short of two points westerly."

All that Columbus wrote in respect to the deviation of the needles referred to his observations on the Atlantic during his first voyage. *Navarrete*, 1st edition, vol. i, p. 8, September 13, 1492, Thursday: "On that day, at nightfall, the needles northwested, and in the morning they northwested somewhat;" page 9, September 17, 1492, Monday: "The pilots [mates] took the north [star] marking it, and found that the needles northwested a full point, and the sailors feared and were troubled, but did not tell why. The Admiral was aware of it, and ordered that they should again mark the north [star] at dawn, and they found that the needles were all right; the cause was that the star which appears moves and not the needles;" p. 15, September 30, 1492, Sunday: "NOTE.—That the stars called las guardias(1), at nightfall, are close to the arm in the west, and at dawn they are in the line below the arm to the northeast, so that it seems that during the whole night they do not advance more than three lines, or nine hours, and this every night: this is what the Admiral says here. Also at nightfall the needles northwest one point, and at dawn they are with the star exactly; from which it appears that the star moves as do the other stars, and the needles always demand the truth;" p. 254: in the letter of Columbus to his sovereigns, giving a narrative of his third voyage: "I remarked that from north to south in traversing these hundred leagues from said islands [one hundred leagues west of the meridian of the Azores], the needles of the compass, which had hitherto northeasted, northwested a full point of the compass, and this took place from the time when we reached that line;" and p. 256: "For in sailing thence one hundred leagues west of

(1) Guardias—name given to two of the most brilliant stars of the constellation Ursa Minor. Dominguez, *Spanish Dictionary*.

the meridian of the Azores the ships go on rising smoothly toward the sky, and the weather was felt to be milder on account of which mildness the needle shifts one point of the compass, and the farther we went the more the needle northwested, this elevation producing the variation of the circle which the north star describes with las guardas." These last two extracts were written during his third voyage, but they refer obviously to what took place on the *first*.

On the 13th September, 1492, Columbus had run 227 leagues—722.3 miles—due west from Gomera, when he discovered that the compasses had westerly variation. By the 17th he had gone 136 leagues—432.2 miles—more on the same course, when the observation of the pilots showed a full point west variation. At dawn, however, under the direction of the Admiral, they again took the bearing of the north star and found that the needles were "all right." The abridger does not give the words of the Admiral, he interprets them, and they are hardly intelligible. Could Columbus have tampered with the compass-card to allay the fears of his crew, as he did at Sardinia to get his vessel to Tunis (Appendix A)? By September 30 he had sailed 295 leagues—940.2 miles—additional; total run from Gomera of 2094.7 miles west, during which he had made but four miles of southing.

In the letter of Columbus to his sovereigns, quoted above, we have his own words, clear enough as to the deviation of his needles, but not in regard to the cause. He wrote that they changed from easterly to westerly on a meridian one hundred leagues—318.2 miles—west of the meridian of the Azores, and thence west the variation increased the farther he went. The meridian of the Azores is, probably, that of Corvo, the most western one. The southeast end is in latitude 39° 41′ north, longitude 31° 07′ west from Greenwich.

Captain Becher has evidently taken it for granted that by the time Columbus got to the Crooked Islands, which are 972 miles west a little south, of the position of September 30, the deviation had gone on increasing so as to be "little short of two points westerly." Columbus went four times to the West Indies, but he never mentions any deviation there. As already stated, he refers to the northwesting of the needles *in the Atlantic Ocean* after he had crossed the meridian of the Azores.

If the variation alleged by Captain Becher is applied to Columbus's courses across the Atlantic his track would go south of the Bahamas. Captain Becher steers Columbus S. W. from Watling to Rum Cay. Two points west variation will take a vessel, at least, six miles east of it. He steers him west from the north shore of Rum Cay to the northwest end of Long Island. Two points west variation would put the vessels on shore eleven miles southeast of the cape. From Bird Rock to the anchorage on Columbus Bank, where Captain Becher anchors Columbus, the course is S. W. by W. But Captain Becher, pp. 160, 161, says that Columbus steered W. S. W.; so *here* he let him have one point only of west variation, and yet he anchors him 19 miles too far to the eastward. If he had given him the two points he says should be allowed there, the vessels would have made S. W., clearing the bank and going out of sight of the "Sand Islands." Columbus anchored *south* of these islands (South Ragged). From there Port Nipe bears S. ¾ E.; a course S. S. W., allowing two points west variation, would not fetch it by three-quarters of a point; and, in addition, there would be the strong westerly current to allow for. It is probable that Captain Becher got his variation from Ferdinand's *Discovery of the West Indies by Christopher Columbus*. The original of this narrative is lost, and the various versions have no standing among scholars where the statements are unsupported. In an English translation (*Collection of Voyages and Travels by Churchill;* London, 1732, vol. ii, p. 587) is this: "Yet the Admiral says he could not from this time give such an account as he would wish, because through overmuch watching his eyes were inflamed and therefore he was forced to take most of his observations from the sailors and pilots. He also says that this same night, being Thursday, the 16th of August [1498], the compasses which till now had not varied, did at this time, at least a point and a half, and some of them two points, wherein there could be no mistake because several persons had always watched to observe it. Admiring at this and grieved that he had not the opportunity of following the course of the continent, he held on N. W. till on Monday, the 20th of August, he came to an anchor between Beaca and Hispañiola." These alleged observations were taken near the island of Margarita, on the coast of Paria. They are worthless on their face, because, without moving, the variation went from nothing to two points. Ferdinand refers to the *third voyage* of his father; but above I have quoted Columbus's own words of the same voyage, from his letter to the king and queen, in which he is not speaking of the variation *on the coast of Paria*, but of that he found *on the Atlantic* during his *first voyage*.

The compass-cards used by Columbus were divided into points, instead of points and quarters, as now. Sights for taking bearings were not introduced until the next century. It appears from the journal, that he depended upon the north star to find his variation. In 1492 the polar distance of this star was 3° 28′; now it is 1° 20′. There is no doubt but that he used the astrolabe and compass to get its bearing, but the difference of 5° and 10° (*Navarrete*, vol. i, p. 255) proves that accurate observations for variation were impossible in 1492. His course across the Atlantic, worked from his log, with no variation allowed, is W. 2° 49′ S. The course from Gomera to Turk Island is W. 8° 1′ S. Conceding that he landed at this the most southern island ascribed to him, he made 5° 12′ southing, which might have been due to the southwest current, that is, is constant between the Canaries and West Indies, rather than to west variation. The courses from Samana or Atwood Cay to Cuba have no allowance for variation.

When Columbus, on the 5th of December, 1492, stood across from Cuba to Nicolas Mole, Hayti, he gave the course S. E. by E. If he started from an offing of 4½ miles to the northeast of Cuba, given on this chart, the true course is S. E. ¼ E. If he steered S. E. by E., he would be set as much as three-quarters of a point to the southward by the current which flows S. W. in the "Windward passage."

August, 1498—third voyage—Columbus sailed from the west side of Margarita Island for the city of St. Domingo, in Hayti. The true course and distance are N. 35° W. 594 miles, but he brought up at Beata, 110 miles west of this city, N. 46° 24′ W. 558 miles from Margarita. He ascribed his falling to leeward solely to the current; Irving's *Columbus*, revised edition, vol. ii, p. 124.

The equatorial current in the Caribbean Sea sets always to the westward; on the coast of South America it is 1½ to 2 miles an hour; in mid-sea, about one mile, or about an average of one mile each hour to a vessel standing across. He was five days making the passage (120 hours), during which he was set to the west 110 miles. On his last voyage he fell to leeward also in crossing this sea, and it was almost fatal to him. Nowhere does he attribute his westing to any cause but the true one—*currents*. If the compass was flying about as Ferdinand wrote, or if there was any deviation in the West Indies worth noticing, a seaman as accurate as Columbus in noting physical things should have recorded it.

Expressing my doubts of the correctness of Captain Becher's allowance for variation to the Superintendent of the United States Coast and Geodetic Survey, he called upon his assistant, Mr. C. A. Schott, for a scientific examination of the subject. The result was a paper written by him, dated April 8, 1881, which will appear in the report of the United States Coast and Geodetic Survey for 1880, appendix 19. Mr. Schott's deductions are that the deviation in 1492 in the Bahamas did not exceed one-quarter of a point west.

For the reasons stated here I have allowed for no deviation of the needle on any course in 1492.

APPENDIX D.

THE LOG OF COLUMBUS ACROSS THE ATLANTIC OCEAN, 1492.

Las Casas's abridgment of this is in the first volume of *Navarrete*, pp. 1–166. Columbus said, in his prologue: "I have decided to write daily and minutely everything that during that cruise I should do and see and how much I should run. * * * In addition to the marking each night my progress during the day, and each day the run made during the night, to construct a new chart," &c.

Pages 3–4: "We left Friday, 3d day of August, 1492, from the bar of Saltes at 8 o'clock; we steered under a strong sea-breeze until sunset to the south sixty miles, which are fifteen leagues; afterwards southwest and south by west, which was the course for the Canaries."

I am informed that the Spanish naval service reject days of the week, and use those of the month only, and that their sea day begins at noon of the civil day. Until 1847 the English and United States naval service kept the usual civil day in port, but at sea the day began at noon, twelve hours before the civil day.

It is not clear what day Columbus used. His prologue seems to refer to the ancient sacred day of the Jews, or that of the Church, beginning at sunset. The Athenians, Chinese, Italians, and others reckoned by this. Reading, carefully, all his log, I find days which might furnish arguments for his use of the present civil day, or that he might have counted either from noon to noon or sunset to sunset. In this paper I shall consider that he used the present way, midnight to midnight. The island of Gomera, from which Columbus sailed, is 14 by 11 miles, nearly a round mass of mountain, rising to 4,400 feet. The harbor of St. Sebastian lies a little south of the east end, and by "Bowditch's Navigator" is placed in latitude 28° 6′ north, longitude 17° 8′ west from Greenwich. After he had left this port he was becalmed until Saturday night, when the first course "logged" is W. Since some departure must be allowed to clear the land, I have put down 3 leagues S. W. ½ W., barely enough to enable him to begin a W. course. I do not know whether he went south or north of Gomera; I make his course south, because the prevailing winds there are from the northward and eastward.

The most western island of the Canaries is the one called Hierro by the Spanish, and Ferro by the Portuguese. The parallel of 27° 44′ north, and the meridian of 18° west from Greenwich, pass through the middle of the island. This latter was the "prime meridian" from Ptolemy until the last century. Hierro is 34 miles S. W. by W. ½ W. from Gomera. Columbus left St. Sebastian Thursday morning, September 6, 1492. "Directing his course for the voyage * * * he was becalmed all day and night." * * *

September 7: "The whole of Friday, and on Saturday until three hours after nightfall, he was becalmed." * * *

September 8: "On Saturday three hours after nightfall it began to blow from the northeast, and he resumed his course to the west," &c.

His voyage began three hours after sunset—about 9h 36m p. m.—Saturday, September 8. The following are the dates, courses steered, and distances:

Date.	Courses.	Distance in leagues.	Remarks.
September 6 to 8, allow	S. W. ½ W	3	This is the allowance for departure.
September 8	West	9	His predetermined course.
Sunday, September 9	...do	49	
10	...do	60	
11	...do	40	
12	...do	33	
13	...do	33	
14	...do	20	
15	...do	27	
Sunday, September 16	...do	39	
17	...do	50	
18	...do	55	
19	...do	25	
20	W. by N	7.5	Baffling winds and calms.
21	West	13	
22	W. N. W	30	Contrary wind.
Sunday, September 23	N. W	......	
	N. W. by N	......	
	West	22	Some calm and high sea.
24	West	14.5	
25	West	4.5	
	S. W	17	Steered S. W., supposing he saw land.
26	West	16	
	S. W	15	Same reason for going S. W.
27	West	24	
28	...do	14	
29	...do	24	

Date.	Courses.	Distance in leagues.	Remarks.
Sunday, September 30	West	14	
October 1	...do	25	
2	...do	39	
3	...do	47	
4	...do	63	
5	...do	57	
6	...do	40	
Sunday, October 7	West	23	
	W. S. W	5	Steered W. S. W. because flocks of birds flew in that direction.
8	W. S. W	11.5	
9	S. W	6	
	W. by N	5	
	W. S. W	20.5	Baffling winds.
10	W. S. W	59	
11	W. S. W	27	
	West	17	Changed his course to west at sunset; gives no reason for it.
Friday, October 12	West	5.5	
	..do	2	Discovered land at 2 a. m., two leagues distant.
		1,111	Columbus's leagues.

Allowing for the detention by calms in the Canaries, departure, and difference of time, he was 33½ days from Gomera to Guanahani.

In the above log I have not copied his daily remarks during the voyage, for they have no bearing upon this discussion. I have, however, noted that he never deviated from his predetermined west course, unless constrained by head winds, baffling winds, or the strong appearance of land to the southward and westward. And the student will take notice that, notwithstanding the observations in regard to the westerly variation, on the 13th, the 17th, and the 30th of September, the Admiral did not alter his courses in order to make true west, but that he held firmly to *west by compass*.

The following is an abstract or "traverse table" of his courses and distances across the Atlantic:

Courses by compasses.	Columbus's leagues.	Nautical leagues.	Nautical miles.	Difference of latitude.		Departure.	
				N.	S.	E.	W.
S. W. ½ W	3	3.2	9.5		6		7.3
West	882.5	936	2,808				2,808
W. by N	12.5	13.3	40	7.8			39.2
W. N. W	52	55.1	165.5	63.3			152.9
S. W	38	40.3	121		85.6		85.6
W. S. W	123	130.4	391		149.4		361
Total	1,111	1,178.35	3,535	71.1	241		3,454

If this table is worked out by "Mercator's Sailing," in "Bowditch's Navigator," which is not so accurate as "plotting" each day on the chart, but is near enough for practical purposes, then his course and distance, by dead reckoning, are W. 2° 49′ S., 3,458 nautical miles.

From Gomera to Grand Turk the course and distance are, W. 8° 1′ S., 2,834 miles; Gomera to Mariguana, W. 6° 37′ S., 3,032 miles; Gomera to Watling, W. 4° 38′ S., 3,105 miles; Gomera to Cat, W. 4° 20′ S., 3,141 miles; and from Gomera to Samana (Atwood's Cay), W. 5° 37′ S., 3,071 miles.

He overran the distance between Gomera and Grand Turk by 624 miles; Gomera and Mariguana by 426 miles; Gomera and Watling by 353 miles; Gomera and Cat by 317 miles; and Gomera and Samana by 387 miles. These overruns might have been due to the current between the

Canaries and the West Indies, which always sets to the southward and westward in mid-ocean, and more westerly, near the West Indies. It varies from 9 to 30 miles per day, according to the force of the trade-winds.

It increases our estimate of the determined spirit of Columbus that he "logged"—*believed that he had actually made*—3,535 miles directly into the "Sea of darkness," exceeding by 500 miles the distance between New York and Liverpool.

In 1492 latitude was found by meridian altitude of the sun, or by the north star.

Major (introduction, p. li) has it, that about 1480, "by the joint labors of Martin Behaim and the Prince's two physicians, Roderigo and Josef, * * * the astrolabe was rendered serviceable for the purposes of navigation, as by its use the seaman was enabled to ascertain his distance from the equator by the altitude of the sun."

Humboldt's *Cosmos*, translated by Otté, London, 1849, vol. ii, p. 670: "The astrolabe described by Raymond Lully, in his *Arte de Navegar*, was almost two hundred years older than that of Martin Behaim." Second volume of Cosmos, p. 630, he speaks of Martin Behaim's invention as "perhaps only a simplification of the meteoroscope of his friend Regiomontannes."

Bossi's Columbus, 2d edition, Paris, 1825, p. 151: "The astrolabe received in the 13th century its form which made it universally used. Andelone del Nero, of Genoa, wrote upon it, and published it at Ferrara, in 1477."

Chaucer's treatise on the astrolabe, 1391 (edited by Walter W. Skeat, London, 1872, p. xxiv), says that it was well known in India and Persia, by the Arabs, and spoken of by *Marco Polo*. On p. xxxiii is a description of its powers, among which are the latitude of any place by two observations of the pole star, or any circumpolar star, or sun's meridian altitude; can be used to discover approximately the four cardinal points of the compass, and in what part of the heavens the sun rises, &c.

The longitude was gotten by "dead reckoning." The speed of a vessel was estimated by the eye. There is no mention of the "log" until the next century.

The time was kept by the "sand-glass."

APPENDIX E.

THE VESSELS OF COLUMBUS.

Very little is known in regard to the vessels that took the first discoverers to the New World. Clark's *Maritime Discoveries*, vol. i, p. xxvii: "The chief characteristics of ships of Da Gama's age (close of the fifteenth and beginning of the sixteenth century) were height of poop and prow, squareness of lower yards, taunt masts, and small round tops."

In Churchill's *Collection of Voyages and Travels*, London, 1732, vol. ii, is Ferdinand Columbus's history (narrative) of the discovery of the West Indies by his father. On p. 586: "The Admiral durst proceed no farther in his ship, which required three fathoms water, being of a hundred tun." This refers to the date of August 10, 1498, third voyage, off the coast of Paria. *Irving's Columbus*, revised edition, vol. i, p. 123: "Peter Martyr, contemporary of Columbus, says: Only one was decked, built up high at the prow and stern, with forecastles at the prow and cabins at the stern."

Columbus's journal, October 11: "The Admiral at 10 o'clock at night standing on the castle of the poop;" farther on, he "requested and admonished them to keep a sharp lookout at the forecastle." In the *History of the Catholic Sovereigns, Ferdinand and Isabela*, by Bernaldez, an extract of which is printed in the *Massachusetts Historical Collections*, vol. viii, third series, pp. 52–53: "They found themselves in only 2 fathoms of water; * * * the vessels being often aground. * * * They found 2 fathoms and a cubit(1) of water and room for the caravels to remain, and they anchored." These extracts refer to the second voyage of the Admiral, when he was among those many islands on the south side of Cuba, which he called the "Queen's Gardens." On this voyage he had three large ships and fourteen caravels; but in February, 1494,

(1) Cubit is generally stated to be 18 English inches—old Paris foot=12.789. F. A. P. Barnard, in *Johnson's Universal Cyclopedia*.

he sent twelve back to Spain, from Navidad, and he pursued his voyage with the caravels (small vessels), as mentioned by Bernaldez. A. Jal, *Archéologie Navale*, Paris, 1840, vol. ii, p. 237: "Tonnage of vessels of the fifteenth century voyaging to the Canaries were 90 tuns (about), supposes a length of keel of 70 to 80 (French feet)(¹)." On p. 229 he deduces the length and breadth of Columbus's vessels, first quoting from *Las Casas's Narrative in Navarrete*, vol. i, p. 70: "Tuesday 27th, 9th month, 1492. This mouth of a stream was of the breadth of 5 (brasses French) brazas, which was in dimensions the length of the boat." Then he adds: "A boat of 5 brazes would suppose a vessel of 27^{m} 77^{c} total length, and 8^{m} 12^{c} amidships, according to Venetian treatise in Memoir 5."

On referring to *Navarrete*, p. 70, November 27, 1492, we find the following to be the true rendering of the day Jal speaks of: "After the vessel had anchored the Admiral jumped into the boat in order to sound the port, which is like a small porringer; and when he was opposite the mouth at the south he found an entrance to a river which was so wide that a galley could enter therein, and in such a manner that it was not seen until it was reached, and entered into at about one boat's length it had five fathoms and eight in depth."

Fincham's History of Naval Architecture, p. 34, date referred to, 1498: "Cabot * * * was authorized to take six ships out of any haven in England, of the burthen of 200 tuns and under."

Page 44: "The largest of Drake's vessels, 1577, was the Pelican of 100 tuns burthen."

Review of the Laws of Tonnage by G. Moorsom, London, 1853, p. 1: "Whatever was originally intended by tonnage has been, and still is, the only term by which we form an idea of the magnitude, or, rather the dimensions of vessels. A law to be established for tonnage admeasurement would have reference only to cargo, and that in its simplest consideration, namely, the greatest weight which a vessel could safely carry."

Moorsom says that the first official measurements of vessels were of those carrying coal, and the date 1422; that in 1694 a government official marked the draft with nails on the stem and stern, by first loading to those marks by a dead weight of tin or lead. In 1720 the English Parliament, under the influence of competition of the tonnage dues being evaded by small vessels bringing spirits into the kingdom, passed this general law for tonnage: "The length of the keel (so much as she trends on the ground) is to be multiplied by the inside midship breadth and the whole divided by 94: the quotient is to be considered the true contents of the tonnage." By acts of 1773 the extreme or external breadth was substituted for the internal breadth; the length of the keel to be three-fifths of the extreme breadth, deducted from the length from the front of the stem to the aft side of the stern post. This law remained in force until the admeasurement of the cubic contents was substituted, by England in 1835–1855, and the United States in 1864.

In the fifth volume of Pepys' *Miscellany*, p. 57, date 1652, the dimensions of the Greyhound are given: Length of keel, 60 feet; breadth, 20 feet 3 inches; depth, 10 feet; burthen, 120 tons; men, 80; guns, 18. This vessel was in the old war which began in 1652, and in Pepys' Memoirs relating to the state of the navy in 1688, this vessel was then at sea.

If we apply the act of Parliament of 1720 to the dimensions of this vessel, subtracting 1.65 feet from breadth as an allowance for thickness of sides, to obtain inside breadth, the result is 120 tons, which shows that the act of 1720 only *confirmed* the *usage* of 1652.

Applying this act to Jal's vessel of 27^{m} 77^{c} length, and 8^{m} 12^{c} breadth, we have a vessel 91 feet long, 75 feet keel, $26\frac{6}{12}$ beam, and 13 feet hold, measuring 254 tons, manifestly too large for Columbus's flag ship.

Spain exported wine in the fifteenth century, as now, and the old English expression of a tun of wine meant two pipes, 252 gallons, each gallon=231 cubic inches. Taking a gallon of wine at 8.33 pounds, this makes a ton only 2,099 pounds, but the difference to reach 2,240 was probably an allowance for the interstices of the casks.

If the ship used by Columbus on his first voyage was called either by him or his contemporaries, in round numbers, 100 tons, it was probably the expression of the dimensions of vessels which traded to England with wine and paid tonnage dues there, which was a specific sum for every tun of wine imported into the kingdom. Therefore, if the act of 1720, and Pepys' dimensions of the Greyhound,

(¹) Cubit is generally stated to be 18 English inches; old Paris foot=12.789.—F. A. P. Barnard, in *Johnson's Universal Cyclopædia.*

1652, which agree, are used to find the dimensions of the hundred-ton vessel ascribed to Columbus, we get: length on deck, 63 feet; length of keel, 51 feet; extreme breadth, 20 feet; inside breadth for tonnage, 18 feet 6 inches; depth of hold, 10 feet, and draft of water, 10 feet 6 inches. These make a vessel of $100\frac{35}{94}$ tons.

The rig of the Santa Maria is mentioned in the journal of October 24 (*Navarrete*, p. 39, and *ante*, p. 371) and this is all the information I can find bearing upon the subject. Columbus wrote: "I carried all the sails of the ship, the main sail, and two bonnets, the fore sail, and sprit-sail, and the mizen, and the main top sail." This omission of a foretop sail seems strange to our nautical ideas, but vessels similarly rigged are to be seen on the map—*Ortelius, Theatrum Orbis Terrarum*, 1570. Sprit-sails have been dispensed with in modern times, only since the steeve of bowsprits has been lessened and the size of jibs increased.

I finished a cruise around the world in the United States brigantine Dolphin, which had a length from front of the stem, under bowsprit, to inside of stern post of 88 feet; breadth of beam outside, 25 feet; inside, 23; depth of hold, 10 feet; draft aft, 10 feet; forward 8 feet, including the keel, which was 1 foot 6 inches. By Pepys' dimensions and the act of 1720, the Dolphin would be 205 tons. Her armament was two 9-pounders and eight 24-pound carronades. Officers and crew, 70. Foretop masthead 71 feet 6 inches above the water, and maintop masthead 81 feet 6 inches. I assume for the masthead lookout of the admiral's ship a height of 60 feet above the sea.

His vessel probably carried four anchors and they all used hemp cables. February 20, at the Azores, returning from his first voyage, he mentions that the cables were chafed off by the rocks and he put to sea. Fourth voyage—*Major*, p. 194: "I anchored at an island where I lost at one stroke three anchors. * * * The *single*(1) anchor that remained to me."

They had pumps—*Major*, p. 195: "With three pumps, and the use of pots and kettles, we could scarcely, with all hands, clear the water that came into the ship."

Rudders.—The ancient way to steer was with two large paddles, one thrust through a port on each quarter. The hinged rudder had come into use in Columbus's time. (See figure of a ship with both, in *Peregrinatio ad Terram Sanctam*, of Breydenbach, Mentz, 1486.)

Boats.—From a careful study of the narrative and words of Columbus I infer that his vessel and also the caravels each had but one boat. October 14 (*ante*, p. 357): "At dawn I ordered the boat of the ship." When his vessel was wrecked, on Christmas eve, 1492, the journal of December 25 says that the boat was got out to lay an anchor astern, but deserted to the Niña, whose commander sent it back with his own to render assistance. It appears from the journal of January 2 that the Admiral left to the colony of Navidad, among other things from the Santa Maria, "the boat of the ship." In the narrative of Diego Mendez—*Major*, p. 220—Mendez wrote with respect to the capture of the boats of the caravels in a river in Veragua, that the three vessels of the Admiral were at sea without boats, which would have been unlikely if any one had carried a spare boat. On his fourth voyage—*Major*, p. 177: "The ship which we had the greatest fear for had put out to sea for safety and reached the island of Gallega, having lost her boat and a greater part of her provisions." When he was at the Azores, February 19, on his return voyage, the Portuguese governor seized the boat and half the crew of the Niña, who were on shore at their devotions, and the Admiral got under way *in his vessel* to open a view of the town, to see what had become of it.

There is a decided difference of opinion in enumerating the number of persons with Columbus on his first voyage. Ferdinand Columbus wrote that 90 went in the three vessels; Peter Martyr and Guistiniani, 120; Jal, p. 228, that he left at Bohio 55 men, and returned to Spain with about 125, making 180 in all; Las Casas, *Navarrete*, vol. i, pp. 121–122, that he left in the island of Española, which the Indians called Bohio, thirty-nine men; Diego de Arana, Pedro Gutierrez, Rodrigo Escovedo, "with all the powers he held from their Highnesses." A notary and constable, carpenter and caulker, gunner and machinist, cooper, physician, and tailor, "and all, he said, that men of the sea."

This enumeration makes 48; but the true one is probably given in *Navarrete* (vol. 2, p. 19): 40 men and the 3 lieutenants, or 43 in all. In the journal of December 26, 1492, we notice that after the shipwreck many of the crew asked the Admiral for permission to remain until his return

(1) *Italics* by the writer.

from Spain, and on the 2d of January it is recorded that he left with them all the goods sent for trafficking, and everything belonging to the wrecked vessel, besides biscuit and wine for a year, and provisions. We learn from *Major*, p. 82, that his stores comprised biscuit, corn, wine, pork, and salt beef. Bernaldez says he took ten Indians with him to Spain. Martin Alonso Pinzon had deserted with the Pinta before the shipwreck, and, since Columbus believed him to be on his way to Spain, he acted as though he had only the little Niña with which to finish the voyage. In these circumstances it is a reasonable belief that, on account of space, if for no other reason, he must have left at Navidad at least as many persons as composed the crew of the wrecked vessel.

February 19, at the Azores, he sent half of the crew of the Niña on shore to perform a vow in a church; one boat from this vessel, which was the smallest of his squadron, took all. This implies that the crew must have been few. These facts persuade me to adopt the enumeration of Ferdinand Columbus, 90 persons for the three vessels. The inscription in the pavement of the cathedral of Seville is: "*Con tres galeras y 90 personas.*"

Neither Spain nor America has founded any enduring memorial to Christopher Columbus.

APPENDIX No. 19.

AN INQUIRY INTO THE VARIATION OF THE COMPASS OFF THE BAHAMA ISLANDS, AT THE TIME OF THE LANDFALL OF COLUMBUS IN 1492.

By CHARLES A. SCHOTT, Assistant.

APRIL 12, 1881.

DEAR SIR: In compliance with your directions and at the request of the Hon. G. V. Fox, I have examined into the subject of the probable amount of the magnetic declination (commonly called "variation of compass") off the eastern coast of the Bahama Islands, at the time of Columbus' approach in 1492. The investigation is based upon such extracts from Columbus' journal as were furnished me by Mr. Fox and includes whatever other information I could obtain bearing upon the subject. In a brief interview I had with Mr. Fox (March 31), I took occasion to express my conviction of the impossibility of arriving at any very definite conclusion, partly on account of the extremely scanty material as to facts and partly in consequence of the want of assistance derivable from purely theoretical grounds; the cause of the phenomenon of the secular change of the magnetic declination being quite unknown and the time comparatively short during which to trace the law of change as hitherto observed. It will therefore not be surprising to find my conclusion given in the form of a reasonable conjecture rather than as a definite result. The present state of our knowledge of terrestrial magnetism does not appear to admit of a definite answer; besides, there are difficulties in the admission of certain evidence given by Fernando Colon.

Before entering upon the subject proper I beg to submit a few remarks in reply to a question bearing upon the early use of the compass and upon navigation towards the close of the fifteenth century. Respecting the ancient use of the magnetic needle or compass, on land and at sea, among the Chinese, with whom the practice originated, accounts will be found in Humboldt's Cosmos, vol. ii (Translation by Otté, London, 1849), and in the Encyclopædia Britannica (9th edition) vol. vi, 1877, art. Compass; there is also an extended account in the Encyclopædia of Experimental Philosophy, London, 1848 (part of the Encycl. Metrop'a.). B. F. De Costa, in a paper read before the Amer. Geographical Society (May, 1880), appears to have made certain extracts from the above works, viz., p. 9: "Necker (probably the same as Alexander Neckam—Sch.) abbot of Cirencester, who died in 1217, was acquainted with the use of the compass. Are Frode, in 1068, speaking of the visit paid to Iceland by Flocke Vilgerderson, says in those times seamen had no loadstone in the northern countries. In the fourteenth century Barber (Barbour) says of the party accompanying King Robert of Scotland from Arran to Carrick, 'they na nedil had na stane,' showing that these aids to navigation were then familiar to seafaring men." The curious story about one Peter Adsiger, of 1269, is satisfactorily disposed of in Walker's Terrestrial and Cosmical Magnetism, Cambridge (England), 1866. He shows that no such person lived.

The works quoted above also contain historical accounts of the compass during the middle ages. Flavio Gioja, a Neapolitan, in 1302, mounted his needles on a pivot and divided his compass into octants; however, needles placed on a pivot and carried on board ship were already referred to in the twelfth century (Alex. Neckam). In the sixteenth century compasses were divided into degrees and provided with sights (remarks of the Portuguese pilot, Alexis da Motta, about 1575), and before 1525 Felipe Guillen, an ingenious apothecary of Seville, constructed the first variation compass (Cosmos, vol. ii).

Referring to the times of Columbus, his compasses were probably divided into points of $11\frac{1}{4}^{\circ}$ and half points (quarters could be estimated). The distances sailed over were most probably estimated by him, since, according to Humboldt, the Admiral did not employ the log-line; time he measured by means of half-hour sand-glasses, and for his determination of position of the ship he probably used the astrolabe, just improved by Martin Behaim (who lived at Lisbon, between 1480 and 1484) for sea use and in connection therewith Behaim's or other tables of the sun's declination when observing the altitude of the sun. Humboldt asserts that the Admiral certainly carried with him Toscanelli's chart, sent him in 1477.

The following information and remarks I received from Mr. Fox, under date of April 1, 1881:

"Personal Narrative of the first voyage of Columbus to America, translated by Samuel Kettell. Published by Thomas B. Wail & Son, Boston; G. C. Carvill, N. Y. and Carey & Lea, Phila., 1827.

"Pages 18, 19: 'September 13, 1492. At the first of the evening of this day the needles varied to the N. W., and the next morning about as much in the same direction.

"'September 17: The pilots took the sun's amplitude and found that the needles varied to the N. W. a whole point of the compass, the seamen were terrified and dismayed without saying why. The Admiral discovered the cause and ordered them to take the amplitude again the next morning, when they found that the needles were true; the cause was that the star moved from its place while the needles remained stationary.'

"It seems incomprehensible that the observations of the next morning showed no declination, unless Columbus tampered with the card as he did in 1459-'63. (See Irving's Columbus, revised edition, 1854, vol. 1, p. 30.)

"On the 13th of September he was 224 leagues (672 geographical miles) west of Gomera, one of the Canaries, which Bowditch places in latitude 28° 06′ north, longitude 17° 08′ west. On the 17th he had gone 360 leagues west of Gomera, or 1 080 geographical miles. Thence he went to the Bahamas, northeast coast of Cuba, north shore of San Domingo (Haiti) and home without again mentioning the declination of the compass.

"Though he made three more voyages to the West Indies, the second from 1493 to 1496, third from 1498 to 1500 and last from 1502 to 1504, he writes of the declination of the compass on the third voyage only, as follows—Select letters of Columbus, 2d edition, translated and edited by R. H. Major, London, 1870; printed for the Hakluyt Society, p. 131—'I remarked that from north to south in traversing these hundred leagues (300 geographical miles) from the said islands (Azores) the needle of the compass which hitherto had turned towards the N. E. turned a full quarter of the wind to the N.W. and this took place from the time when we reached that line.'

"Page 135: 'For in sailing thence (Azores) westward the ship went on rising smoothly towards the sky and then the weather was felt to be milder, on account of which mildness the needle shifted one point of the compass; the further we went the more the needle moved to the N. W., this elevation producing the variation of the circle which the north star describes with its satellites.'

"In the Landfall of Columbus, by A. B. Becher, captain R. N., London, 1856, Appendix, pp. 330-337, are extended remarks about the declination. Captain Becher claims 2 points westerly declination in 1492 for the Bahama Islands. Columbus' remarks on the declination in his third voyage do not refer to the coast of Paria but to the route west of the line of 100 leagues west of the Azores."

Under date of April 2, Mr. Fox writes: "I have found Captain Becher's authority for saying that Columbus discovered 1½ points westerly variation on the 16th of August, 1498. In Collection of Voyages and Travels, by Churchill, London, 1732, vol. ii, p. 587, is the following extract from Ferdinand Columbus' life of his father:

"'Yet the Admiral says he could not from this time give such an account of it as he would wish, because through overmuch watching his eyes were inflamed, and therefore he was forced to take most of his observations from the sailors and pilots. He also says that this same night, being Thursday, the 16th of August, 1498, the compasses which till now had not varied, did at this time at least a point and a half and some of them two points, wherein there could be no mistake because several persons had always watched to observe it. Admiring at this and grieved that he had not the opportunity of following the course of the continent, he held on N. W. till on Monday the 20th of Aug. he came to anchor between Beaca and Hispaniola.'

"This declination seems to have been determined, August 16, the day after he left the coast of Paria, at a place where the island of Margarita bore west. The east point of that island by

Bowditch is in latitude 10° 59′ north, longitude 64° 30′ west. Ferdinand has been accused of many misstatements and errors of date. His history has never been found. All translations are from an Italian copy. Columbus, as I have quoted to you from his third voyage, refers, in speaking of the declination, to what he discovered 100 leagues west of the Azores in his *first* voyage. I think, therefore, that Ferdinand wrote from memory, not having his father's letter before him, which we have. He was not a sailor. He says, until *now* the compasses had not varied. Columbus was about Paria from the 1st of August, and yet he says they did not vary until the 16th. As we have Columbus' own letters of this voyage wherein he speaks of the declination, I think we cannot say that there was 1½ points (W.) declination on the coast of Paria in 1498."

Returning to the Admiral's remarks in his first voyage, we may be certain of the fact that on September 13, 1492, he had reached far enough to the westward to come from a previously eastern declination within a region of westerly declination and that on September 17 it amounted to a whole point (11¼°). This constitutes his well-known discovery of a part of a line of no-declination.

Two hundred and twenty-four leagues, or near enough for our purpose, 672 nautical miles west of the island of Gomera would place him on September 13, in latitude 28° 06′ north and in longitude 12° 42′+17° 08′=29° 50′, according to Bowditch, or if we take the position of the harbor of Sebastian near the eastern point of Gomera Island, according to admiralty chart No. 1873, viz, latitude 28° 05′.5 and longitude 17° 06′.3 and considering that 11° 12′ correspond to 12° 42′ of difference of longitude in that latitude, we have for a point in the line of no-declination the latitude 28° 05′ and longitude 29° 48′. In E. Walker's treatise on Terrestrial and Cosmical Magnetism, Cambridge (England), 1866, p. 300, we read: "The history of this line dates from the 13th of September, 1492, when Columbus observed the needle pass from the east to the west of the meridian in latitude 28° N., longitude 28° W." (probably roughly adding 11° of difference of longitude to 17° for longitude of Gomera). According to my computation of the daily position of the Admiral's flagship and based upon his log-book, he was on September 13 in latitude 28° 21′, longitude 29° 16′. It is evident that the extract from the third voyage is but an amplification of his first account and expresses his conviction that west of the Azores, where the declination was a little easterly it changed to the westward, being nearly zero at Corvo and gradually increasing to one point or 11° W. at a distance of 300 nautical miles W. of the longitude of Corvo. The position of Rosario on the S. E. part of the island of Corvo is, according to the Carta Esferica de las Islas Azores, Madrid, 1855, in latitude 39° 41′ and longitude 24° 53′ west of San Fernando, or in 31° 07′ west of Greenwich (according to the Conn. des Temps), 100 leagues or 300 nautical miles west of this longitude would correspond (in latitude 28°) to 5° 40′ and would bring the Columbus line in longitude 36° 47′ W. According to my computation of the daily track, Columbus was on September 17, 1492, in latitude 27° 38′ and in longitude 36° 30′, when he noted 11° west declination. The statement of Humboldt, in Cosmos, vol. ii (Otté edition) p. 657, is that 2½° *east* of Corvo the variation changed from E. to W. on September 13, 1492, he thus appears to take the longitude of Corvo as 31° and that of Columbus' position as 28½°. Though the accounts transmitted may admit of different interpretations there can be no question as to the fact of the discovery of a part of the line of no-declination passing towards the close of *the fifteenth century* from the vicinity of the Azores southward. At that time there was east declination at Palos, Spain, also at the Canaries and the eastern Azores. There was at that time but a slight westerly (not more than about 1½°) declination at Paris, France, as may be seen from my discussion of the observations made at Paris between 1541 and 1869 (see "Secular change of the magnetic declination," Appendix No. 9, Coast and Geodetic Survey Report of 1879, which is illustrated by a diagram herewith reproduced). Thus, the agonic line of 1492 must have passed a short distance to the south of Paris, France. In the Cosmos, as quoted above, Humboldt remarks: "The great Spanish navigator has not only the merit of having discovered a region in the Atlantic Ocean where, at that period, the magnetic meridian coincided with the geographical, but also that of having made the ingenious observation that magnetic variation might likewise serve to determine the ship's place with respect to longitude. In the journal of the second voyage, April, 1496 (on his home voyage), we find him trying to determine his position by the observed declination." Such an idea might well be entertained in an age when but the rudest means were available to the navigator for finding his longitude and when the course of the isogonic lines was but little understood; this idea is well known to have been revived in later times.

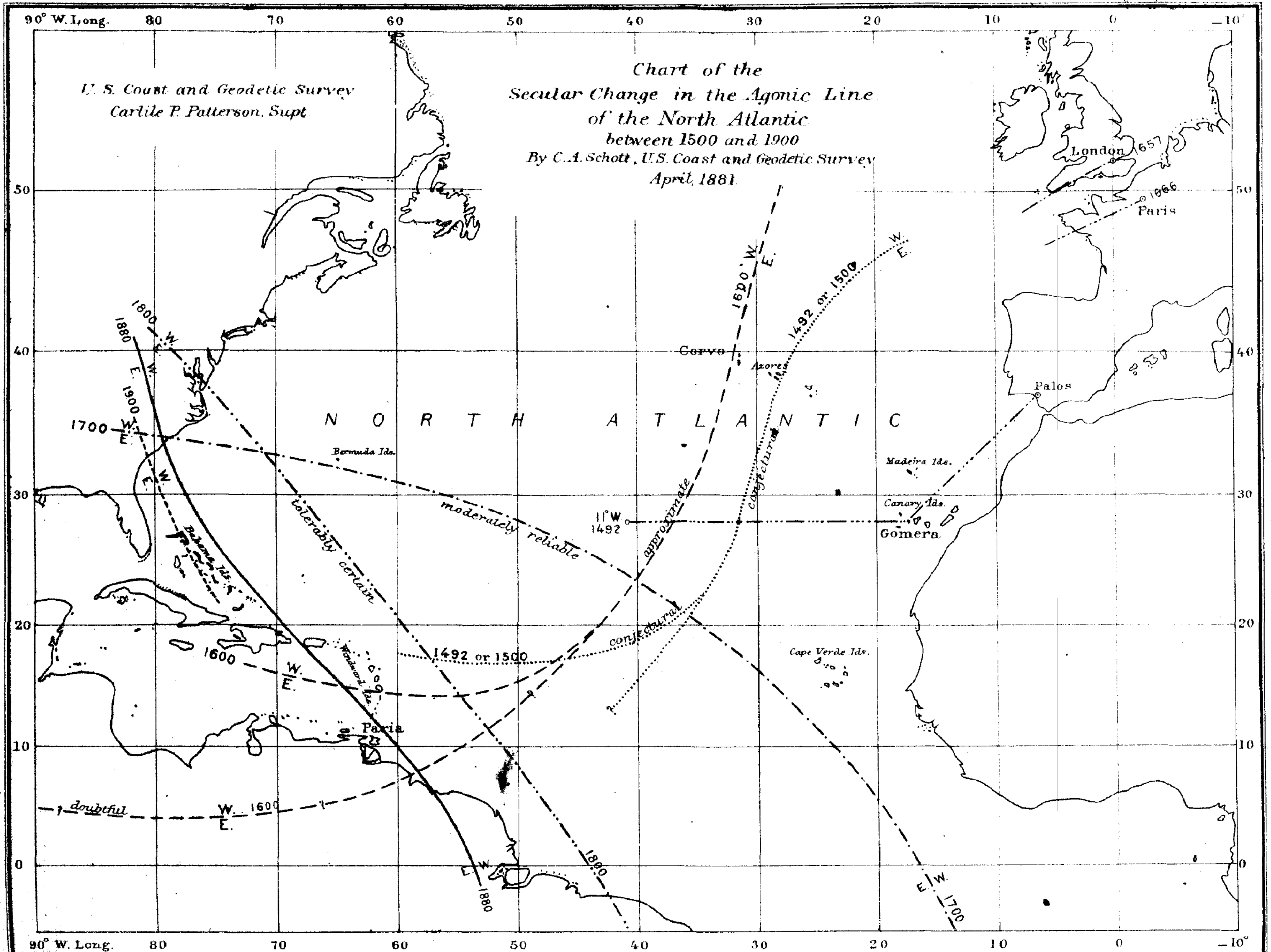
Chart of the
Secular Change in the Agonic Line
of the North Atlantic
between 1500 and 1900
By C. A. Schott, U.S. Coast and Geodetic Survey
April, 1881
U. S. Coast and Geodetic Survey
Carlile P. Patterson, Supt
N O R T H A T L A N T I C
90° W. Long.
80
70
60
50
40
30
20
10
0
-10°
London
Paris
Palos
Gomera
Cervo
Azores
Bermuda Ids.
Madeira Ids.
Canary Ids.
Cape Verde Ids.
Bahama Ids.
Windward Ids.
Paria
tolerably certain
moderately reliable
approximate
conjectural
doubtful
1492 or 1500
1600
1700
1800
1880
1900
1657
1666
11° W.
1492

The course of the agonic line of 1492 towards the southwest is very uncertain, as it must entirely rest on the value we assume for Paria; and whether we accept the above circumstantial account given by Fernando in connection with Columbus' third voyage, or whether we reject it as vague and unreliable, our conclusion as to the declination in the West India Islands must in a great measure depend on it. Mr. Fox disposes of the matter in a very summary manner and while I reach the same conclusion, viz, that in all probability there was no west declination in that part of South America in 1492, I reach it on different grounds. If we accept the Paria observations it would necessitate a declination of not less than 2 points west for the Bahama Islands. Referring to the accompanying chart of the North Atlantic, showing the more or less probable positions of the agonic line for different early centuries, that for 1500 (answering equally well for 1492) has been laid down from the evidence cited in this paper, but its southwesterly course would either pass into the region between the Orinoco and Amazon Rivers, if Fernando's account was trustworthy, otherwise it would pass towards the Greater Antilles, as I conjecture it did.

Looking over the records and deductions for the secular change of the declination in the West Indies, in the fourth edition of my paper—Appendix No. 9, Coast and Geodetic Survey Report of 1879—we find there the earliest records for Havana, Cuba, 6° E. in 1700 and 4½° E. in 1730 and at Kingston, Jamaica, 6½ E. in 1660 and the same in 1700. The agonic line for 1600, as originally given, I have taken from Hansteen's Erdmagnetismus (1819). This line of 1600 mainly depends on Kircher's Ars Magnetica and on Purchas' Pilgrims, but in accordance with above facts I have shifted it towards the north, so as to traverse the northern part of the Caribbean Sea. It would seem to me that the line for 1500 requires a similar correction. Considering that the analytical expressions established by me in the secular change paper referred to, for all stations in this region have a limited range of change, not exceeding 5° from a supposed average position, it will be seen from the early observations cited above that the limit of variation may have approached nearly to zero and that, unless a total change in the law of the secular progression of the declination took place in those early times, the statement by Fernando Colon as to west declination off the island of Trinidad must be regarded as spurious. Yet, in a matter of such extreme difficulty in the present state of our knowledge of the changes in the distribution of the earth's magnetism and while admitting that no certain or definite conclusion can be reached, I may, nevertheless, state as my opinion that at the time of Columbus' first landfall on one of the Bahama Islands the declination was *very small* and probably less than ½ point west.

Reverting again to the chart of the positions of the agonic line of the North Atlantic, Humboldt, in his Examen Critique, refers to Gilbert's Physiologia Nova to show that in 1600 the line of no-declination still passed through the Azores; and it may be noted that Sir Walter Raleigh's observation* on October 28, 1617, in latitude 7° N., longitude 28½° W., viz, 7°, and he thinks *east*, falls in well with the corrected curve on the chart. In the Azores, at Funchal Bay, the declination was observed 3° 05′ E. in 1589 and at Santa Maria 1° 40′ E. in 1610. At the Cape de Verde Islands the declination was observed 3° 30′ E. in 1610 (see Encyclopædia of Experimental Philosophy, London, 1848, p. 836). The line for 1700 is well founded and is taken from Halley's magnetic chart (Tabula Nautica, Variationum Magneticarum index, juxta observationes, anno 1700), reproduced in the Greenwich observations for 1869. Respecting the position of the lines for 1800 and 1880, no further remarks are required in this place. The motion of an agonic line may be regarded as typical for the motion of other isomagnetic lines in its vicinity and which may be taken as running parallel to it within certain limits. Between 1600 and 1880 the agonic line turned in the direction of the hands of a watch through fully a right angle, but between 1500 and 1600 the motion appears to have been partly retrograde. To obtain some idea as to a *scale of change* for distance from the earlier agonic lines, we may use the American observations made on our coast, on or near the Gulf of Maine, by Hudson and Champlain, between 1604 and 1612; their average result is nearly 18° W. We can do no better than suppose the scale also to apply to distances from the agonic line of 1500, corresponding to and, for intermediate values of west declination, proportional to the distance of our coast from the line of 1600; but at best this would be a very rough proceeding.

In response to a second inquiry, respecting the track of Columbus between Gomera and his

* Mr. Fox gives the reference "Hakluyt," vol. iii, p. 196.

first landfall, I would remark that the computed latitude of the landfall depends almost entirely on the assumed declination along his track (*de facto*, the problem might be inverted and from a known position of the landfall the distribution of the magnetic declination might be inferred). In strict adherence to the conclusion I came to respecting the magnetic declination, I have adopted the daily values as given in the accompanying table of resulting positions. The courses were corrected so as to represent true courses. The magnetic courses and distances in leagues are those given in Columbus' log-book; the latter were converted into nautical miles roughly by taking one league equal to three nautical miles, or three minutes of arc of a great circle of the earth's surface considered as a sphere.

According to Clarke's figure of the earth, a nautical mile is nearly 1 855.3 meters, or 6 080.3 feet. Fortunately the actual length of the Columbus league—that is, the league of his time, and, what is more important, *his practical conception of it*, that is, his and his pilots' *estimates* of its length—does not seriously affect the result of our problem, as will appear from the consideration that the total distance must land him somewhere on the eastern line bounding the Bahama Islands; and if we find his distances to overrun this limit, which I found to be the case, all we have to do is to diminish them by a suitable percentage. Accepting the length of the Columbus league as given by Mr. Fox, viz, 6 456 yards and computing the track across the Atlantic, I found it necessary, in accordance with the above indispensable condition, first to reduce the distances by one-tenth and then by one-hundredth more, which lands me just inside the line of keys. Columbus, when departing from Gomera, apparently took a northerly course in clearing it, so as to elude more easily the Portuguese, who were on the lookout for him at Hierro.*

Track of Columbus in 1492 *across the Atlantic, from the Canary Islands* (*Gomera*) *to the Bahama Islands.*

Date.	Distance in leagues.	Course, magnetic.	Corrected distance, nautical miles.	Declination allowed.	True course azimuth, from S. to W.	Latitude φ.		Longitude λ.	
				°	°	°	′	°	′
Sept. —	3	....	8.5	....	....	28	14	17	14
8	9	W.	25.5	3 E.	93	28	15	17	43
9	49	W.	138.9	2	92	28	20	20	21
10	60	W.	170.1	1	91	28	23	23	34
11	40	W.	113.4	0	90	28	23	25	43
12	33	W.	93.6	0	90	28	23	27	29
13	33	W.	93.6	1 W.	89	28	21	29	16
14	20	W.	56.7	3	87	28	18	30	20
15	27	W.	76.6	5	85	28	12	31	46
16	39	W.	110.6	7	83	27	58	33	51
17	50	W.	141.8	8	82	27	38	36	30
18	55	W.	155.9	8	82	27	16	39	24
19	25	W.	70.9	8	82	27	06	40	42
20	7.5	W. by N.	21.3	8	93.25	27	07	41	06
21	13	W.	36.8	8	82	27	02	41	47
22	30	{ W.N.W. N.W. N. }	85.0	8	{ 104.5 127 172 }	27	23	43	20
23	22	W.	62.4	8	82	27	53	44	06
24	{ 14.5 4.5	W. W.	41.1 12.8 }	8	{ 82 82 }	27	48	44	52
25	{ 17 16	S. W. W.	48.2 45.4 }	8	{ 37 82 }	27	08	45	39
26	15	S. W.	42.5	8	37	26	28	46	58
27	24	W.	68.0	8	82	26	18	48	13
28	14	W.	39.7	8	82	26	13	48	57
29	24	W.	68.0	8	82	26	03	50	12
30	14	W.	39.7	8	82	25	58	50	55

* Port of Hierro (Spanish) or Ferro (Portuguese), on the northeast coast of the island, is, according to Admiralty Chart No. 1873, in latitude 27° 46′.2 and longitude 17° 54′.2

Track of Columbus in 1492 across the Atlantic, from the Canary to the Bahama Islands—Continued.

Date.	Distance in leagues.	Course, magnetic.	Corrected distance, nautical miles.	Declination allowed.	True course, azimuth from S. to W.	Latitude φ.	Longitude λ.
				°	°	° ′	° ′
Oct. 1	25	W.	70.9	8	82	25 48	52 14
2	39	W.	110.6	7	83	25 32	54 16
3	47	W.	133.2	6	84	25 19	56 43
4	63	W.	178.6	5	85	25 03	59 59
5	57	W.	161.6	4	86	24 52	62 57
6	40	W.	113.4	4	86	24 45	65 01
	23	W.	65.2		86		
7	5	W. S. W.	14.2	3	64.5	24 34	66 27
8	11.5	W. S. W.	32.6	3	64.5	24 20	66 59
	6	S. W.	17.0		42		
	5	W. by N.	14.2		98.25		
9	20.5	W. S. W.	58.2	2	65.5	23 45	68 24
10	59	W. S. W.	167.3	1	66.5	22 39	71 12
	27	W. S. W.	76.6		66.5		
11	17	W.	48.2	0	90	22 09	73 19
	5.5	W.	15.6		90		
12	2	W.	5.7	0	90	22 09	73 42

The total developed course is 3 150 nautical miles and it is surprising that simply by dead reckoning, over so long a track, a result should be reached which cannot be far from the truth. By adopting more *west* declination along certain parts of the track, say, 11° instead of 8°, the landfall would be materially *depressed* into a lower latitude, in fact, the result is latitude 21° 13′, longitude 71° 29′, which would place the landfall in the vicinity of the Turk Islands; in this case the developed track was 3 054 nautical miles. The more westerly declination we allow, the more will the track be deflected to the southward and this confirms the previous conclusion of the improbability of much westerly declination in the West Indies about the time of Columbus. Making little or no allowance for declination the track may be carried to the north and there are those who have placed the landfall as high north as Cat Island.

The above calculation terminates the track near Mariguana Island, but the uncertainty in the magnetic data is so great that it may be swayed all along the region between Grand Turk and Samana; to this uncertainty we must still add that arising from currents and it is not unlikely that between October 9 and 12 a northwest current was met with. It does not appear that we have any record of astronomical determination of latitudes, either on board ship or on land, made by the Admiral. There is another and apparently far more promising method of investigation for the position of his first landfall than that of following the Admiral across the Atlantic, viz: the inverse proceeding of starting from an identified landing-place on the eastern end of Cuba and tracing his courses and distances, as recorded, *backwards* to his first landfall. Here the variation of the compass may be taken zero. A third method may be based upon the physical aspects of the islands as described by him.

Yours, respectfully,

CHAS. A. SCHOTT,
Assistant United States Coast and Geodetic Survey.

Mr. Carlile P. Patterson,
Superintendent United States Coast and Geodetic Survey.

LIST OF SKETCHES.

ILLUSTRATIONS.

National Oceanic and Atmospheric Administration

Annual Report of the Superintendent of the Coast Survey

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