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REPORT OF THE SUPERINTENDENT

OF THE

U. S. COAST AND GEODETIC SURVEY

SHOWING

THE PROGRESS OF THE WORK

FROM

JULY 1, 1897, TO JUNE 30, 1898.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER

FROM

THE SECRETARY OF THE TREASURY,

TRANSMITTING

The report of the Superintendent of the United States Coast and Geodetic Survey, stating progress made in that work during the fiscal year ending June 30, 1898.

TREASURY DEPARTMENT, OFFICE OF THE SECRETARY,
Washington, D. C., December 30, 1898.

SIR: In compliance with the requirements of section 4690, Revised Statutes, I have the honor to transmit herewith, for the information of Congress, a report addressed to this Department by Henry S. Pritchett, Superintendent of the Coast and Geodetic Survey, showing the progress made in that work during the fiscal year ended June 30, 1898, and accompanied by maps illustrating the general advance in the operations of the Survey up to that date.

Respectfully, yours,

O. L. SPAULDING,
Acting Secretary.

The VICE-PRESIDENT OF THE UNITED STATES
AND PRESIDENT OF THE SENATE.

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LETTER OF TRANSMISSION.

UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C., December 30, 1898.

SIR: In conformity with law and with the regulations of the Treasury Department, I have the honor to submit herewith, for transmission to Congress, the Annual Report of progress in the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898. It is accompanied by maps illustrating the general advance in the field work of the Survey up to that date.

Respectfully, yours,

HENRY S. PRITCHETT,
Superintendent.

The Honorable the SECRETARY OF THE TREASURY.

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PREFATORY NOTE.

The subject-matter of the present report is considered under four heads, as follows:

I. The Survey and its progress.
II. The scientific and technical results.
III. The administration.
IV. The appendices.

In Section I will be found a statement as to the general plan of operations and facts bearing on the general development of the work.

In Section II the results are stated somewhat at length, without, however, going into details of a routine character. This section is subdivided into: Coast work, geodetic work, magnetic work, special operations, publication of results.

In Section III appear the office details, including personnel and expenditures.

In Section IV are given professional papers on scientific subjects, written by members of the staff.

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III. THE ADMINISTRATION.
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SECTION I.

THE SURVEY AND ITS PROGRESS.

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THE SURVEY AND ITS PROGRESS

1. INTRODUCTION.

The present volume is the Sixty-seventh Annual Report issued by this Bureau. It consists of two distinct portions:

I. An Administrative Report, covering the operations of the Survey during the fiscal year ending June 30, 1898.

II. A series of technical papers by various members of the scientific corps of the Survey.

While the first part of the volume gives in detail the operations of the year, a few words of explanation concerning certain changes which have occurred, and which have concerned the general amount of the work of the Survey, may not be without interest.

Gen. W. W. Duffield, the eighth Superintendent of the Survey since its inauguration, in 1807, having resigned office on December 1, 1897, the writer succeeded to the place at that time. The first half of the fiscal year was already drawing to a close, and the work of the remaining part of the year was necessarily continued along lines already practically fixed by the character of the appropriations.

An important modification of these plans was made necessary by the action of Congress in January, 1898, in adding to the urgent deficiency bill an item appropriating $100,000 for the special survey of the Yukon River. This work assumed new and pressing importance in view of the large number of vessels now drawn to the Alaskan trade by the discoveries of gold. It was felt to be a matter of great importance to survey the region about the mouth of the Yukon, and to determine definitely whether an entrance for ocean-going vessels could be found thereto.

The problem of surveying the region about the mouth of this great stream formed the most important work undertaken by the Survey for the summer of 1898. The plan of operations adopted, including the design and construction of boats suitable for the work, is due to Assistant J. F. Pratt.

The necessity for immediate surveys of the region covering the Delta of the Yukon and the approaches to it had also been fully anticipated by Lieut. Commander E. D. Taussig, U. S. N., and his plan for inaugurating this work included the survey of the outside bar and a search for a deep-water channel. to be conducted by Lieut. J. M. Helm, U. S. N., in the steamer *Gedney*.

The detachment of Lieutenant-Commander Taussig and of other officers of the Navy, consequent upon the outbreak of the war, together with the transfer of the *Gedney* to the Navy Department, necessitated the postponement of this part of the work until the following season.

Other questions of moment also suddenly came up for disposition, and which materially affected the plan of operations. The most important of these was occasioned by the outbreak of the war between Spain and the United States, in April, 1898, in consequence of which naval officers who had for some years commanded the Survey ships engaged in hydrographic work were withdrawn for war service. About thirty officers were on duty in the Coast Survey at the beginning of hostilities. These were all immediately recalled for regular duty in the Navy, and three of the ships of the Survey—the *Patterson*, the *McArthur*, and the *Gedney*, all on duty on the Pacific coast—were temporarily transferred by the President to the Navy Department. None of these were, however, actually used, and a few months later were returned to the Survey. The Survey steamer *Bache* was also used by the Navy Department for some weeks as a dispatch boat between Key West and Havana.

The vessels of the Survey have since this date been under the command of Assistants in the regular corps of the Survey who, fortunately, had been fitted by long experience in hydrographic work for this duty. Under their charge the hydrographic work was vigorously prosecuted during the remainder of the year. Owing to the increased demand on the field force of the Survey, various members of the office force were, by the authority of the Secretary of the Treasury, temporarily assigned to field duty.

The resources of the Survey were utilized to furnish the greatest possible amount of assistance to the military and naval authorities in the conduct of the war. In addition to the collation and preparation of information regarding maps of Puerto Rico, Cuba, and the Philippines the Survey furnished to the Navy Department between April 1 and June 30, 1898, 27 678 charts.

The extra expense involved in meeting this unexpected demand was supplied by an allotment of $1 700 from the national defense provided by Congress under the deficiency act of March 9, 1898, and by special appropriation of $5 000 under the deficiency act of July 7, 1898.

In order to meet this unprecedented demand for charts all supplying of charts to private parties was stopped and the presses were run from 8 a. m. to midnight. The additional work thus imposed fell chiefly upon the Assistant in Charge, the chief of the drawing and engraving division, the chief of the chart division, the foreman of the printing office, and those employed in these divisions. In all cases the extra work imposed was most cheerfully assumed and faithfully carried out.

Except for the change just mentioned, namely, the withdrawal of officers of the Navy from duty on Coast Survey vessels, the organization of the Bureau has remained during the past year the same as for some years past, except for slight changes in the divisions of the office.

This organization was as follows:

1. General Administration.

Superintendent.

Assistant in charge of office, having personal supervision of the details of office work.

Hydrographic inspector, having general charge of hydrographic work and of the repairs and maintenance of the vessels of the Survey.

Executive officer, having general supervision of the operations of field parties engaged in geodetic operations.

2. FIELD WORK AND COMPUTATIONS.

Field assistants and aids; Tidal Division; Computing Division.

3. PUBLICATION OF RESULTS.

Drawing and Engraving Division; Chart Division.

4. ACCESSORY OFFICES.

Instrument Division; *Library and Archives; Accounting Division.*

Exclusive of petty officers and sailors serving on the vessels of the Survey, who are enlisted men of the Navy, detailed to the Coast Survey under the provisions of the general appropriation for enlisted men of the Navy, the personnel of the Survey on June 30, 1898, was as follows:

1. Field force:	
Assistants	38
Aids	4
Total	42
2. Office force:	
Disbursing agent	1
General office assistant	1
Chief librarian	1
Computers	11
Draftsmen	15
Engravers	17
Electrotypers, photographers, etc	22
Clerks	15
Chart correctors, etc	14
Messengers, etc	24
Total	121

The total number of persons employed on fixed salaries on June 30, 1898, was, therefore:

In the field force	42
In the office force	121
In all	163

In addition, there were on that date 212 enlisted petty officers and sailors serving on Coast Survey vessels, making a total of 375 persons regularly engaged in the work of the Coast and Geodetic Survey.

(*a*) APPROPRIATIONS.

The sundry civil act of June 4, 1897, placed at the disposal of the Survey, for expenditure during the ensuing fiscal year, the sum of $496 070. In the Administrative Report which follows is given a detailed statement of the expenditure of the sum,

which covered salaries as well as field expenses. The following classification of items of expense indicate the general purposes to which the fund was devoted:

I. Field expenses:		
Surveys of Atlantic, Gulf, and Pacific coasts		$63 600
Surveys in Alaska		15 000
Special hydrographic surveys, Coast Pilot, etc		15 800
Geodetic work, including triangulation, magnetic and level observations, State surveys, etc		30 400
In all, for field expenses		124 800
II. Repairs and maintenance of vessels	$35 000	
Pathfinder	75 000	
		110 000
III. Salaries:		
Field force	$90 400	
Office force	136 470	
In all, for salaries		226 870
IV. Office expenses:		
For materials of all sorts, instruments, photolithographing charts, publication of observations, etc		34 400
Total		496 070

In addition to this amount, there was expended by the Navy Department, for the pay and subsistence of petty officers and sailors serving on Coast Survey vessels, $112 676 52.

The salaries of naval officers serving on Coast Survey vessels between July 1, 1897, and April, 1898, amounted to $45 353 74.

The total expenditures, therefore, by the Government, on the work of the Coast and Geodetic Survey during the fiscal year ending June 30, 1898, were as follows:

Appropriated in sundry civil bill	$496 070
Expended in naval appropriation for pay and subsistence of enlisted men	112 676
Pay of naval officers	45 354
Total	654 100

(*b*) THE WORK OF THE YEAR.

In the Administration Report which follows is given, in detail, the work accomplished by the Survey during the year. Beside the routine correspondence and clerical work, the results obtained may be roughly divided into three classes: (1) The field observations; (2) The office reduction and discussion; (3) The publication and distribution of the results.

While the principal work of the Survey is along the coasts, the geodetic operations with which it is charged, including triangulation, precise leveling, determinations of geographic positions, and of the force of gravity, extend over the entire country.

In the nature of the case, any survey of coast lines is unremitting and never-ending. The rains are constantly bringing down tons of detritus into the bays and harbors from the mountainous slopes of the eastern and western boards, while the slower action of the tides and winds are constantly changing the contours of the ocean bed near the

land. Cultural features, such as new buildings and industries, also modify, from year to year, the aspect of the shore. Necessary resurveys and examinations will thus always be required to furnish the information for keeping most charts up to date. With a coast line which, exclusive of Alaska, embraces some 5 500 miles, such resurveys will for many years form an important part of the work of the Coast and Geodetic Survey.

During the past year two of the most important pieces of work which the Survey prosecuted was the continuation of the resurvey of Chesapeake Bay and of San Francisco Bay. The work in both of these large and important bodies of water is being pushed to completion rapidly, and in both cases changes of an important character are shown by the new surveys, which will funish data not only of immediate practical value to commerce but to the student of physical hydrography and of geography as well.

In Alaska, where a long and tortuous coast and a suddenly developed commerce are imposing upon the Survey work of a most important character, good progress was made. The Pribilof islands were completely surveyed and mapped and good progress was made in the surveys of southeast Alaska.

The geodetic operations of the year have included the practical completion of the work on the thirty-ninth parallel, the continuation of the line of precise levels between the Atlantic and the Pacific, magnetic observations in California, Virginia, West Virginia, Ohio, and Alaska, and pendulum observations at three stations.

The publications of the Survey during the year have been of the usual character. These publications take two forms, (1) charts and maps, and (2) textual publications.

The charts and maps are drawn in the office of the Survey, and charts are, as a rule, engraved and printed there. The exceptions are in the cases of new charts reproduced by photolithography.

During the year 13 new chart plates have been finished, and engraving has progressed on 16 additional ones. Fifty-three old charts have been revised and printed as new editions, and 103 588 charts have been issued.

In textual publications, in addition to the Annual Report with its appendices of scientific papers, there are issued the Annual Tide Tables, the Coast Pilots, and Notices to Mariners, and Special Bulletins which are issued when the information gathered demands immediate publication. Every effort is being made to reduce and discuss observations promptly, and to place the results before the public in such time and in such manner as may make them of greatest value.

HENRY S. PRITCHETT,
Superintendent.

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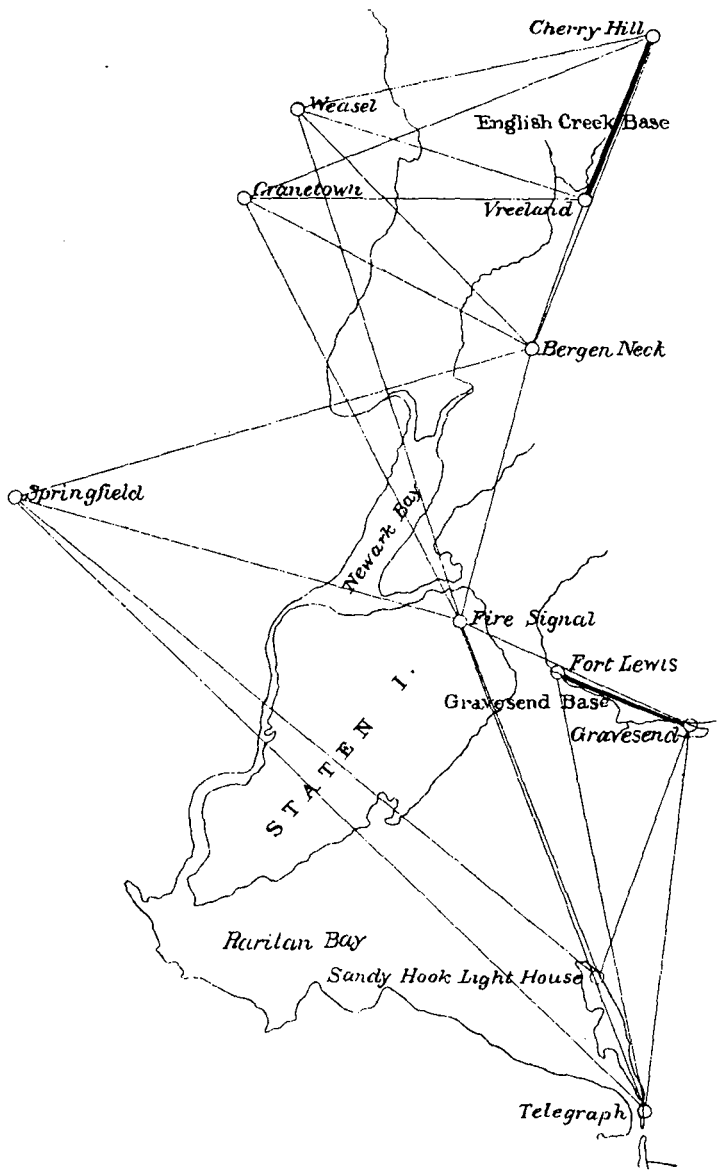
THE BEGINNING OF THE U. S. COAST SURVEY



TRIANGULATION NEAR NEW YORK CITY

1817

Scale 1:400 000

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2. HISTORICAL SKETCH OF THE U. S. COAST AND GEODETIC SURVEY.

An act of Congress, approved February 10, 1807, authorized a Survey of the Coast of the United States. On the 25th of March a circular letter from the Secretary of the Treasury requested plans for the execution of the work. Nothing was immediately done beyond the consideration of these plans, and no further action was taken until 1811 (April 16). Mr. F. R. Hassler, whose plans had been approved by President Jefferson, was then sent to Europe to procure the necessary instruments. He sailed on August 29, spent four years in England and on the Continent, and returned with his ontfit complete on the 16th of October, 1815. Field work actually began on the 6th of August of the following year. From this time until April 14, 1818, operations were continued in the vicinity of New York (cut No. 1). A base line was measured in the valley of English Creek (May 7, 1817) and one of verification, twice measured, was completed December 6 of the same year. Eleven trigonometrical points were occupied. The triangulation connecting the measured lines represents the nucleus of the work of the Coast Survey and embodies its first tangible results. It is the beginning of our vast scheme for the measurement of the national domain. The trigonometric work now spans the country from the Atlantic to the Pacific, and from Maine to Mobile. It covers the entire coast and promises ultimately, the cooperation of Canada and Mexico having been assured, to encompass the continent from Acapulco to the Arctic Ocean.

On the date above mentioned, April 14, 1818, it was enacted by Congress that so much of the law relating to the survey of the coast as authorizes the employment of other persons than those belonging to the Army and Navy be repealed.

Between 1818 and 1832 little work was done. The instruments, records, and funds were transferred to the War Department, and the Coast Survey may therefore be considered an army service during this period. Ex-President Jefferson, who had always been a strong advocate of the methods adopted by Hassler, proposed to acquire the instruments for the use of the University of Virginia.

In 1823, 1824, and 1825 efforts were made by the Navy Department to establish a hydrographic corps, but public sentiment soon returned to the ideas of Jefferson. Bills were introduced in Congress in 1828 and 1831, and one was finally passed in 1832 (July 10) carrying into effect the original law of 1807. The same year (August 9) Hassler was again appointed Superintendent. Field work was taken up in April, 1833. Less than a year later (March 12, 1834) the administration of the Survey was transferred from the Treasury to the Navy Department, Mr. Hassler, however, remaining in charge.

These conditions held for two years, when a retransfer was effected (March 25, 1836), and the Treasury Department again assumed control. Operations continued without interruption until 1843 (March 30). On this date a board of reorganization was convened, with Hassler as chairman. The plan submitted for the execution of the work was approved by the President, and in its general features has now been followed for fifty-five years. In 1879 the name Coast Survey was changed to "Coast and Geodetic Survey," a title comporting with its actual status and reflecting more faithfully the character of its operations. Up to the present time the Service has been fourteen years under the War Department, two years under the Navy Department, and seventy-six years under the Treasury Department.

The Superintendents, with dates of their tenure of office, are as follows:

Name.	From—	To—
Hassler	Aug. 3, 1816	Apr. 14, 1818
Hassler	Aug. 9, 1832	Nov. 20, 1843
Bache	Dec. 12, 1843	Feb. 17, 1867
Pierce	Feb. 26, 1867	Feb. 17, 1874
Patterson	Feb. 17, 1874	Aug. 15, 1881
Hilgard	Dec. 22, 1881	July 23, 1885
Thorn	July 23, 1885	June 30, 1889
Mendenhall	July 9, 1889	Sept. 20, 1894
Duffield	Sept. 20, 1894	Nov. 30, 1897
Pritchett	Dec. 1, 1897	

SECTION II.

THE SCIENTIFIC AND TECHNICAL RESULTS.

1. COAST WORK.
2. GEODETIC WORK.
3. MAGNETIC WORK.
4. SPECIAL OPERATIONS.
5. PUBLICATION OF RESULTS.

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1. COAST WORK.

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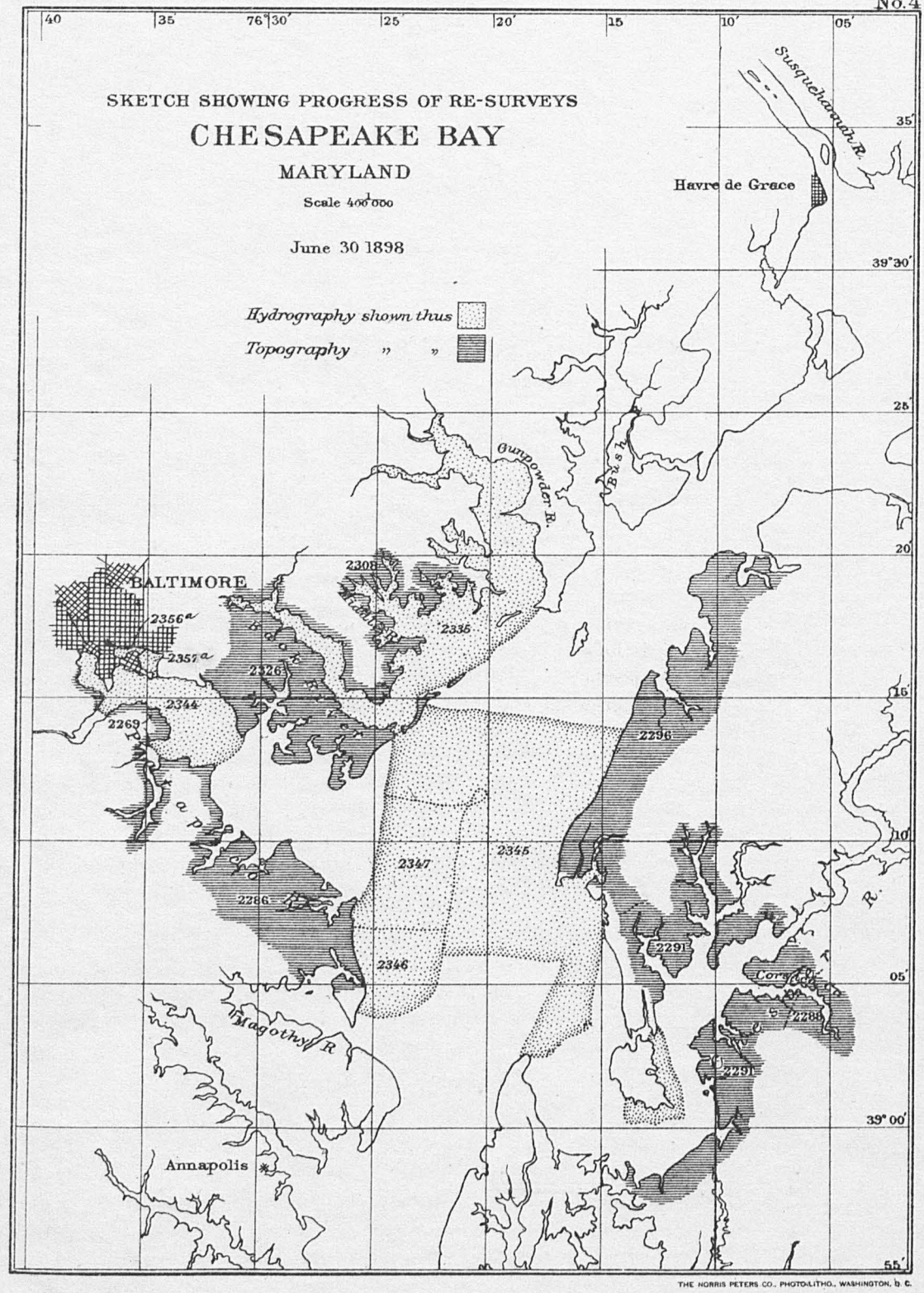

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II. THE SCIENTIFIC AND TECHNICAL RESULTS.

1. COAST WORK.

[See cuts 2 and 3 for general reference throughout the report (in pocket).]

(*Hydrography and topography.*)

(*a*) GENERAL STATEMENT.

All of the operations pertaining to the making of maps and nautical charts, including the necessary triangulations, may be classified under the definition of hydrography and topography. More specifically, hydrography covers marine surveying, including soundings, examinations of grounds, and tidal observations; while topography, as here understood, relates entirely to the surveying of shore lines and adjacent territory to a sufficient distance in the interior to develop general features. It will be seen from this that these branches are of a scientific character, the aim and nature of which is to explore the geography of a coast region for the purpose of charting. The application of the facts thus ascertained to the immediate use of navigation, and their practical bearings to the navigator, such as the laying out of courses and indicating hidden rocks, buoys, light-houses, etc., devolves upon the Coast Pilot section. The work of this section is detailed on succeeding pages.

As both hydrographic and topographic parties are jointly employed in the production of the same result, close cooperation between the two is desirable, if not essential. At least in the matter of plan of operations and connection of triangulation, the work is practically identical in its scope. It is for this reason that in the largest surveys—as in that of Chesapeake Bay (cut No. 4)—the supervision by one assistant of the entire operations of all parties has, during the past year, been found to achieve, in the most economical manner, the best results.

Vessels.—For the prosecution of the Survey's work in these branches a fleet, comprising the following ships, has been employed throughout the season, except at times when executing office work or undergoing repairs.

The *Blake*, *Gedney*, *Patterson*, *Endeavor*, *McArthur*, and *Bache* are steamers, and the *Matchless* and *Eagre* are the large schooners. All of the steamers, with the exception of the *Patterson*, are schooner-rigged, and have from 160 to 645 tons displacement. The

Patterson, now the largest vessel of the fleet, has a displacement of 718 tons and is barkentine-rigged. All of the steamers are single-screw propellers and have a speed of from 8 to 10 knots per hour. The *Blake* was built in 1874 and the *Bache* in 1871. The latter has an iron frame and is sheathed with wood. The former is wooden-framed, fastened with composition and iron. The *Patterson* was built at Brooklyn, N. Y., in 1883, and has a wood hull. The *Endeavor*, built at Norfolk, Va., in 1862, as a Confederate gunboat, from funds raised by Norfolk ladies, has a wood hull, as has also the *McArthur*, built in 1874 at the Mare Island Navy-Yard, Cal. The *Gedney* is a composite vessel, built at New York in 1875. The schooner *Matchless*, 88 feet long, was built in 1859 at Key West, Fla. (rebuilt in 1895), of mahogany and oak; the *Eagre* was built in 1875 at Brooklyn, with a wood hull, 131 feet long; and the *Quick*, built in 1873, at Baltimore, Md., has a composite hull and is 60 feet long.

During the present year contract has been let for the construction of a new steamer (the *Pathfinder*), which will be by far the largest vessel of the fleet, having a displacement of 875 tons. She is brigantine-rigged. Her steaming radius is about 7 000 miles and her average speed about 12 knots under full steam. She is 196 feet in length. Her regular complement of officers and crew will number about 80 men. All of these vessels have quarters for a considerable scientific staff, and are provided with special apparatus for taking soundings, as well as the best class of instruments for different kinds of surveying.

Fuller description of the vessels will be found under the heading "Administration," hydrographic division.

The larger vessels above described have been employed in the greater undertakings and furnish quarters for the larger parties of hydrographers. In connection with them, however, a large number of both steam and oil launches and whaleboats have, of course, been utilized for the running of lines and the development of local features.

The topographic field parties, of which there have been sixteen, have made their headquarters at convenient points for triangulation along the shore. Where no better accommodations have been available, the usual tents or other temporary quarters have been provided. The assistant in charge of each party is selected on account of experience or peculiar fitness for the conduct of the responsible work in hand. The plan of operations is usually to begin with triangulation, connecting the points in the new field with old established ones, if such are available.

The following are the important operations of the year, and their results:

The resurvey of Buzzards Bay, Massachusetts, resulting in the development of the dredged channel of the New Bedford wharves, and two sheets on scales of 1–10 000 and 1–20 000, respectively, in the vicinity of Gooseberry Neck, and the completion of the work on the eastern side of the bay (cut No. 5). In connection with this survey should be mentioned the series of soundings made on the route between Fenwick Islands and Five-Fathom Bank light-ships. The resurvey of Buzzards Bay is now completed. Two topographic sheets on a scale of 1–20 000 have been plotted of Marthas Vineyard and the adjacent islands of Chappaquiddick and No Man's Land. The Survey developed many interesting facts in relation to the wearing away of beaches and the formation of new shoals. This topographical work supplements a survey previously made in 1887 and 1888.

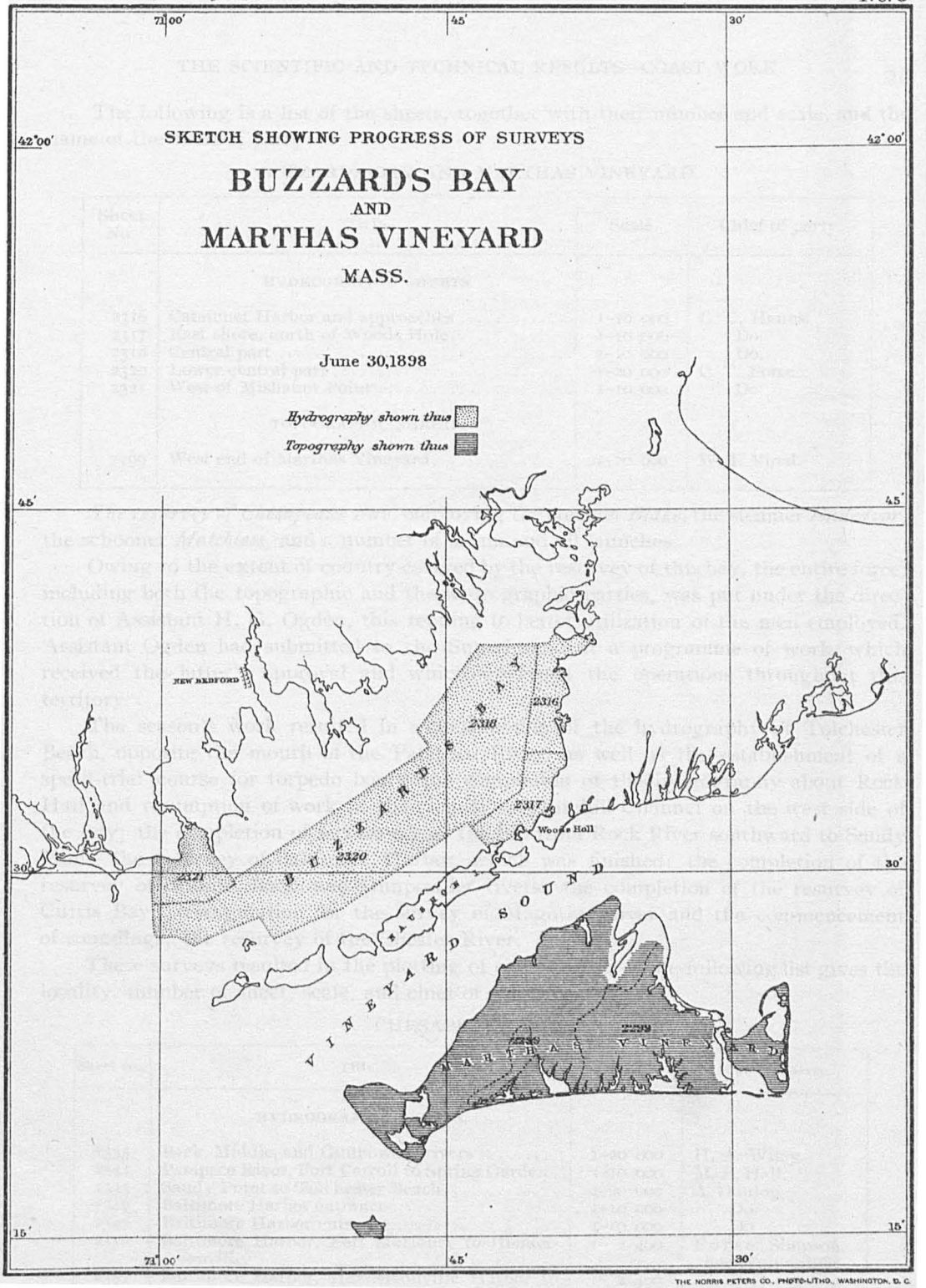
SKETCH SHOWING PROGRESS OF SURVEYS

BUZZARDS BAY
AND
MARTHAS VINEYARD
MASS.

June 30,1898

Hydrography shown thus

Topography shown thus



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The following is a list of the sheets, together with their number and scale, and the name of the chief of party:

BUZZARDS BAY AND MARTHAS VINEYARD.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2316	Cataumet Harbor and approaches	1–10 000	G. C. Hanus.
2317	East shore, north of Woods Hole	1–10 000	Do.
2318	Central part	1–10 000	Do.
2320	Lower central part	1–20 000	C. T. Forse.
2321	West of Mishaum Point	1–10 000	Do.
	TOPOGRAPHIC SHEETS.		
2299	West end of Marthas Vineyard	1–20 000	W. I. Vinal.

The resurvey of Chesapeake Bay, employing the steamer *Blake*, the steamer *Endeavor*, the schooner *Matchless*, and a number of steam and oil launches.

Owing to the extent of country covered by the resurvey of this bay, the entire force, including both the topographic and the hydrographic parties, was put under the direction of Assistant H. G. Ogden, this tending to better utilization of the men employed. Assistant Ogden had submitted to the Superintendent a programme of work, which received the latter's approval and which governed the operations throughout this territory.

The season's work resulted in a continuation of the hydrography of Tolchester Beach, opposite the mouth of the Patapsco River, as well as the establishment of a speed-trial course for torpedo boats; the completion of the hydrography about Rock Hall and resumption of work in the vicinity of Craighill Channel on the west side of the bay; the completion of section across the bay from Rock River southward to Sandy Point; the resurvey of Baltimore Harbor, which was finished; the completion of the resurvey of Middle, Back, and Gunpowder rivers; the completion of the resurvey of Curtis Bay; triangulation for the survey of Magothy River and the commencement of soundings; the resurvey of the Chester River.

These surveys resulted in the plotting of eight sheets. The following list gives the locality, number of sheet, scale, and chief of party:

CHESAPEAKE BAY.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2335	Back, Middle, and Gunpowder rivers	1–20 000	H. A. Wiley.
2344	Patapsco River, Fort Carroll to Spring Garden	1–10 000	M. E. Hall.
2345	Sandy Point to Tolchester Beach	1–20 000	A. Dunlop.
2346	Baltimore Harbor entrance	1–10 000	Do.
2347	Baltimore Harbor entrance	1–10 000	Do.
2356	Baltimore Harbor, Fort McHenry to Hendersonville.	1– 2 400	Forse, Simpson, and Wainwright.
2357	Baltimore Harbor, Hendersonville Harbor to Light street.	1– 2 400	Do.
2375	Chester River,	1–20 000	W. I. Vinal.

The topographic results are of equal magnitude. Five large parties were in the field during the entire season, plotting the shore lines and the interior topography for several miles in. As the original survey had been made some fifty years previous, the great changes that had ensued since that time in regard to cultural features and roads made it necessary to disregard old surveys in the prosecution of the new work. Hence the new plottings are, to all intents and purposes, a complete new survey of the territory covered.

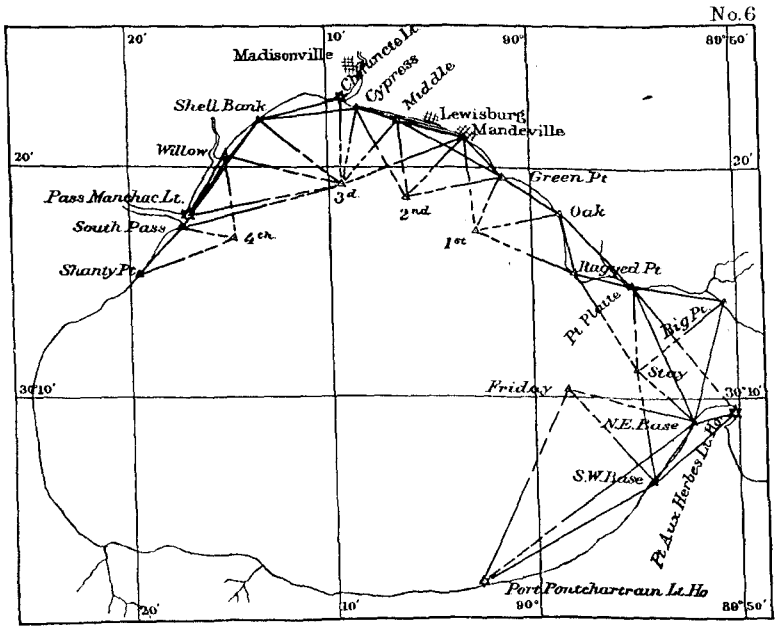
All of the new sheets were plotted on a scale of 1–10 000 or 1–20 000, and are as follows:

CHESAPEAKE BAY.

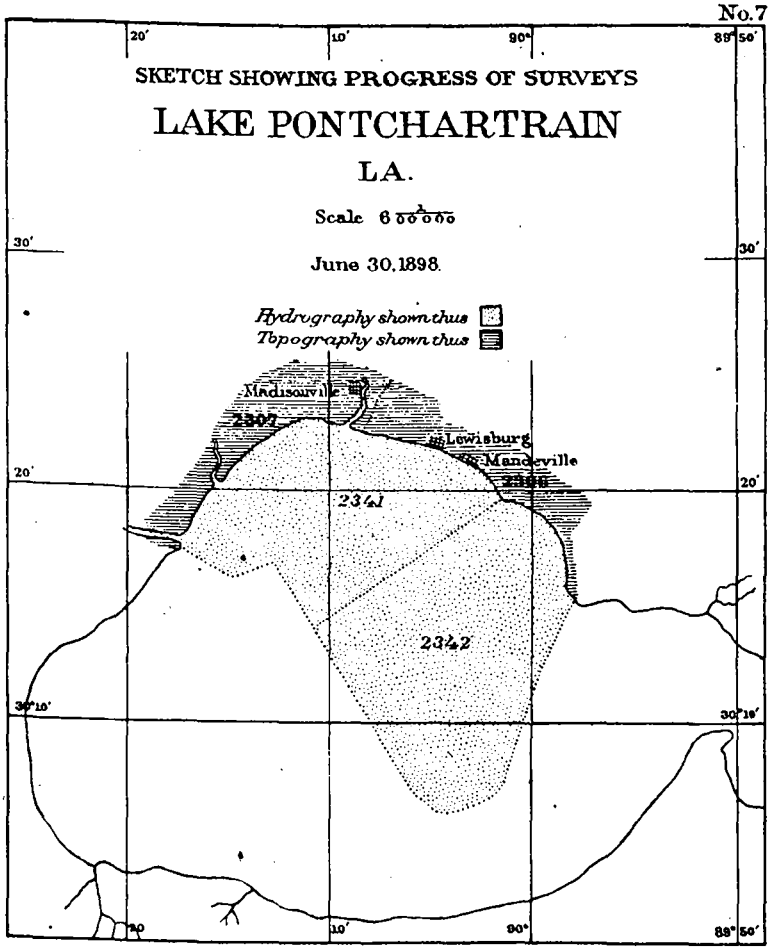
Sheet No.	Title.	Scale.	Chief of party.
	TOPOGRAPHIC SHEETS.		
2269	Patapsco River, vicinity of Baltimore	1–10 000	O. B. French and J. W. Donn.
2286	Patapsco River, Magothy River to Stony Creek.	1–20 000	H. G. Ogden and O. B. French.
2288	Head of Corsica River	1–20 000	J. A. Flemer.
2291	Chester River, from Long Point to Deep Point.	1–20 000	Do.
2296	Mouth of Chester River to Still Pond	1–20 000	J. Nelson.
2308	Bush River to Back River	1–20 000	Wm. Bowie.
2326	Patapsco Neck, below Colgate Creek	1–20 000	Do.

The combined result of this topographic and hydrographic work is a complete and accurate survey of the shores of Chesapeake Bay in the region of Baltimore and approaches, as already shown (cut No. 4).

A commencement has been made on the resurvey of the mouth of the Susquehanna, the Northeast, and the Elk rivers, the three main tributaries of the bay from the north.



Lake Pontchartrain Triangulation



The resurvey of Lake Pontchartrain has been completed (cuts Nos. 6 and 7).

Besides the preliminary work in triangulation and azimuth operations, a number of tide gauges have been established at favorable points, as well as a reconnoissance for the continuation of the survey in Lake Maurepas.

The following sheets were made by this party:

LAKE PONTCHARTRAIN.

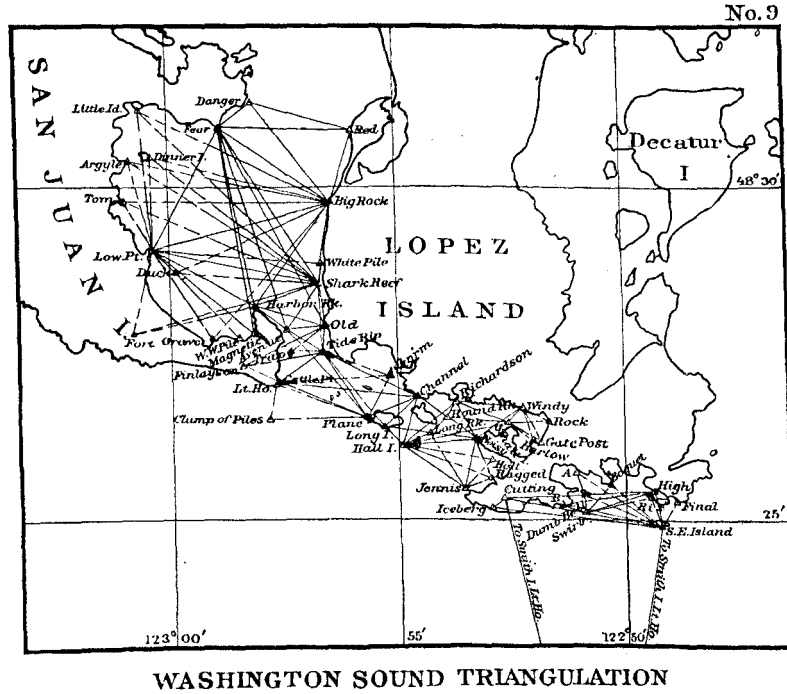
Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2341	Mandeville to Pass Manchac	1–20 000	P. A. Welker.
2342	Ragged Point to Mandeville	1–20 000	Do.
	TOPOGRAPHIC SHEETS.		
2306	Ragged Point to Chefuncte River	1–20 000	P. A. Welker.
2307	Chefuncte River to Pass Manchac	1–20 000	Do.

The resurvey of San Francisco Bay was conducted, on its hydrographic side, by the steamers *Gedney* and *McArthur*, and on its topographic side by two parties under the general direction of Assistant A. F. Rodgers, in charge of the San Francisco suboffice (cut No. 8). The portions of this bay thus far taken up are the extreme northern end, including San Pablo Bay, and the regions to the southward of San Francisco. They were originally surveyed as far back as 1853 and 1857. As in the case of Chesapeake Bay, the earlier surveys were of little value so far as contouring was concerned, and the results may therefore be said to provide an entirely new survey of these shores. The following original sheets, covering this work, were forwarded to this Office:

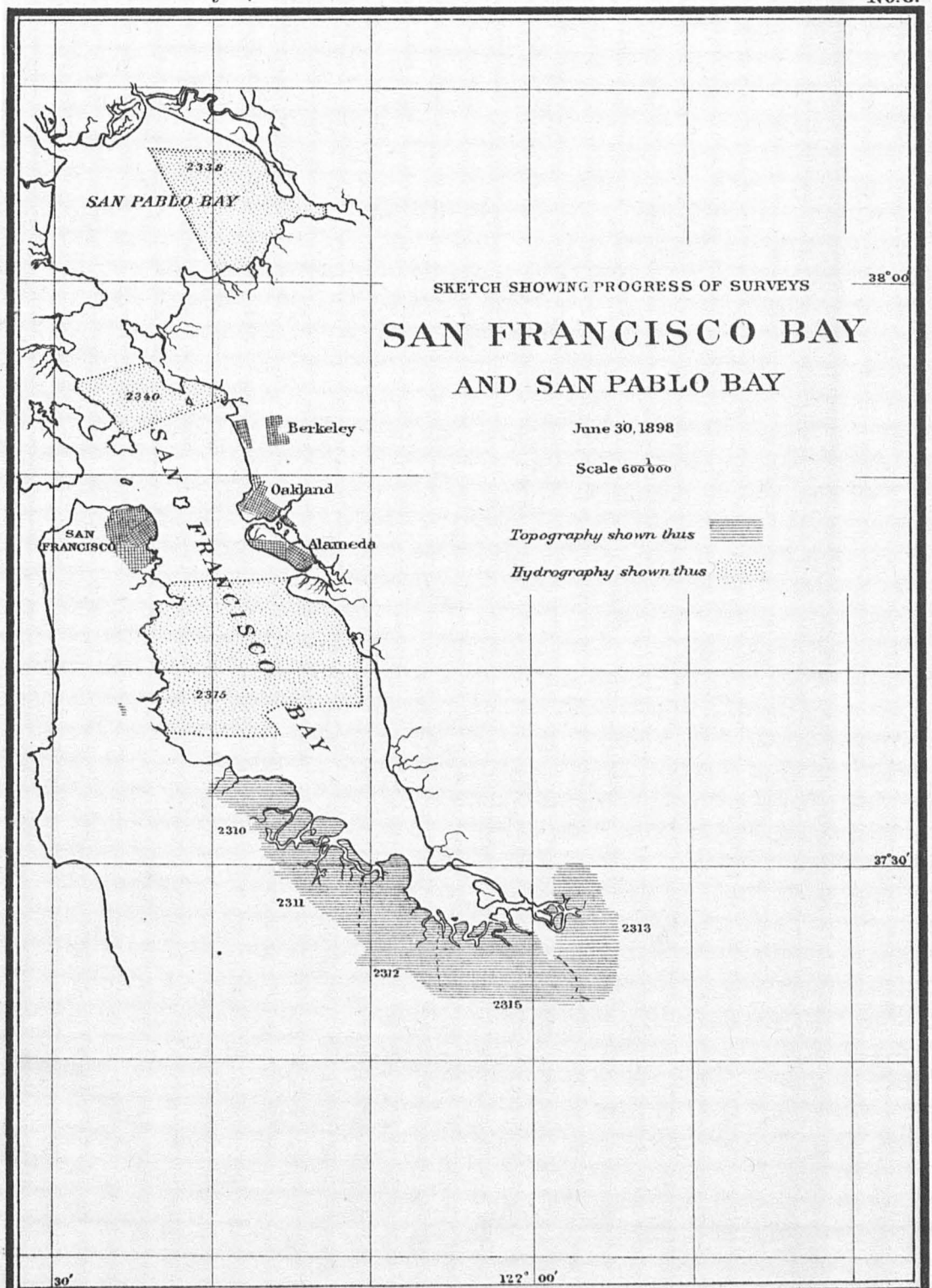
SAN FRANCISCO BAY.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2315	Point Avisadera to San Bruno	1–20 000	J. M. Helm.
2338	San Pablo Bay, Penole Point to Karquines Strait.	1–20 000	A. P. Osborn.
2340	Simptons Point to California City Point	1–10 000	Do.
	TOPOGRAPHIC SHEETS.		
2310	San Mateo to San Carlos	1–10 000	A. F. Rodgers and F. Westdahl.
2311	San Carlos to Menlo Park	1–10 000	Do.
2312	Menlo Park to Mountain View	1–10 000	Do.
2313	Alviso to Warm Springs	1–10 000	F. Morse and F. Westdahl.
2315	Mountain View to Alviso	1–10 000	A. F. Rodgers and F. Westdahl.

No. 9



WASHINGTON SOUND TRIANGULATION



SKETCH SHOWING PROGRESS OF SURVEYS

SAN FRANCISCO BAY

AND SAN PABLO BAY

June 30, 1898

Scale $\frac{1}{600\,000}$

Topography shown thus

Hydrography shown thus

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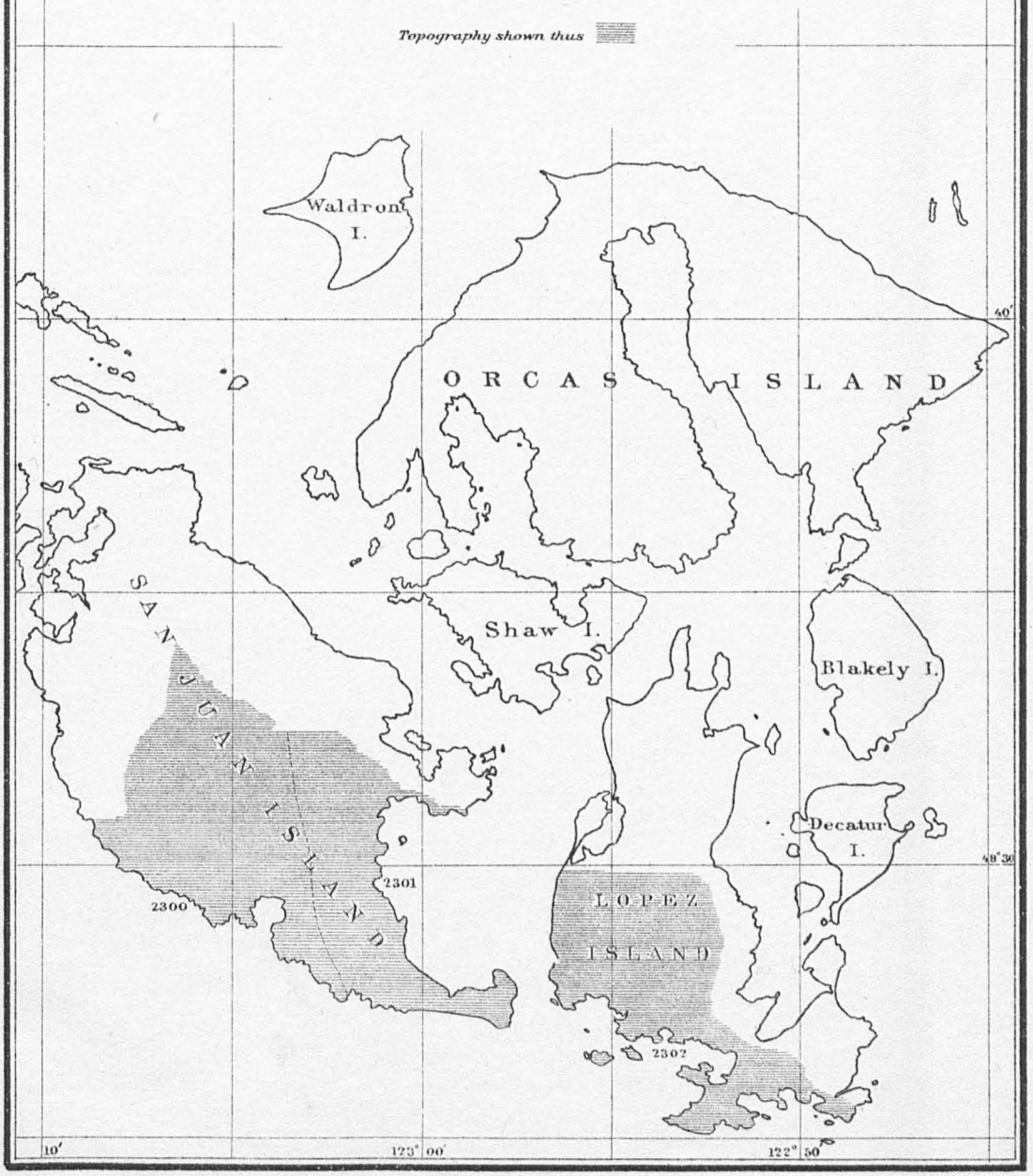
SKETCH SHOWING PROGRESS OF SURVEYS

WASHINGTON SOUND

WASHINGTON

June 30, 1898

Topography shown thus



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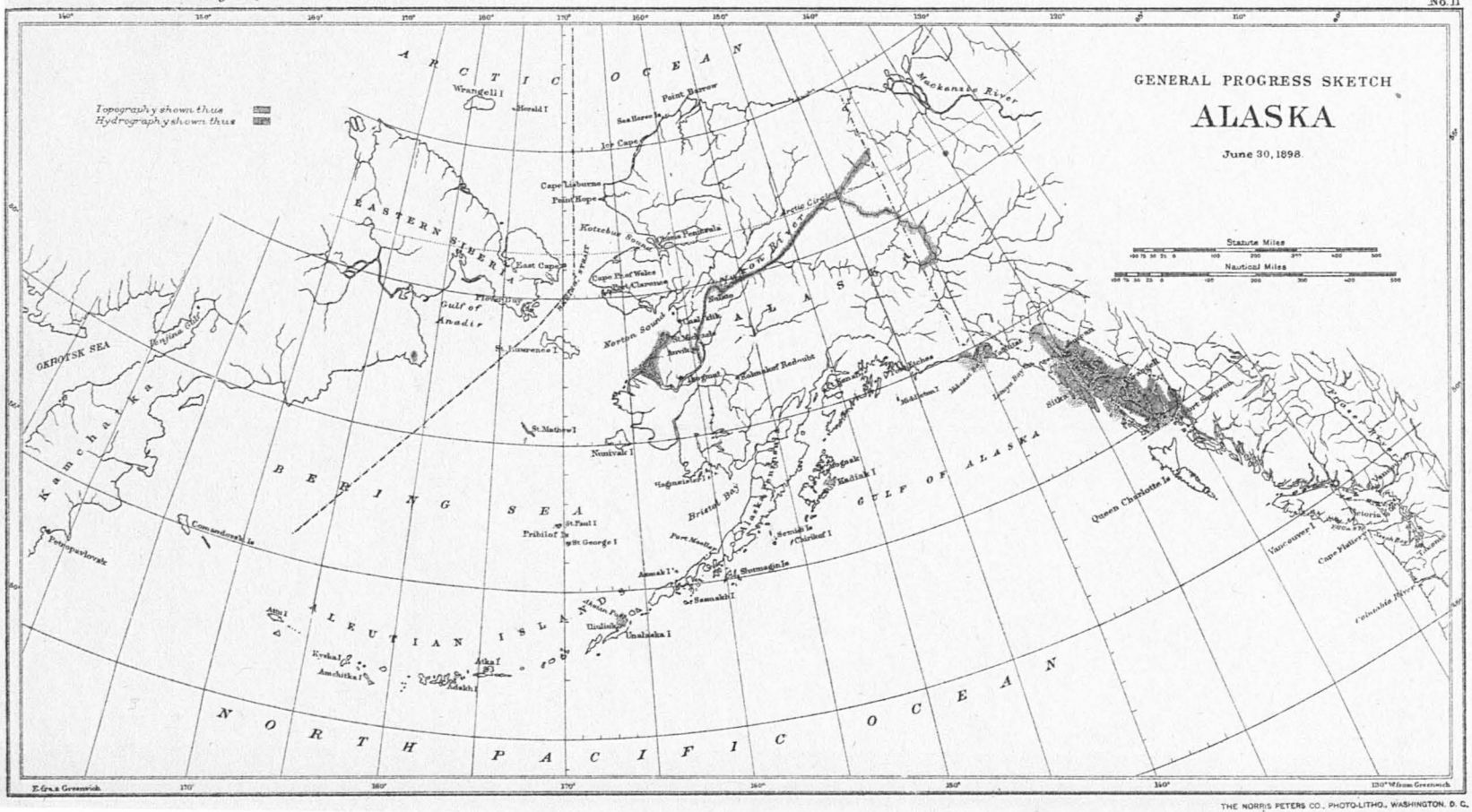

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The survey of Washington Sound, Oregon, has resulted in the completion of its triangulation and the preparation of three topographic sheets—one of the unsurveyed portion of Lopez Island and the others of the unsurveyed portions of San Juan Island (cuts Nos. 9 and 10).

Alaska.—The recent rapid development of the Territory of Alaska, due in a great measure to the gold discoveries in the Yukon region, the consequent large influx of population, and increase in the carrying trade thither, were regarded of such importance as to call for special surveys on that coast. To that end an appropriation of $100 000 was made by Congress in January, 1898. At the opening of navigation in the spring three parties were fitted out and sent to Alaska. One of these was directed to make an exploration and survey of the delta of the Yukon River (cut No. 11), the chief waterway to the interior, with a view to the discovery of a better and deeper channel into the river than that now used. At present not more than 5 feet of water can be carried through what is known as the Aproon Mouth of the river, the only channel used by vessels, while after getting in the river a depth suitable for ocean-going craft is found.

The second party was directed to make a survey of the coast in the vicinity of the Copper River, which it is hoped will supply a base for an all-American route to the Upper Yukon. The third party was to make a topographical reconnoissance of the country adjacent to the Chilkoot and Chilkat passes, this work having an important bearing on the question of the boundary line between Alaska and the British possessions.

Hydrographic surveys along the southeastern coast of Alaska have made excellent progress, and charts of the localities most frequented by vessels are being perfected as rapidly as possible.

The new method of photo-topographic surveying, used so extensively by the surveyor-general of Canada and in surveys of several foreign countries, has been applied to the mountainous and well-nigh untraversable regions of southeastern Alaska, where the encroachments of the sea have formed an archipelago, and along Lynn Canal leading up to White and Chilkoot passes. The methods used have been fully described by the chief of the Lynn Canal party, Assistant Flemer, in Appendix No. 10, Coast and Geodetic Survey Report for 1897, and entitled "Photo-topographic methods and instruments."

A word should be said in passing of the unusual difficulties of taking exact surveys along the rugged and stormy coast of Alaska. Some mishaps were bound to occur, but, fortunately, no permanent loss has resulted therefrom. One launch was wrecked, but by extraordinary effort recovered and saved for future use. Many torrential streams, which pour down the steep sides of the continental range, caused great annoyance and almost unsurmountable difficulties. Hardships were undergone by the assistants and their parties, as a matter of course, but they encountered many dangers, waded the icy streams, and pursued their various operations in an arctic climate without complaint and with a care and accuracy which have greatly redounded to the value of the surveys executed.

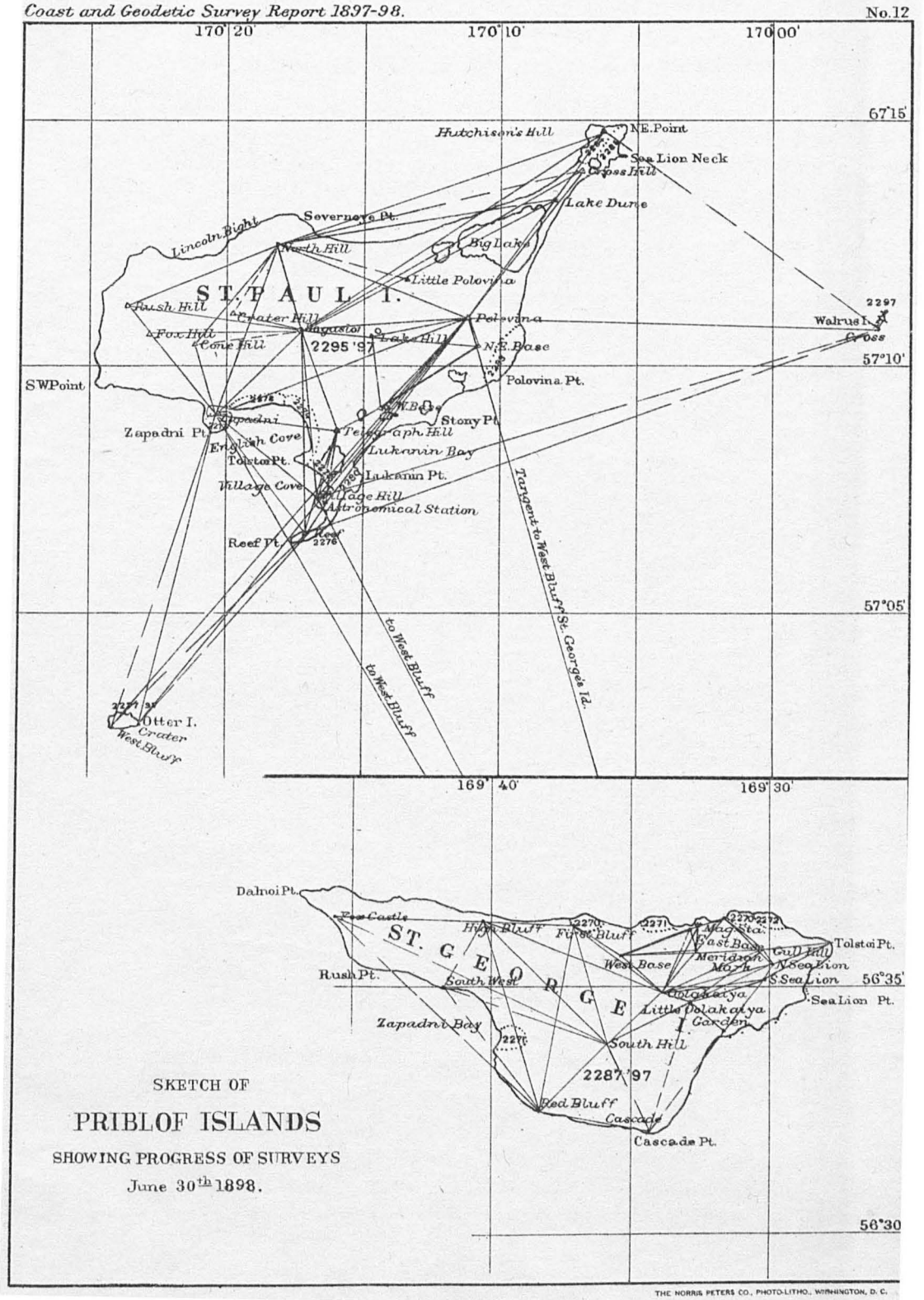
In the hydrographic work the soundings were carried out to great depths and developed extraordinary features in the sea bottoms, such, for example, as the deep hole discovered off Cape Edgecumbe, going down some 530 fathoms. In this work the most improved devices, such as the Thompson sounding machine and the deep-sea recorder, were utilized.

The work of last year was not in the vicinity of that undertaken in 1889 to 1890 by Messrs. McGrath and Turner, but was devoted particularly to the coast lines where recent commercial developments have made more exact information essential. The earliest work done were the isolated explorations and survey of Assistant G. Davidson in 1867 along the Albatross Bank and the Aleutian Islands.

As to the number of original sheets, the results have been exceedingly satisfactory. Sheet have been turned into the Office on a scale of 1–20 000, 1–10 000, and 1–2 000, the latter being for the most part of the seal rookeries of the Pribilof Islands (cut No. 12). Below is a list of all the sheets plotted during the year in the Alaska division:

ALASKA.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2319	Off Salisbury Sound and west of Kruzof Island.	1–60 000	E. K. Moore.
2333	Chatham Strait and Frederick Strait	1–80 000	Do.
2334	Murder Cove and Bay of Pillars	1–10 000	Do.
2336	Haggett Bay, Gut Bay, and Red Bluff Bay, Chatham Strait.	1–10 000	Do.
	TOPOGRAPHIC SHEETS.		
2271	Zapadni Rookery, St. George Island	1–2 000	W. W. Duffield.
2272	North Rookery, St. George Island	1–2 000	Do.
2273	East Rookery, St. George Island	1–2 000	Do.
2274	Tolstoi Rookery, St. Paul Island	1–2 000	Do.
2275	Sketch of vicinity of Mount St. Elias	1–400 000	E. B. Latham.
2276	Reef, Gorbatch, and Ardiguen rookeries, St. Paul Island.	1–2 000	W. W. Duffield.
2277	Zapadni Rookery, St. Paul Island	1–2 000	Do.
2278	Little Zapadni and Zapadni Reef rookeries, St. Paul Island.	1–2 000	Do.
2279	Lagoon Rookery, St. Paul Island	1–2 000	Do.
2280	Lukanin and Kitovi rookeries, St. Paul Island	1–2 000	Do.
2283	Polovina, Polovina Cliffs, and Little Polovina rookeries, St. Paul Island.	1–2 000	Do.
2284	Vostochni Rookery, St. Paul Island	1–2 000	Do.
2285	Morjovi Rookery, St. Paul Island	1–2 000	Do.
2287	St. George Island, Bering Sea	1–20 000	Do.
2295	St. Paul Island, Bering Sea	1–20 000	Do.
2297	Otter Island and Walrus Island, Bering Sea	1–20 000	Do.
2298	Chatham and Frederick sounds	1–80 000	E. K. Moore.
2303	Bay of Pillars, Chatham Strait	1–20 000	Do.
2304	North end of Sitka Sound	1–20 000	Do.
2305	Outside coast from Cape Edgecumbe to Khaz Bay.	1–60 000	Do.
2314	Buildings at Dyea and wharves at Skagway	1–10 000	A. F. Rodgers.



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Miscellaneous charts.—The following sheets, resulting from work in various localities, have also been turned into the Office as part of the year's operations:

ATLANTIC COAST.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2303	Speed Course, Hudson River, near Poughkeepsie	1–20 000	W. J. Barnette.
2311	Examination of Gloucester Harbor	1–10 000	Do.
2312	Break in the Haulover, Nantucket Island	1–10 000	Do.
2313	Montauk Point to Block Island	1–40 000	Do.
2337	St. Johns River, rocks off Jacksonville	1–5 000	J. T. Pillsbury.
2339	Grand Bay, Mississippi Sound examination	1–40 000	F. Swift.
2343	Brunswick Bar, Georgia	1–1 200	H. L. Marindin.
2348	Dry Tortugas Harbor, southern part	1–10 000	W. J. Barnette.
2349	Dry Tortugas Harbor, northern part	1–10 000	Do.
2350	Dry Tortugas Harbor, approaches (no work on this chart).	1–10 000	Barnette & Davis.
2351	Dry Tortugas Harbor, Garden Key Channel	1–600	A. H. Davis.

PACIFIC COAST.

Sheet No.	Title.	Scale.	Chief of party.
	HYDROGRAPHIC SHEETS.		
2314	Bank south of Santa Barbara	1–40 000	A. P. Osborn.
	TOPOGRAPHIC SHEETS.		
2300	San Juan Island, Dead Mans Bay to Eagle Point.	1–10 000	J. J. Gilbert.
2301	San Juan Island, Pear Point to Eagle Point	1–10 000	Do.
2302	Part of Lopez Island, Big Rock to Point Calville.	1–10 000	Do.

MISCELLANEOUS.

Sheet No.	Title.	Scale.	Chief of party.
	TOPOGRAPHIC SHEETS.		
2309	Salt Lake base line	1–10 000	W. Eimbeck.
2267	Sketch of Mount Mansfield	1–10 000	A. T. Mosman.

Fish Commission charts.—The following hydrographic sheets and tracings are filed in the archives and registered. They are not the work of the United States Coast and Geodetic Survey, however, but that of the United States Fish Commission steamer *Albatross*. They should be regarded more as the result of reconnoissance than completed surveys:

Sheet No.	Title.	Scale.	Chief of party.
2322	Karluk, Kadiak Island	1-10 000	J. F. Moser.
2323	Uganuk Bay, Kadiak Island	1-20 000	Do.
2324	Larseris Bay, Kadiak Island	1-10 000	Do.
2325	Ayak Bay, Kadiak Island	1-10 000	Do.
2326	Klawak Inlet, Prince of Wales Island	1-20 000	Do.
2327	Hunters Bay, Prince of Wales Island	1-10 000	Do.
2328	Orca Inlet and part of Cordova Bay, Prince William Sound.	1-20 000	Do.
2329	Anchorage Bay, in Chignik Bay	1-20 000	Do.
2330	Chignik Bay	1-80 000	Do.
2331	Cordova Bay, northeast side	1-80 000	Do.
2332	Red Fish Bay, Baranof Island	1-5 000	Do.

(*b*) DETAILS OF FIELD OPERATIONS.

EASTERN DIVISION.

Buzzards Bay (Cut No. 5).—The resurvey of Buzzards Bay, Massachusetts, at the beginning of the fiscal year, was being carried on by the party in the schooner *Eagre*, under command of Lieut. G. C. Hanus, U. S. N., assistant, Coast and Geodetic Survey; on July 5 the steamer *Endeavor*, under command of Lieut. Commander C. T. Forse, U. S. N., assistant, Coast and Geodetic Survey, was ordered to New Bedford, to assist in the work; and the joint labors of these two parties completed the undertaking on October 26. The *Eagre* finished the work on the eastern side of the bay, and developed the dredged channel leading up to the New Bedford wharves.

The *Endeavor*, in its passage north, making examinations for reported changes, ran a series of soundings between Fenwick Island light-ship and Five Fathom Bank light-ship. The work assigned to the steamer in the resurvey of the bay was included in two projections, one extending from Dumpling Rock light-house to Gooseberry Neck, on a scale of 1–10 000, and the other extending from Cormorant Rock to Gooseberry Neck, on a scale of 1–20 000. Great difficulty was experienced in running the lines of soundings in the first projection, on account of the irregularity in the set of the currents, strong winds, and rough seas, together with dense fogs. The work on the second projection was delayed to some extent by the same causes. On completion of the work in Buzzards Bay the vessels were transferred to Baltimore for cooperation in the Chesapeake Bay work and for extensive repairs to the machinery of the *Endeavor*.

At the beginning of the fiscal year the parties of Assistants W. C. Hodgkins and W. I. Vinal were already engaged in a topographical survey of Marthas Vineyard and adjacent islands. Three projections, on a scale of 1:20 000, had been laid out for the work, one of which included Chappaquiddick Island, and another the island of No Mans Land. The shore line, except that of the south beach, with adjacent detail,

including the towns of Vineyard Haven, Cottage City, and Edgartown, had been previously surveyed by Assistant Vinal, in 1887, and Assistant J. W. Donn, in 1888. Copies of the former surveys were furnished, in order to expedite the work.

The survey of the western half of Marthas Vineyard, and of the island of No Mans Land, was assigned to Assistant Hodgkins; the eastern half of Marthas Vineyard and Chappaquiddick Island were assigned to Assistant Vinal.

Owing to unfavorable weather, and the dense undergrowth, which covered a large portion of the island, progress was necessarily slow, much traverse work having to be done. On Chappaquiddick Island the conditions were found more favorable, much of the land being clear.

The principal changes discovered in the progress of the survey of Marthas Vineyard were along the south beach, which appears to be wearing away. This beach is narrow and quite steep, and is not protected by outside reefs. The most noticeable change is in the narrow strip separating Katama Bay from the ocean. Besides a general change in the position of the entire beach, the direct or south inlet, shown by former surveys, was found to be closed. The inlet found by Mr. Vinal was a canal-shaped passage between an outer shoal and the fast land of Chappaquiddick Island. Considerable changes were found at the north end of Chappaquiddick Island, and what was formerly called Skiffs Islands is now a shoal, covered at all stages of the tide.

Assistant Hodgkins's party remained in the field until November, 1897; resumed work in April, 1898, and was still engaged in this duty at the close of the fiscal year. Assistant Vinal's party closed operations in this section on November 17, 1897.

Chesapeake Bay (Cut No. 4).—In pursuance of the policy of the Survey to use all available force to bring to the earliest possible conclusion surveys of localities of prime importance, the resurvey of Chesapeake Bay was prosecuted vigorously throughout the year. Every vessel of the Survey that could be spared for this enterprise was engaged, and there was no cessation of work because of inclemency of season, harbor surveys being continued when winter storms put a stop to outside work.

At the beginning of the fiscal year the steamer *Blake*, under command of Lieut. Commander A. Dunlap, U. S. N., Assistant, Coast and Geodetic Survey, was at Baltimore, Md., undergoing repairs. On July 17 the vessel proceeded to Tolchester Beach, Maryland, and work was continued in the hydrography of Chesapeake Bay, off the Eastern Shore, and opposite the mouth of the Patapsco River. This having been finished on the 19th of August, the headquarters were changed to Rock Hall, Md., and work in that locality was continued until finished, although interrupted by operations undertaken in connection with the speed trials of torpedo boats, which occupied ten working days.

Hydrography.—On the 13th of September the hydrography in the vicinity of Rock Hall and Love Point having been finished, work was resumed in the vicinity of Craighill Channel, on the west side of the bay.

The work was pushed as much as possible, with a view to the completion of the section across the bay from Rock River southward to Sandy Point before the winter should set in, and in addition to the two launches attached to the *Blake*, the use of steam launch No. 25, with officers and men from the steamer *Endeavor*, was obtained to aid in the work; oil-burning launches Nos. 30 and 32, from the *Endeavor* and *Eagre*, were also assigned for use in event of the steam launches breaking down, which occasionally

happened. The weather became so unfavorable, however, that the completion of the work was prevented, and Lieutenant-Commander Dunlap was obliged to suspend operations on December 18, the vessel proceeding to Baltimore for repairs. While the repairs were in progress the party was engaged in resurveying the eastern part of the inner basin of Baltimore Harbor, a part of which was finished. On the completion of repairs the vessel was sent to Key West for the execution of special hydrographic work for the Navy Department.

While the *Endeavor* was undergoing repairs in Baltimore the party on board began the hydrographic resurvey, on a large scale, of the inner harbor of Baltimore. Lieutenant-Commander Forse was relieved from the command of the vessel on February 3 by Lieut. E. Simpson, U. S. N., Assistant, Coast and Geodetic Survey, and on April 2 the latter was detached from the Survey and the command of the vessel was transferred to Assistant D. B. Wainwright, Coast and Geodetic Survey, who continued the work to the close of the fiscal year. The resurvey of the inner harbor of Baltimore was completed on June 7, besides a space left unfinished by the *Blake's* party. The repairs to the *Endeavor* being completed, the vessel was then moved to Tolchester Beach to continue the resurvey of the bay north of that point, and was engaged in that work at the close of the fiscal year.

The hydrographic party on board the schooner *Eagre* commenced work in the vicinity of Baltimore on October 5, and the resurvey of Middle River, Back River, and Gunpowder River was completed on December 9.

Work on the Patapsco River, from Fort Carroll to Spring Garden, was begun on January 14 and prosecuted until April 2, when the vessel was taken to the Washington Navy-Yard and laid up. Lieut. G. C. Hanus was detached from command on November 1, turning the vessel over to Ensign Henry A. Wiley, U. S. N., Assistant, Coast and Geodetic Survey, who in turn was relieved by Lieut. M. E. Hall, U. S. N., Assistant, Coast and Geodetic Survey. Lieutenant Hall was detached on April 4, and on May 16 Assistant H. L. Marindin, Coast and Geodetic Survey, was placed in charge of the vessel and party. In the latter part of May work was resumed near Baltimore, and by June 30 the resurvey of Curtis Bay and part of the Patapsco River below Fort Carroll had been completed.

On May 16, 1898, Mr. John B. Boutelle, United States Coast and Geodetic Survey, was directed to organize a party on the schooner *Matchless* for hydrographic and topographic work in Chesapeake Bay. The vessel proceeded to the Magothy River, and after a sufficient number of points had been determined by triangulation for the hydrography and topography, the party commenced soundings on June 25. The work was in progress at the end of the fiscal year.

The hydrographic party in charge of W. I. Vinal, Assistant, Coast and Geodetic Survey, began the survey of the Chester River on June 13, 1898, and was carrying on the work at the close of the fiscal year. The equipment assigned to this party for the execution of the work consisted of a steam launch and pulling boats. A violent storm on June 25 destroyed nearly all the signals which had been erected for the use of this party, and several days had to be devoted to repairing the damage sustained.

Current observations.—At the beginning of the fiscal year, Lieut. E. H. Tillman, U. S. N., Assistant, Coast and Geodetic Survey, with the hydrographic party on

board the schooner *Matchless*, was engaged in the occupation of stations for current observations in Chesapeake Bay, near the entrance to Baltimore Harbor.

Work at Primary Station No. 2, near Sandy Point light-house, was completed on July 22. Secondary Station No. 1, about 3·1 miles south 59° east (true) from Greenbury Point light-house, was occupied between July 28 and August 12. Secondary Station No. 2, 6·3 miles south 34° west (true) from Bloody Point Bar light-house, was occupied between August 15 and August 28. The number of observations at each station was as follows:

Primary Station No. 2	638
Secondary Station No. 1	350
Secondary Station No. 2	288
Total	1 276

Lieutenant Tillman states that April, May, June, and July are the best months for current observations in these waters. The tidal currents, as well as the tides, at the localities of observation were found to be greatly affected by continuous winds of even moderate force from a northerly or southerly direction. Easterly or westerly winds had very little effect unless of long duration and great force.

The command of the vessel and the direction of work having been transferred to R. L. Faris, Assistant, Coast and Geodetic Survey, on September 2, the *Matchless* proceeded to Primary Current Station No. 3, near Thomas Shoal light, where a series of observations was made through a period of one lunar month, or about 29¾ days. At this station a copper cylinder was substituted for the inverted conical wooden float previously used on current pole. The cylinder has a decided advantage over the wooden float, both in maintaining its adjustment for depth, also because of the reduction of the length of the current pole above water, thus lessening the effect of wind and waves. The scheme provided for observations being made hourly throughout the twenty-four hours of the day, but care was taken to have observations as free from the effects of wind as possible, and no observations were taken during the prevalence of very rough seas. Observations were completed at Station No. 3 on October 1. Secondary Current Station No. 4, opposite James Point, was occupied between October 4 and October 19, and on the 22d the vessel began observations at a primary station off Plum Point, Maryland. This station was abandoned, however, because of heavy weather, and on October 28 the vessel proceeded to occupy Secondary Station No. 5, off the entrance of the Patuxent River. Observations at Station No. 5 were concluded on November 11, and the vessel proceeded to Baltimore.

During the current observations a tide station, with self-registering gauge and tide staff, was maintained at Sparrows Point, Maryland.

In the records the exact location of each station was given, and the elaborate notes contain complete data as to conditions of the weather, sea, and tides.

Topography.—The topographical resurvey of the shores of Chesapeake Bay was pressed with the same vigor that characterized the hydrographic work in the same section. The relations of these two classes of operations being so intimate, a common direction for their prosecution insured the most favorable results and economic utilization of the forces employed, and to provide for this, Assistant H. G. Ogden received

instructions from the Superintendent giving him general charge of the hydrographic and topographic parties operating in the bay in the summer of 1898, a programme of work for the season having been previously submitted by Assistant Ogden and approved by the Superintendent.

On July 13, 1897, Mr. William Bowie, aid, Coast and Geodetic Survey, took the field for the execution of the topography (and incidental triangulation) along the north bank of the Patapsco River, Maryland, between North Point and Baltimore. By the close of the season, on November 30, the survey of the shore line of a portion of the north bank of the Patapsco from Bear Creek to Colgate Creek, and the entire shore line of Humphreys Creek, Bear Creek, Back River, and Middle River had been completed. The topography of the interior of that portion of the neck of land lying between Back River, Bear Creek, the Patapsco River, and Colgate Creek was also done. A naphtha launch, transferred to Mr. Bowie from the steamer *Blake*, was found of great service in transporting the party. The shore line of Middle River was furnished to Lieut. G. C. Hanus for use in the hydrographic work under his charge. Blue prints of the old topography of the bay were furnished by the Office, but were not used except as a guide for the work. Owing to extensive changes in the streams, marshes, and in the interior topography, Mr. Bowie states that the old work can be used but little in the survey, and he recommends that it be not put in the field projections.

The party under Assistant H. G. Ogden took the field on July 22, 1897, for continuation of the resurvey of the shores of Chesapeake Bay. The party was organized at Fairview, the mouth of Rock Creek, and work was prosecuted until September 24 by Assistant Ogden, who was then obliged to leave the field on account of illness. The work was continued under Mr. H. F. Flynn's direction until October 14, when Assistant O. B. French took charge of the party, working under direction of Assistant Ogden until October 21, and afterwards assuming full charge of the operations.

The work executed by October 21 extends from Gibson Island and the north shore of Magothy River along the bay northward to Bodkin Point and thence up the Patapsco River to include Rock Creek. It reaches back from the river to the country road from Baltimore, about 3½ miles from the shore, practically embracing the limits of the original survey of fifty years ago, and also the shore line to Hawkins Point. The topography of Tick Neck and the shore line of Stony Creek and part of Curtis Creek were completed between October 14 and October 21. Owing to extensive changes in the shore line, cultural features, and roads it was found impracticable to make any use of the old surveys in the new work.

On October 22 operations were begun above Rock Creek and continued to and including Stony Creek. The party was then moved to Baltimore and work taken up on Curtis Creek. Owing to the requirements of the hydrographic parties, the work after October 30 was confined to the shore line and such topography as could be readily reached from the shore. The whole of Curtis Creek and its branches was surveyed on the same sheet used by Assistant Ogden, scale 1–20 000; but the remainder of the work was done on a sheet which covers the upper part of the Patapsco River and includes a portion of the city of Baltimore. This sheet is on a scale 1–10 000, and contains the shore line from Hawkins Point to Curtis Creek, from Curtis Creek to very nearly the mouth of Gwynns Falls, including about 2 miles of the mouth of the Patapsco; thence, with the exception of about half a mile at the head of Middle Branch, it embraces all

the shore line to Fort McHenry, and on the northeast side of the Patapsco River from Lazaretto light-house to Colgate Creek, where it joins the work executed by Mr. Bowie. The work was closed on December 6.

A naphtha launch belonging to the steamer *Endeavor* was assigned to Mr. French for the transportation of the party and found very useful.

The party in charge of Assistant J. A. Flemer at the beginning of the fiscal year was engaged in the topographical survey of Chester River (cut No. 4). Working from Bogles Landing, East Neck Island, and using a sailboat for transportation, work was continued until the eastern fringe of topography had been completed to Robin Cove, below Holton Point, and the western strip to Piney Neck, in Lankford Cove. On August 6 the party moved to Earles Landing, at the mouth of Corsica River, from which locality the survey of the west fork of Lankford Bay was completed, the east fork surveyed to Kings Creek, the Chester River survey was continued to Deep Point, and Corsica River was surveyed to Centerville, near its head. The plane-table work was then checked, using triangulation points determined by Assistant F. W. Perkins. Comparison with former surveys showed such marked changes in shore line as to render necessary an entire resurvey of the localities embraced.

Field work was closed on December 4.

In pursuance of instructions, directing him to organize a party for work on the topographical resurvey of Chesapeake Bay and the triangulation incident thereto, Mr. John Nelson, Assistant, Coast and Geodetic Survey, proceeded to Tolchester Beach, Maryland, and commenced topographical operations at Mitchells Bluff on July 19, 1897. The work was carried northward to Fairlee Creek and southward to Swan Point, including Pooles Island, until August 24, when the party removed to Rock Hall, about 10 miles below Tolchester Beach. Topography was resumed on August 25 and continued until the lower half of the sheet was completed on September 10, joining the work of Assistant J. A. Flemer below Rock Hall.

The party then moved to Worton Manor Beach, on Worton Creek, and the triangulation was taken up in order to secure points for the continuation of the topography northward from Fairlee Creek. The topography was resumed on October 18 and the sheet was finished on November 24, when the party was disbanded and Mr. Nelson returned to Washington.

On June 21, 1898, Mr. J. W. Donn, extra observer, Coast and Geodetic Survey, took the field for the continuation of the topographical resurvey of Chesapeake Bay in the vicinity of Baltimore, and at the end of the fiscal year this work was in progress. The work assigned to Mr. Donn includes the topography of the approaches to the city of Baltimore, embracing the shores of the Patapsco River from Curtis Bay on the south and Colgate Creek on the northwest to the head of tide water.

The party under Mr. John B. Boutelle, whose hydrographic operations have been referred to, began the topographic work, in connection with the resurvey of the Magothy River, on June 27, and the work was in progress at the close of the fiscal year.

MIDDLE DIVISION.

Lake Pontchartrain (cuts Nos. 6 and 7).—The resurvey of Lake Pontchartrain was finished during this fiscal year by the party under the direction of Mr. P. A. Welker, Assistant, Coast and Geodetic Survey.

On the completion of the necessary preliminary triangulation and azimuth operations, subparties began hydrographic and topographic work about the middle of March, simultaneously at different points about the lake. The combined operations were pushed vigorously, and the survey closed on May 4. Tide gauges were established at West End, Pass Manchac light-house, and Chefuncte light-house; and the reading of mean low water on the Chefuncte light-house gauge was established by comparison with the Pass Manchac light-house gauge. A number of days were spent in removing the hydrographic signals that had been placed in the water of the lake, and which might be considered dangerous to navigation; one day was employed in making a reconnoissance with a view to continuing the survey through Pass Manchac into Lake Maurepas, and then on May 13 the party was disbanded.

WESTERN DIVISION.

San Francisco Bay.—The hydrographic operations of the resurvey of San Francisco Bay (cut No. 8) were carried on by the parties on board the steamers *Gedney* and *McArthur*. On the return, early in July, 1897, of the *Gedney*, Lieut. Commander A. P. Osborn, U. S. N., Assistant, Coast and Geodetic Survey, commanding, from Guadalupe Island, Mexico, where she had been engaged in the investigations and surveys described in the last Annual Report, the party on board that vessel resumed work on the hydrographic resurvey of San Francisco Bay from Angel Island to California City Point. On August 23 the steamer was detached for special examinations required for the Coast Pilot, but on her return she was employed in the resurvey of San Pablo Bay, from November 29 to January 15. On January 17 she was moved to Oakland Creek for repairs.

The resurvey of the section of San Francisco Bay between Point Avisadera and Point San Bruno was completed in the first half of the fiscal year by the party on the steamer *McArthur*, under the command of Lieut. J. M. Helm, U. S. N., Assistant, Coast and Geodetic Survey.

On February 1 Lieutenant Helm was placed in command of the *Gedney* to take charge of the repairs on that vessel and make preparations for the work contemplated about the mouth of the Yukon, and Lieut. Commander A. P. Osborn assumed command of the *McArthur* and resumed work on the resurvey of San Pablo Bay, which he had commenced with the *Gedney*. The breaking out of the war with Spain and the consequent detachment of the officers of the *McArthur* brought this work to a close on April 4.

San Pablo Bay.—The topographical resurvey of San Francisco and San Pablo bays by Assistant E. F. Dickins and Ferdinand Westdahl was continued under the general direction of Assistant A. F. Rodgers. Mr. Dickins began his field work on November 15 and completed the resurvey of San Pablo Bay on June 14. The section covered by the topographical work had been originally surveyed between 1853 and 1857, but was found so changed as to necessitate an entirely new survey, except so far as the contouring was concerned. This, however, had to be supplemented in some portions to complete the sheet. Unfavorable weather during the winter months delayed progress materially.

Mr. Westdahl commenced work at the extreme southern end of San Francisco Bay, immediately north of Alviso. During the months of November and December the

party was employed in the vicinity of Redwood City, and a survey was made of Redwood City Creek and its branches. The shore line of that portion of the bay was in December carried to a junction with the work in the vicinity of Point San Mateo, thus completing the shore-line resurvey southward from the city of San Francisco. In the early part of February a topographic sheet, making final connections between the several sheets of the resurvey of the southern shore of San Francisco Bay, was completed.

On May 21 Assistant Westdahl organized a party for the hydrographic survey of the southern end of San Francisco Bay, and was assigned a steam launch and pulling boat for use in his work. He remained in charge of these operations until June 30, when he was relieved by Mr. E. F. Dickins, Assistant, Coast and Geodetic Survey, and, taking command of the *Gedney*, he proceeded to outfit her for work on the coast of Washington.

Washington Sound.—At the beginning of the fiscal year Mr. J. J. Gilbert, Assistant, Coast and Geodetic Survey, was in the field engaged in the survey of Washington Sound. On the completion of the triangulation the topographical work was taken up. The first topographical sheet completed embraced all of the hitherto unsurveyed portion of Lopez Island and the many small islands along its shores. This sheet was commenced on July 8 and finished on August 9. Two projections were made to cover the unsurveyed portion of San Juan Island, one including all of Griffins Bay and around Cattle Point to Eagle Point, and the other extending northward from Eagle Point to Dead Mans Bay. By working on these two sheets alternately, as the weather conditions permitted, Mr. Gilbert was able to complete one of them on September 28 and the other on October 2. Field operations were then closed. This work completes the survey of the islands of Washington Sound, which was begun in 1889 and continued in 1894 and 1895.

DIVISION OF ALASKA.

(Cut No. 11.)

The extensive operations of the season of 1897 along the coast of southeastern Alaska were executed by the party attached to the steamer *Patterson*, under the command of Lieut. Commander E. K. Moore, U. S. N., Assistant, Coast and Geodetic Survey.

The operations of this party included hydrography, topography, tidal and current examinations, triangulation, and investigation of reported dangers to navigation, and were executed during the season in sections embraced between the Gulf of Georgia and Salisbury Sound.

The principal localities surveyed were the seaward sides of Kruzof and Chichagof islands, from Sitka Sound to Khaz Bay; the greater portion of Clarence Strait between Point Gardner and Cape Ommaney, and the western part of Frederick Sound to a connection with the work of 1889 and 1895.

At the beginning of the fiscal year the party was completing the outside work along the shore and off the southern end of Kruzof Island. The soundings were carried out to the 100-fathom curve, which was found at 15 miles off Salisbury Sound and 9 miles off Cape Edgecumbe. The inshore hydrography, running out 2 or 3 miles, was done with launches in the usual way, while that offshore was done with the ship, the Thomp-

son sounding machine and the deep-sea recorder being employed. A hole with a depth of 530 fathoms was discovered 10 miles southwest from Cape Edgecumbe, but was not developed beyond the limits of the hydrographic sheet, the average width of which was about 12 miles. Owing to the exposed nature of the coast all of this work could only be done under favorable conditions of sea and weather.

Work in the vicinity of Sitka being finished on July 15, the vessel proceeded to Point Gardner and took up the survey in that locality where it had been left at the close of the season in 1895. The shore line and hydrographic work were connected with that of 1889 and 1892 and then carried down Chatham Strait for 30 miles to Point Ellis, including Surprise Harbor, Murder Cove, and Herring Bay on the north side of Frederick Sound; Washington Bay and the Bay of Pillars on the east side, and Red Bluff, Hoggatt and Gut bays on the west side of Chatham Strait. The topography was carried from Point Caution, on the east side of Chatham Strait, around Point Gardner to Herring Bay, on the north side of Frederick Sound. Hydrographic work was closed in September, and the steamer returned to Sitka, leaving two officers with the steam launch *Cosmos*, who were to continue the topography as long as practicable and then rejoin the main party at Sitka. On October 1, while anchored in Bear Bay, the *Cosmos*, during a falling tide, caught on a submerged rock. A heavy gale caused her to careen and she subsequently filled and sank. Immediately on receiving notice of the accident the *Patterson* proceeded to the rescue, and with the assistance of Commander Asa Walker, of the U. S. S. *Concord*, and of Capt. L. W. Smith, of the steamer *Wigwam*, secretary of the Baranof Packing Company, raised the *Cosmos* and towed her to Sitka. Recognition is also due to Captain Peel, of the trading schooner *North Star*, for valuable aid in recovering the launch.

The *Patterson* left Sitka on October 9 for San Francisco, and while en route made investigations and gathered information for the Coast Pilot at the northern end of Wrangell Strait and in the vicinity of New Metlakahtla. Continuing her course south she stopped at Seymour Narrows, to examine the work done at the tidal station and receive on board the party engaged in tidal and current observations during the season; thence to Departure Bay to coal ship; from here to Seattle to carry out the instructions relative to the disposition of the steamer *Hassler*. She arrived at San Francisco on October 27, 1897.

The photo-topographical survey of the country about the head of the Lynn Canal was begun on May 24, 1898, the date of the parties' departure from their base of supplies at Haines's Mission, Chilkoot Inlet, and the work was in progress at the end of the fiscal year. The general direction of the work was under the supervision of Mr. J. A. Flemer, Assistant, Coast and Geodetic Survey. The operations in the drainage area of the Chilkat River were carried on by his immediate party, and those in Khatochin region by Mr. John Nelson, Assistant, Coast and Geodetic Survey. Much delay was occasioned by bad weather, and progress was necessarily slow because of the mountainous character of the country and the unusual difficulties encountered in moving instruments, supplies, and camp equipment in this section. The most favorable condition for transportation is where a stream can be followed, but up the wild torrents which furnish the waterways boats are towed with difficulty, and the character of the banks compels the travelers to wade in the icy waters nearly all the time. On June 29 one of the boats, under charge of Assistant Nelson, while coming down the rapids in the Khatochin

River, struck on a snag and went to pieces. Everything on board, including instruments, photographic plates and records, and other articles of outfit, were lost or ruined by water, and the three men in the boat barely escaped with their lives.

Under the instructions from the Superintendent, A. F. Rodgers, Assistant, Coast and Geodetic Survey, proceeded to Taiya Inlet, at the head of Lynn Canal, on September 8, 1897, for the purpose of obtaining at Dyea and Skagway information needed in the preparation of charts for those localities. A study was made of the physical hydrographic conditions at Seward City, Dyea, and Skagway, and special supplemental surveys were made to locate the improvements and changes in the shore line conditions since the last surveys in these localities. This work was completed on October 7.

The party under Mr. Homer P. Ritter, Assistant, Coast and Geodetic Survey, which was directed to make a survey of the vicinity of the mouth of Copper River, arrived in Prince William Sound on May 22, 1898. On June 7 the main portion of the party arrived in the Copper River delta and began field operations, which were in progress at the close of the fiscal year. The details will be described in the report for the next fiscal year.

The topographic survey of the Pribilof Islands (cut No. 12) and the detailed surveys of the seal rookeries on the islands of St. George and St. Paul, were made by the party, under the direction of Mr. Will Ward Duffield, Assistant, Coast and Geodetic Survey, between June 4 and September 25, 1897. The field work of the topographical surveys began on June 4, but the arrival of the female seals necessitated a suspension of this branch of the work between June 14 and June 29, the remaining work being finished on September 25. Complete topographical surveys were made of St. Paul, St. George, Walrus, and Otter islands, on a scale of 1–20 000; and eighteen seal rookeries were surveyed on a scale of 1–2 000.

The topographical operations of the party under Mr. J. F. Pratt, Assistant, Coast and Geodetic Survey, employed in the survey of the delta of the Yukon River and vicinity must be noticed in detail in the report for the next fiscal year. The late date of the opening of navigation in this region made an early beginning of field operations an impossibility, and at the close of the period of this report the U. S. S. *Wheeling* with the party on board had just reached St. Michael, the point for disembarkation and the place where the survey was to begin.

(*c*) COAST PILOT.

Under the general direction of the Superintendent and supervision of the hydrographic inspector the duties of the Coast Pilot party involve the execution of work in the field and in the office.

From the beginning of the fiscal year to April 20, 1898, Lieut. J. C. Gillmore, U. S. N., who was in charge of the hydrographic division, acted as chief of party. Mr. John Ross, nautical expert, was employed from the beginning of the fiscal year until May 25, 1898, when he resigned to accept a commission in the Navy. During the entire year Mr. Talbot Pulizzi was employed as clerk, and after Mr. Ross resigned had entire charge of the files of the party and attended to the correction and issue of Coast Pilot volumes.

The party prepared and published 6 supplements to Coast Pilots of the Atlantic Coast; 1 supplement to Coast Pilot of Alaska, embodying the reports of hydrographic parties for the years 1896 and 1897, and revised and published a second edition of United States Coast Pilot, Atlantic Coast, Part V. Additional Coast Pilot information was prepared for the use of naval vessels cruising in the vicinity of Key West and the Florida reefs. Extensive memoranda were also prepared for the guidance of a hydrographic party engaged in the collection of data for the revision of the Pacific Coast Pilot. The plans and specifications for the new steamer intended for service in Alaska and the Aleutian Islands were referred to the party and changed as found necessary. In November, 1897, Mr. John Ross was absent from the office eleven days on duty in connection with the revision of United States Coast Pilot, Atlantic Coast, Part V, and the verification of a trial course for naval vessels in Chesapeake Bay.

The issue of United States Coast Pilot, Atlantic Coast, volumes has increased from 1 209 copies during the fiscal year ending June 30, 1897, to 1 532 copies issued during the fiscal year ending June 30, 1898. These volumes are corrected by the party to date of issue, and this work, which has increased steadily since it was first undertaken, now keeps the clerk almost constantly employed.

EASTERN DIVISION.

The hydrographic operations along the coast between New York and Gloucester, Mass., were a continuation of examinations and special determinations of changes in shore lines and hydrography for the perfection of the charts and Coast Pilot, and were executed by the party on the steamer *Bache*. Lieut. Commander W. J. Barnette, U. S. N., Assistant, Coast and Geodetic Survey, assumed command of the *Bache* on July 1, 1897, and began at once the special work of determination of compass ranges for the use of vessels in the vicinity of New York.

From July 12 to August 10 the party was engaged in work which is described under "Special operations," and on August 11 returned to the determination of compass ranges as far east as Newport, R. I., and on August 13 proceeded to New Bedford, Mass., for repairs. On August 20 an examination of the tide rips off the eastern end of Long Island Sound, between Block Island and Montauk Point, New York, was commenced, and this work was continued during favorable weather until September 30. To the northward of the Endeavor Shoal a new line of shoals was found, with soundings ranging from 5¼ to 7¾ fathoms. A partial examination was made off the southwest end of Block Island and over the Southwest Ledge, but no important changes were discovered. The wharf at Great Salt Pond, Block Island, was located. As a result of this work there is no shoaling off the eastern end of Long Island which has not been noted, with possibly the exception of the vicinity of Washington Shoal and Shagnong Reef. These, owing to the limits and scale of the projection, could not be completely developed at this time.

On October 1 the *Bache* left New London for Nantucket, to investigate the break through the beach at the "Haulover." Work was begun on October 4 by determining the shore line on either side of the cut and by sounding. The resurvey shows a marked cutting away of the shore on the ocean side, and this continues beyond the limits of the work. The neck of land separating the head of the bay from the ocean

was found to be reduced to such an extent as to render it liable to be broken through by severe gales. At the time of the survey the beach was about 450 metres wide, with a maximum depth of 11 feet at low water, the channel being near the southern point, and thence shoaling rapidly seaward to 4½ feet, the greatest depth on the bar at low water. A strong current was found to run through the cut at the time of maximum tidal flow. The channel was reported to be shifting, as was also the case with the outside shoals. Tidal stations were established inside and outside the break at the "Haulover" and at the Commercial Wharf, Nantucket, and the staff gauges were connected with the bench mark at Squam Head triangulation station by a line of levels. Simultaneous tidal observations were taken on October 6 and 7 at the three gauges, and at the same time current velocities were measured at the point in the cut where the strength of the current appears to be a maximum.

Upon the completion of the survey at Nantucket the *Bache* proceeded to Gloucester Harbor, Massachusetts, to investigate certain reported dangers, and on the way determined the position of several aids to navigation at Pollock Rip and vicinity. Examination was made at Gloucester for four reported shoal places, but carefully executed soundings and dragging gave no indication of their existence. While searching for the 20-foot spot reported between red spar buoy No. 6 and Ten Pound light, which could not be found, on the same line and about 71 metres nearer Ten Pound light rocks were discovered having only 16.4 feet of water on them. Several other rocks not shown on the charts were found and located. The position of the outer end of the breakwater, which has been continued out about one-third farther than shown on the chart, was determined. The tidal observations made in connection with the work in this harbor were made at Fish Commission Wharf, Ten Pound Island; the gauge was referred to bench mark No. 2, established by Lieut. W. F. Low, U. S. N., Assistant, Coast and Geodetic Survey, in 1894.

Work at Gloucester was finished October 20, and the vessel returned to New Bedford, thence to New York, arriving on October 27, where she was repaired and refitted.

WESTERN DIVISION.

On the Pacific Coast special surveys and investigations were made by the parties on the Steamers *Gedney* and *Patterson*.

On August 23 Lieut. Commander A. P. Osborn, U. S. N., on the steamer *Gedney*, took up the examination of the California coast to the southward of San Francisco Bay, the principal results being the location of a bank to the southward of Santa Barbara Island and the collection of data for the Coast Pilot. On November 1 the party returned to San Francisco and was engaged for the remainder of the month preparing the results of the investigation for transmission to the Office.

After the return of the steamer *Patterson* from Alaska, Lieut. Commander E. K. Moore, U. S. N., commanding, she was ordered to San Diego, Cal., where, in addition to computing the office work connected with operations of the season in Alaska, the party made an examination inside the entrance to San Diego Bay. It was found that the channel had deepened by the action of the jetty, and that a reported shoaling of the water outside one of the channel beacons was found to exist.

DIVISION OF ALASKA.

(Cut No. 11.)

When the *Patterson* was returning south at the end of her field season in Alaskan waters in 1897, Lieut. Commander E. K. Moore, U. S. N., made several investigations of reported uncharted reefs.

On October 10 and 11 a special investigation was made near the northern entrance to Wrangell Strait and off Vexation Point, where the steamer *Alki* struck last year.

Another stop was made at New Metlakahtla, where various rumors about the wreckage of the steamer *City of Mexico* were investigated and an examination made to decide on the probability that she had struck on an uncharted rock. No evidence of such a rock being found, the *Patterson* sailed the same day for Seymour Narrows. The party arrived at Seattle on the 19th and at San Francisco on the 27th, thus ending the field work for the season.

(*d*) TIDAL WORK.

General Statement.

The tidal work of this Survey is naturally separated into two great divisions, consisting on the one hand of all those phenomena growing out of the vertical motion of the water constituting the *tides* proper, and on the other hand of all those phenomena arising from its horizontal motion, designated as *currents*. The mariner is deeply concerned about both of these movements of the water, for the tidal motion alternately opens and closes many harbors to commerce, while the speed and course of a vessel may be greatly affected by the currents.

In order to assist navigation by enabling mariners to know the times of greatest and least depth at the various stages of the tide, this Survey publishes annually a volume of tide tables for the principal maritime ports of the world. Full predictions of the time and height of every high and low water occurring in the year are given for 70 ports, and by means of tidal differences and ratios these predictions are extended to nearly 3 000 ports, distributed as follows: 1 520 in North America, 237 in South America, 549 in Europe, 204 in Asia, 116 in Africa, and 274 in the islands of the Pacific Ocean, including Australia and New Zealand. The work also contains about 50 stations, at which the direction and velocity of the currents are approximately given for each hour of the tide. The full predictions of tides were made by the Ferrel tide-predicting machine, which is described in Appendix 10 of the Superintendent's Report for 1883.

Another practical use made of tidal observations, in addition to serving as the basis for predictions, consists in the determination of various tidal planes, such as mean low water, mean sea level, mean high water, etc., which are essential to the construction of charts and to many engineering operations. The direct soundings obtained during the survey of any tidal harbor can not be used upon a chart, for some of them are made at high water, some at low water, and others at various intermediate stages of the tide. Before these various soundings can be compared they must all be reduced to a uniform datum, called the *plane of reference*, which is derived from the tidal observations. In order to preserve the plane of reference and other tidal planes for future use *bench*

marks are established of a more or less permanent character, according to the importance of the location. These tidal bench marks are of great use in engineering operations and in measuring the elevation above the sea of points upon the land.

Harmonic analyses were completed for a year of hourly ordinates at each of the six following stations: Willets Point, N. Y.; Washington, D. C.; Wilmington, N. C.; St. Marks Light, Fla.; Mobile Point, Ala.; and Victoria, British Columbia. The nonharmonic reductions completed during the year consist of thirty series, the equivalent of about seven years of continuous records of high and low waters. It is planned to publish at some future time a collection of the results from all the harmonic analyses made by this Survey, together with such harmonic constants as have been obtained from other sources.

It may be well to state that work upon the tides is in a transition stage—the present tendency being toward the harmonic treatment to the exclusion of other processes. But terms having reference to the high and low water phases of the tide are such a convenience in describing its character at a given station, and are so much easier for the average person to understand than the more artificial harmonic symbols, that they must be retained. In order to keep both the old and the new terms, it became necessary to reconsider the old nonharmonic quantities in the light of the harmonic analysis, and to work out processes by which they might be derived from one another so far as possible. These, among many other considerations, notably the want of auxiliary tables, rendered the production of a Manual of Tides a matter of necessity, and Dr. R. A. Harris was intrusted with its preparation. The work he designed to consist of five parts, three of which have already been prepared and relate to the more practical side of tidal work; that is, to the observation, the reduction of analysis, and the prediction of tides, together with some definitions and historical matter. Parts I and II of this manual were completed during the year and published as Appendices 8 and 9, Superintendent's Report for 1897. Part III, published as Appendix 7, Superintendent's Report for 1894, had been prepared out of its order, because much of the matter it contains was wanted immediately in tidal work. Part IV will treat of tidal theory; its main subject will be the application of hydrodynamical principles to the tides of nature. The author will endeavor to establish, so far as possible, a logical connection between the known causes and observed effects. Part V will treat of tidal streams or currents. Their action in bringing about changes of depth and shore line will be considered.

As Parts I and II of a Manual of Tides were completed within the year, a brief review of them will be given:

The principal aims of Part I, which is entitled "Introduction and historical treatment of the subject," may be stated as follows: To give tolerably constant definitions of terms connected with tides; to show the meaning of tidal inequalities, how they may be obtained from observations and used in making predictions; to show how the character of the tide may be described by nonharmonic quantities; to explain the more important methods which were in use here and elsewhere prior to the introduction of harmonic analysis.

The aim of Part II is, in a general way, indicated by its title, "Tidal observations, equilibrium theory, and the harmonic analysis." In order to make clear what the various tidal components represent, or to infer what periodical oscillations should exist

in the tide wave, a few pages are devoted to pointing out their connection with well-known astronomical periods.

The chapter relating to the analysis of tidal observations gives directions for the construction and use of a labor-saving device known as *stencils*, invented by Mr. L. P. Shidy, which have been in constant use in the Survey for more than thirteen years. For a long series of observations it may be found advantageous to reduce the labor still further by means of *secondary stencils*, recently suggested by Mr. F. M. Little, or by using bihourly or less frequent ordinates. Several computing machines are mentioned, together with a brief description of Thomson's harmonic analyzer. A brief description is also given of a machine proposed by Dr. Harris, which is designed to sort and sum the hourly heights in the various ways required for the analysis of many components, the heights being entered into the machine but once by the operator, in order to obtain simultaneously the sums for all the components.

In connection with the analysis of hourly heights, a process used by Ferrel for clearing the results from the effects of components other than the one sought is described. Another refinement of considerable importance in certain localities is introduced into the stencils themselves. It consists in so constructing them that one, and only one, hourly height shall fall upon each component hour.

A new and thorough method for the harmonic analysis of high and low waters and brief statements relating to the analysis and prediction of tidal currents are also given.

OBSERVATIONS.

EASTERN DIVISION.

Automatic tide gauges have been kept in operation at Fort Hamilton, N. Y.; Reedy Island Quarantine Station, Delaware; United States Navy-Yard, Washington, D. C.; Morehead City, N. C., and Fernandina, Fla. All of these gauges have been in use throughout the year, except that at Morehead City, which was established on April 29, 1898, and has since been in successful operation. Toward the close of the year it was noticed that silt was accumulating about the gauge established at the Washington Navy-Yard in 1891, and it was deemed advisable to change its location; accordingly a new gauge was set up at the wharf of the Norfolk and Washington Steamboat Company, at the foot of Seventh street, Washington, D. C., on June 30, 1898. Both gauges will be run for a few months.

The tide indicators at Fort Hamilton, N. Y., and Reedy Island Quarantine Station, Delaware, have given satisfaction throughout the year.

WESTERN DIVISION.

For the whole or part of the fiscal year automatic tide gauges were in operation at Sausalito and Presidio, San Francisco Bay. The gauge at Sausalito had been kept in successful operation since February, 1877, but was discontinued on September 1, 1897, a new gauge having been established at Presidio in July, which was kept in operation throughout the year.

The naval authorities at the Puget Sound Naval Station, Bremerton, Wash., have continued throughout the year a series of tidal observations with a self-registering tide gauge, and have courteously furnished a copy of the results weekly to the Coast and Geodetic Survey.

DIVISION OF ALASKA.

Very important series of tidal and current observations were made in connection with the work of the steamer *Patterson* in Alaska in 1897.

Permission was secured last year from the Canadian government to establish a tidal and current station at Seymour Narrows, and accordingly when the *Patterson* was going north Lieutenant-Commander Moore established a tide gauge at this point and left a party in charge which made observations upon the tides and the times of the slack waters during daylight hours, from April 18 until October 14. A similar station was occupied at Sergius Narrows, and at Sitka an automatic tide gauge was in operation throughout the season, from April 30 to October 1. Through the courtesy of the minister of marine and fisheries of Canada we have obtained the tidal curves of Esquimault and Frazer River during the above observations, so that now direct comparisons can be made with these stations. It is hoped that the data obtained will enable us to predict the times of slack current in the narrows with practical accuracy.

The latter will be of great importance to mariners, as all the steamers in the southeastern Alaska trade traverse Seymour Narrows, while Sergius Narrows is on the regular course to Sitka, and both, when the tides are large, are navigable only at or about the time of slack water for any but the most powerful steamers.

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2. GEODETIC WORK.

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II. THE SCIENTIFIC AND TECHNICAL RESULTS.

2. GEODETIC WORK.

(*a*) GENERAL STATEMENT.

The geodetic work of the Survey is the foundation of a map of the country. Upon its accuracy rests the value of subsequent surveys; upon its extent depends the ability of State governments to continue the work and give each county geographical positions which render future disputes improbable and geodetic contradictions impossible. These operations have been pushed in all directions during the past year. The transcontinental arc has been finished; the work on the ninety-eighth meridian has been continued, and in all sections more or less activity has been displayed.

A reconnoissance has been made through South Carolina and Georgia to connect the primary triangulation along the Blue Ridge with that along the Atlantic coast. The former forms a part of the great oblique arc from Calais, Me., to Mobile, Ala. Being some distance from the coast, the topographical and climatic conditions are more favorable to long lines, and the work possesses great strength. The connection of the two will effectually control the weaker coast triangulation. This, indeed, was the original object of the connection.

The reconnoissance for the extension of a triangulation scheme from stations in Missouri on the transcontinental arc, and which will be prolonged through Arkansas and Louisiana, was begun.

Extensive progress was made in the reconnoissance for the primary triangulation along the ninety-eighth meridian in Texas. This triangulation when joined with similar work to be undertaken by the Canadian and Mexican Governments will form a meridian arc extending through 50° of latitude. The measurement of such a long arc with instruments and methods of refinement unknown in earlier geodetic work will furnish valuable data for more accurately determining the size and figure of the earth and at the same time will serve as an accurate framework for future local or governmental surveys.

Another important reconnoissance undertaken was for the extension of the triangulation from the Salt Lake basin northward through Idaho. In California work was resumed on the proposed extension of the triangulation in southern California to the Mexican boundary, and the preliminary reconnoissance for this was completed. This is to form part of an oblique arc bearing the same relation to the Pacific coast triangulation that the eastern oblique arc does to that of the Atlantic coast.

The triangulation results for the year include the completion of several very important undertakings of the Survey.

A connection was established between Mount Royal, near Montreal, with the primary triangulation in New England and New York. The recent determination of the difference of the longitudes of this station and Greenwich, England, made by the Canadian authorities, supplies an additional link in the correction of our standard longitude net with the prime meridian at Greenwich.

The triangulation along the oblique arc, connecting the primary triangulation of the Blue Ridge with the work on the Gulf coast, was completed during the year. Another connection made was that of the triangulation systems of the east and west coasts of Florida. The reconnoissance northward from the thirty-ninth parallel of latitude through Kansas into Nebraska having made sufficient progress, the triangulation was taken up and materially advanced. In Nevada and Utah the base stations for the triangulation which is to extend through Idaho were occupied.

An important series of stations in California and Nevada were occupied to insure the connection of certain astronomical stations in those States with the great transcontinental survey.

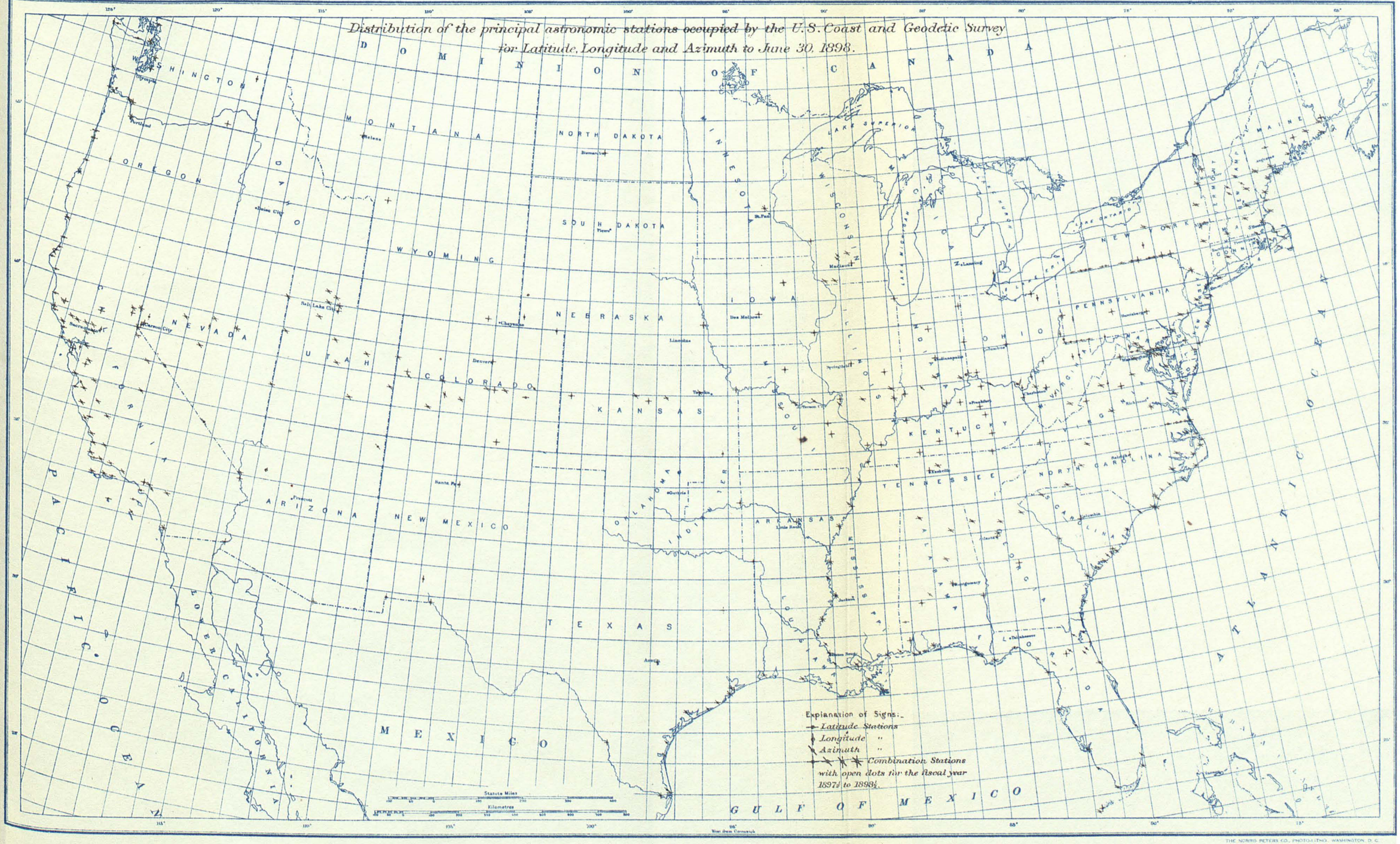
Following the foregoing in importance were the operations for determining the geographic positions of light-houses in Narragansett Bay and Providence River, the work done in connection with the resurvey of Chesapeake Bay, and the completion of the survey of Lake Pontchartrain. In Washington Sound, southeastern Alaska, and the Pribilof Islands triangulation was carried on in connection with hydrographic and topographic operations.

The precise levels of the Survey were extended from Ellis, Kans., almost to Colorado Springs, Colo., connections being made wherever possible with the triangulation stations of the transcontinental geodetic work. This, when completed, will be a continuous line of levels of a high degree of precision from the Atlantic at Sandy Hook, New Jersey, to the Pacific near San Francisco, having many connections with other lines of precise levels at points east of the ninety-eighth meridian. The hypsometric condition of this latter work was also further strengthened by the occupation of stations near its western terminus for trigonometrical determinations of elevation through simultaneous reciprocal observations of vertical angles. In all the primary triangulation work the programme for the occupation of the stations included the measure of the vertical angles on the stations in sight as well as the horizontal directions to them. In the triangulation executed in southeastern Alaska and the Pribilof Islands the heights of stations were determined trigonometrically for the control of the topographic operations.

The principal astronomical operations of the year were undertaken to satisfy the requirements of the measurement of that portion of the great oblique arc, between Atlanta, Ga., and Mobile, Ala.; and of the transcontinental arc, connecting the surveys of the Atlantic and Pacific coasts along the thirty-ninth parallel (cuts Nos. 13 and 14). Azimuth latitude and longitude observations were made at numerous stations in the triangulation chains covering both arcs. An azimuth was measured at Bronson, Fla., on the line between Fernandina and Cedar Keys; another at Southwest Base, Lake Pontchartrain; a latitude, longitude, and azimuth station was occupied on St. Paul Island and on St. George Island, in the Pribilof group. The longitude base station for these determinations was on Unalaska, one of the Aleutian Islands.

The only gravity station occupied during the year was situated on St. Paul Island, one of the Pribilof group.

Distribution of the principal astronomic stations occupied by the U.S. Coast and Geodetic Survey for Latitude, Longitude and Azimuth to June 30, 1898.



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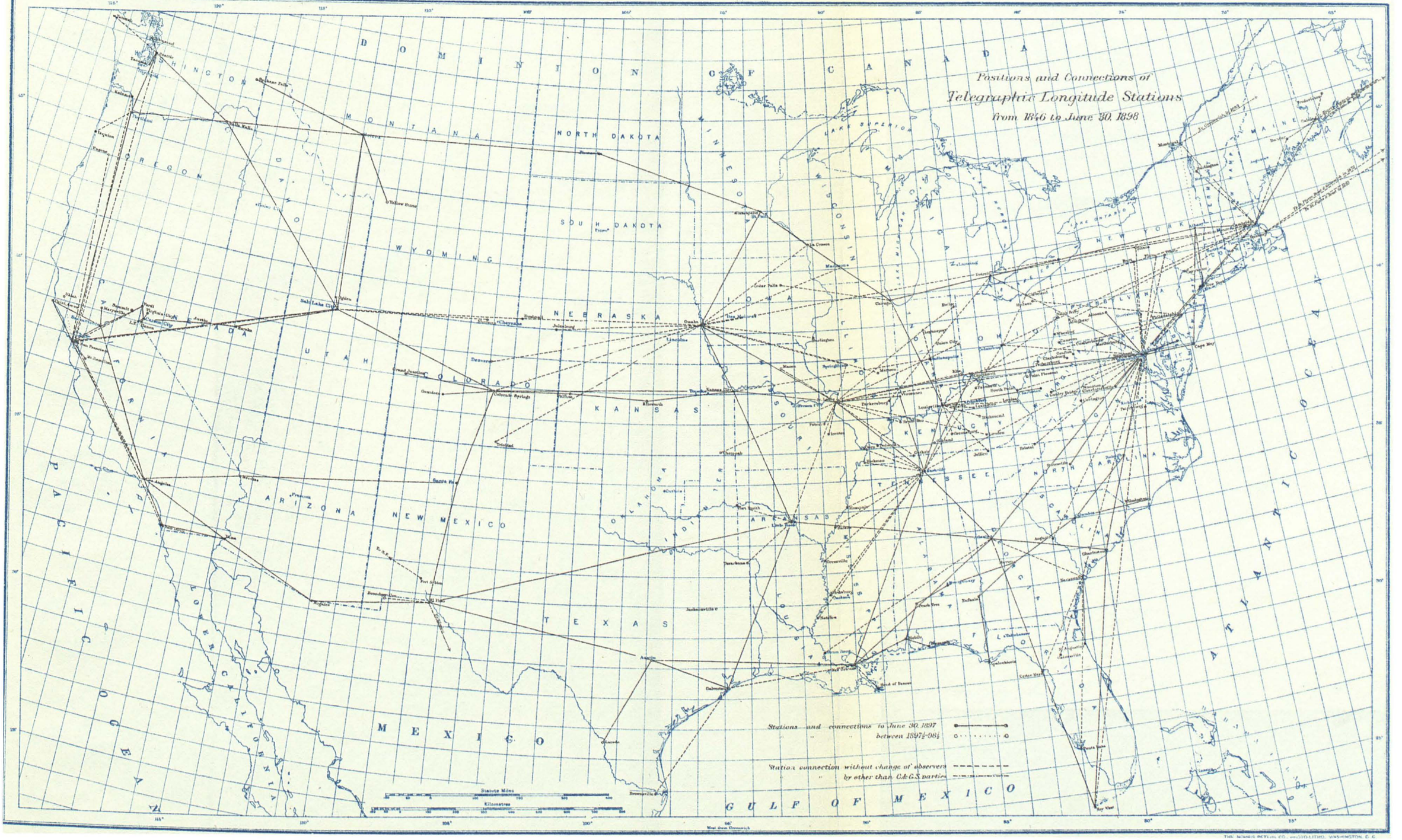

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(*b*) RECONNOISSANCE.

EASTERN DIVISION.

The execution of a reconnoissance for a scheme to connect the primary triangulation of the Blue Ridge, forming a part of the great oblique arc, with the triangulation along the southern Atlantic coast was assigned to Mr. F. W. Perkins, Assistant, Coast and Geodetic Survey. The work was begun on August 13 and completed on September 11. The general direction of the scheme follows the course of the valley of the Savannah River, and it extends from the mountain base to McKnight, a station about 12 miles northwest of Augusta, Ga., and overlooking the country south of that point.

The scheme developed consists of 1 quadrilateral and 8 triangles, of an average area of 277 square miles; of 22 lines, varying in length from 11 to 46 miles, or an average length of 25 miles; the whole covering an area of 2 300 square miles and commanding two or three times that area. Two old mountain points were recovered and 13 new points selected, making 15 points located, of which 12 will be used finally.

MIDDLE DIVISION.

On July 1 Mr. R. L. Faris, Assistant, Coast and Geodetic Survey, took the field for the purpose of making a reconnoissance for primary triangulation in central Missouri, having in view the ultimate extension of the triangulation through Arkansas and Louisiana. As it was desired that the reconnoissance should proceed from the Versailles, Mo., primary base line, and that the scheme should correspond approximately in magnitude with the transcontinental arc, the line Hunter to Belshe in one of the Versailles Base figures of the transcontinental arc was adopted as a base line for this work.

The region covered by the reconnoissance being heavily timbered and devoid of prominent elevations, it was found necessary to use high tripods and signals in order to make the points intervisible.

The work was inaugurated on July 1 and continued until July 28. In this time the stations forming one quadrilateral were located and marked, their approximate geographic positions were determined, and signals erected over them. The localities for the stations for a second quadrilateral were also determined upon and all the conditions which had to be provided for before the stations could be occupied thoroughly investigated. Sudden emergencies demanding the immediate execution of work in other localities, the party was disbanded.

The reconnoissance for the primary triangulation along the ninety-eighth meridian, northward from the Rio Grande to southern Kansas, was placed in charge of Mr. S. Forney, Assistant, Coast and Geodetic Survey, in March, 1898. The party was organized at San Antonio, Tex., and then proceeded to Seguin, Tex., where the reconnoissance was commenced. An examination had previously been made of the country about San Antonio for a base line site, but a better location was found in the Guadalupe Valley, halfway between Seguin and New Braunfels, where a line 5 miles long can be measured.

By June 30 the reconnoissance had been completed from Seguin to Lampasas, Tex., a distance of 105 miles, with a scheme of well-developed quadrilaterals all the way, having points on both sides of the ninety-eighth meridian, which passes approximately through the center of the scheme.

An examination of the country 10 miles on either side of the meridian was made between Seguin and Lampasas.

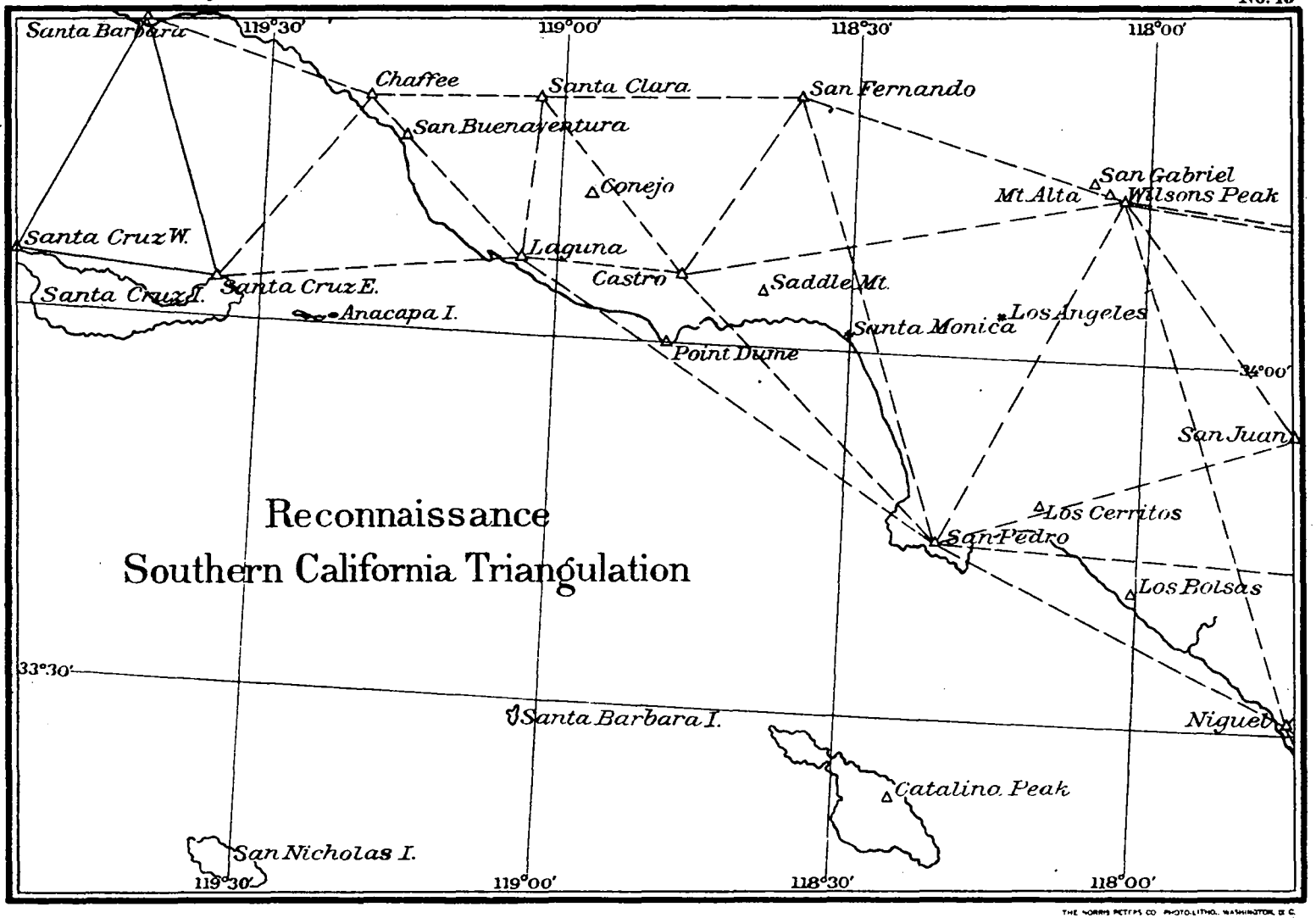
WESTERN DIVISION.

In compliance with instructions for reconnoissance and triangulation in Utah, Nevada, and Idaho, Mr. P. A. Welker, Assistant, Coast and Geodetic Survey, proceeded to Salt Lake City, Utah, and at the beginning of the fiscal year had organized a party and was ready to take the field.

The first work undertaken was a reconnoissance of the country to the northward of the primary triangulation line Ogden–Pilot, and extending into the State of Idaho. On the morning of July 1, 1897, the party left Ogden, Utah, for Ogden triangulation station, and the point was occupied for reconnoissance purposes on July 4, with satisfactory results. The first points selected for the scheme, to the northward, were Cache Peak (10 500 feet elevation) and Oxford Peak (elevation 9 400 feet), Idaho. After visiting and determining the availability of these stations, it was deemed advisable to discontinue the reconnoissance until the base stations Pilot and Ogden had been occupied for observations of horizontal directions and vertical measures. This work was completed on September 16, and on September 27 the party resumed the reconnoissance at Pocatello, Idaho. Permission having been secured from Lieutenant Irwin, U. S. A., agent in charge of the Fort Hall Indian Reservation, for traveling, camping, and working in the reservation, examinations were continued which resulted in the selection of South Putnam (elevation about 8 900 feet), which will be the interior station in a pentagon. The other stations selected and occupied in the reconnoissance are: Big Butte (elevation 7 650 feet), in the Snake River Desert; Black-foot, and Mount Pisgah. On October 20 the party was disbanded at Salt Lake City, Utah. The area covered by this reconnoissance embraces 25 000 square miles. The triangulation is on a large scale; the diagonal of the first quadrilateral being considerably more than 100 miles in length.

Between August 13 and December 3, 1897, and in May and June, 1898, Mr. C. H. Sinclair, Assistant, Coast and Geodetic Survey, was employed in connecting the astronomical stations in Nevada and California with the triangulation of the transcontinental arc, and in the determination of additional stations, which were necessary to provide a proper balancing of the astronomical conditions of the system. This necessitated reconnoissance for the schemes connecting the astronomical stations Genoa, Carson City, Virginia City, Austin, and Eureka, in Nevada; and Ukiah and Marysville, Cal., with the main triangulation. Additional details of the work executed in the periods referred to above are given in the accounts of the triangulation and astronomical operations of the Survey.

The reconnoissance for the primary triangulation in southern California having been placed in charge of Mr. A. T. Mosman, Assistant, Coast and Geodetic Survey, he proceeded to Los Angeles, and on March 1, 1898, began the organization of a party for the work. The field work was begun on March 8 at San Pedro Hill, and in quick succession the stations Saddle Mountain, Santa Barbara, Laguna, Chaffee, Castro, Santa Clara, and San Fernando were visited, selected, and occupied for the necessary angles (cuts Nos. 15 and 16. The unconnected points belong to an old scheme, now abandoned). The resulting network of triangulation having been approved by the Superintendent, the extension of the scheme southward to the Mexican boundary was then taken up and stations San Juan and Santiago examined. Owing to continual fog and haze, the work along the coast was so much delayed that Mr. Mosman, after a long, fruitless detention at Soledad, decided to transfer his party to the high mountains, and return to



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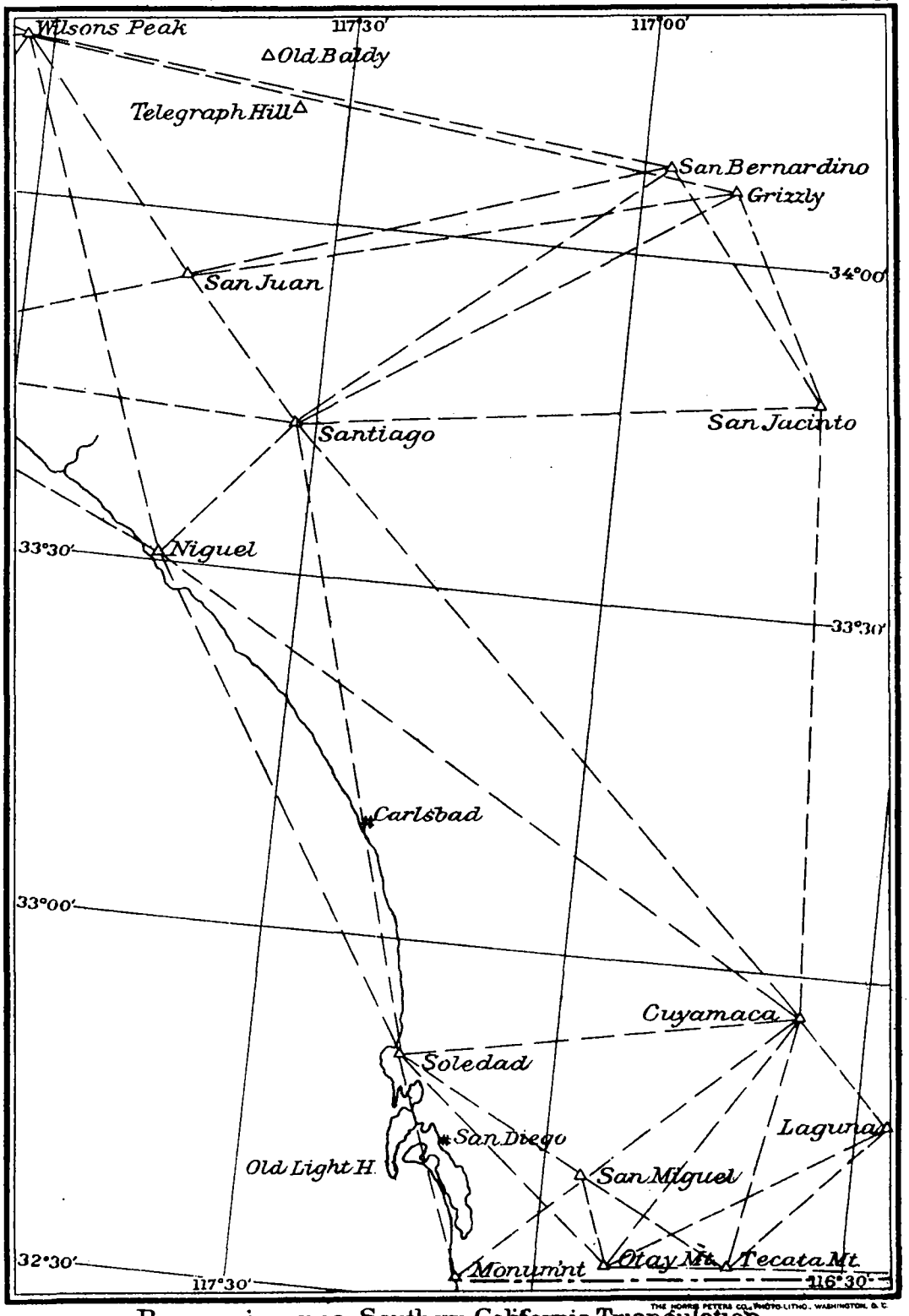


Reconnaissance, Southern California Triangulation

Soledad later. The weather was favorable at Cuyamaca Mountain and the requisite observations were obtained there, but at Campo, Tecato Mountain, and Otway Mountain observations were prevented by thick weather, and the party returned to San Diego. Soledad was visited without success on May 5 and 6. Returning to San Diego, Monument No. 258 on the Mexican boundary was visited and determined, and a second visit paid to Niguel, which was without favorable result, the weather remaining unpropitious. From May 12 to 21 the party was engaged on Wilsons Peak, Mount Lowe, and San Fernando in locating obstructions between Wilsons Peak and San Fernando. A scheme of triangulation from the line of Wilsons Peak to San Juan was then sent to the Superintendent for approval, and preparations were made for putting a double party in the field to occupy the stations Santa Barbara and Santa Cruz E simultaneously.

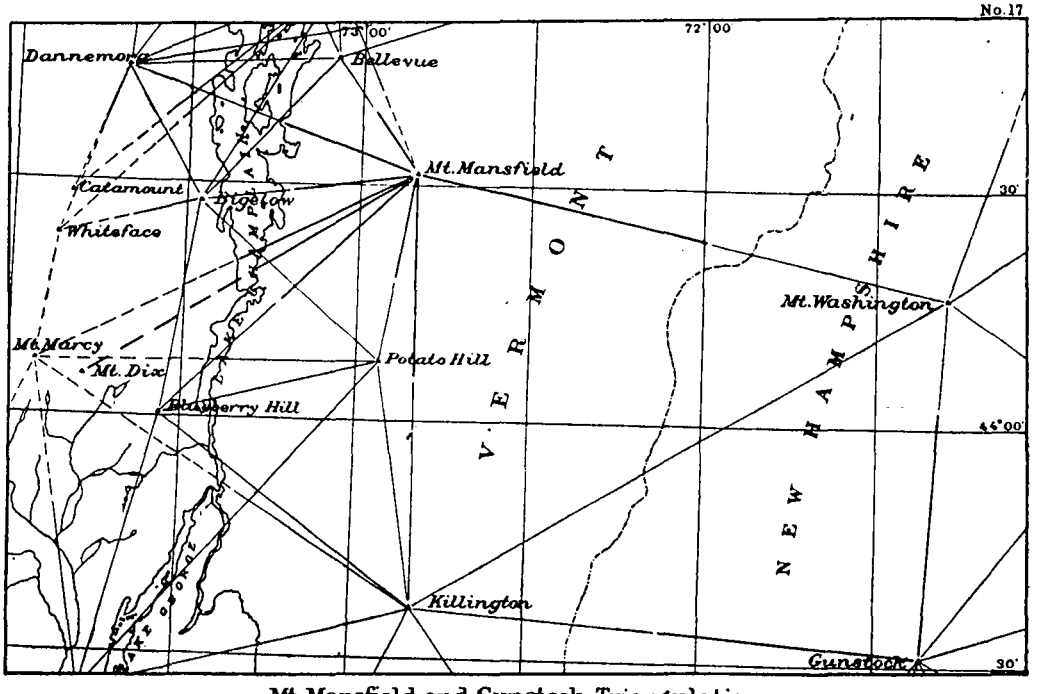
DIVISION OF ALASKA.

The reconnoissance for the survey of the delta of the Copper River by the party in charge of Mr. H. P. Ritter, Assistant, Coast and Geodetic Survey, commenced on June 7, 1898, with the arrival of the party at the mouth of the river, and was in progress at the close of the fiscal year. The work of this party will be described in the Annual Report for the next fiscal year.

(*c*) TRIANGULATION.

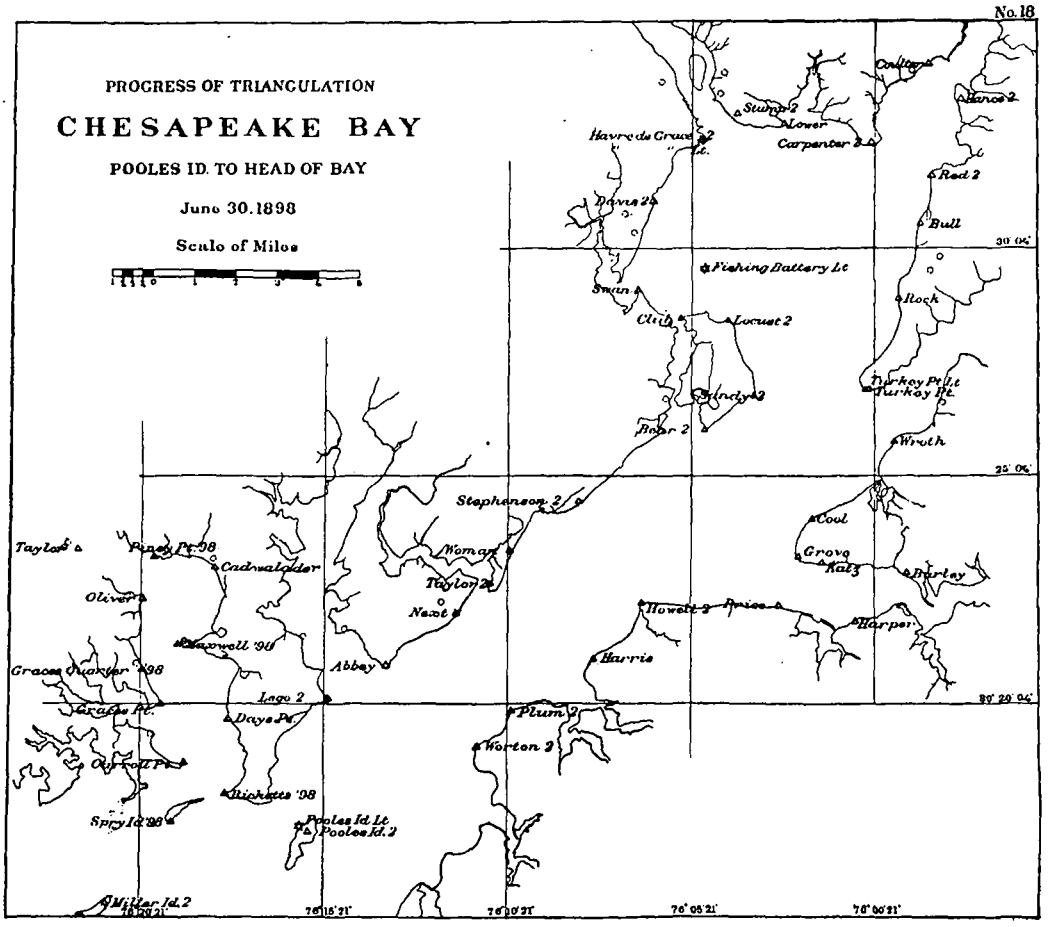
EASTERN DIVISION.

At the beginning of the fiscal year Mr. A. T. Mosman, Assistant, Coast and Geodetic Survey, was in charge of a primary triangulation party occupying Mount



Mt. Mansfield and Gunstock Triangulation.

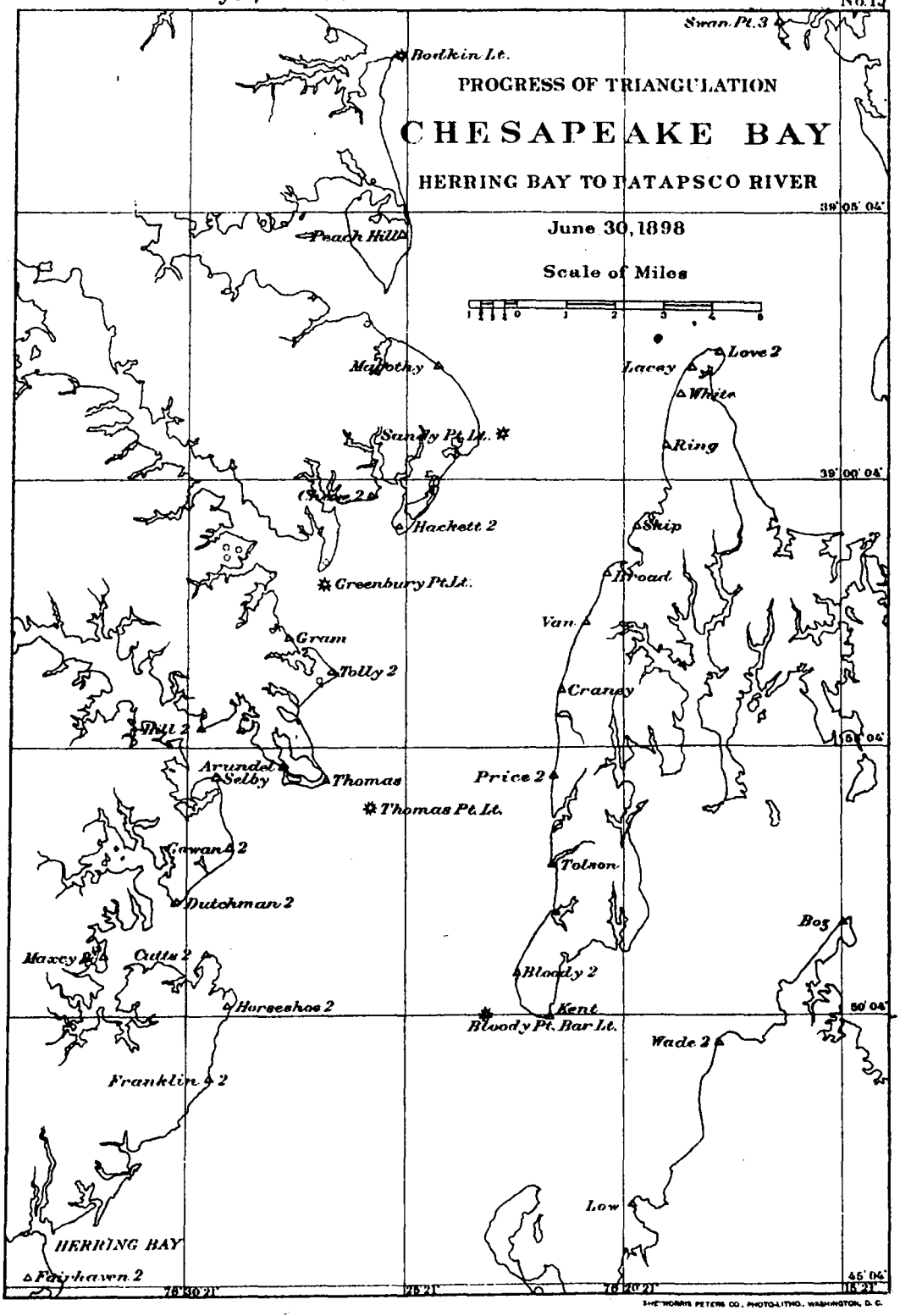
Mansfield, Vt., engaged in completing the connection of the triangulation along the Hudson River Valley with the longitude station at Montreal, Canada, and with the primary triangulation of New England at Mount Washington, Gunstock, and Monadnock (cut No. 17). Owing to unfavorable weather, observations at Mount Mansfield were not completed until August 31, when the party moved to station Gunstock, in New Hampshire. Heliotropes were posted at Mount Washington and Killington Peak, and the instruments mounted at Gunstock on September 14. Observations were com-



pleted on September 30, the instruments were shipped to Washington, and the party disbanded.

On July 1, 1897, Mr. D. B. Wainwright, Assistant, Coast and Geodetic Survey, was in the field, engaged in the determination of the geographical positions of lighthouses in Narragansett Bay and Providence River, through connections made with the established triangulation points in those sections. This work was completed on July 30, 1897.

Mr. John Nelson, Assistant, Coast and Geodetic Survey, while employed in the resurvey of Chesapeake Bay, between September 13 and October 7, having suspended


Swan Pt. 3
Bodkin Lt.
PROGRESS OF TRIANGULATION
CHESAPEAKE BAY
HERRING BAY TO PATAPSCO RIVER
39° 05' 04"
June 30, 1898
Scale of Miles
Peach Hill
Love 2
Lacey
White
Ring
Sandy Pt. Lt.
39° 00' 04"
Hackett 2
Ship
Broad
Greenbury Pt. Lt.
Van
Gram
Tolly 2
Cranes
Thomas
Price 2
Thomas Pt. Lt.
Tolson
Dutchman 2
Bos
Cutts 2
Bloody 2
Horseshoe 2
Kent
Bloody Pt. Bar Lt.
50' 04"
Wade 2
Franklin 2
Low
HERRING BAY
Fairhaven 2
76° 30' 21"
76° 25' 21"
76° 20' 21"
45' 04"
15' 21"
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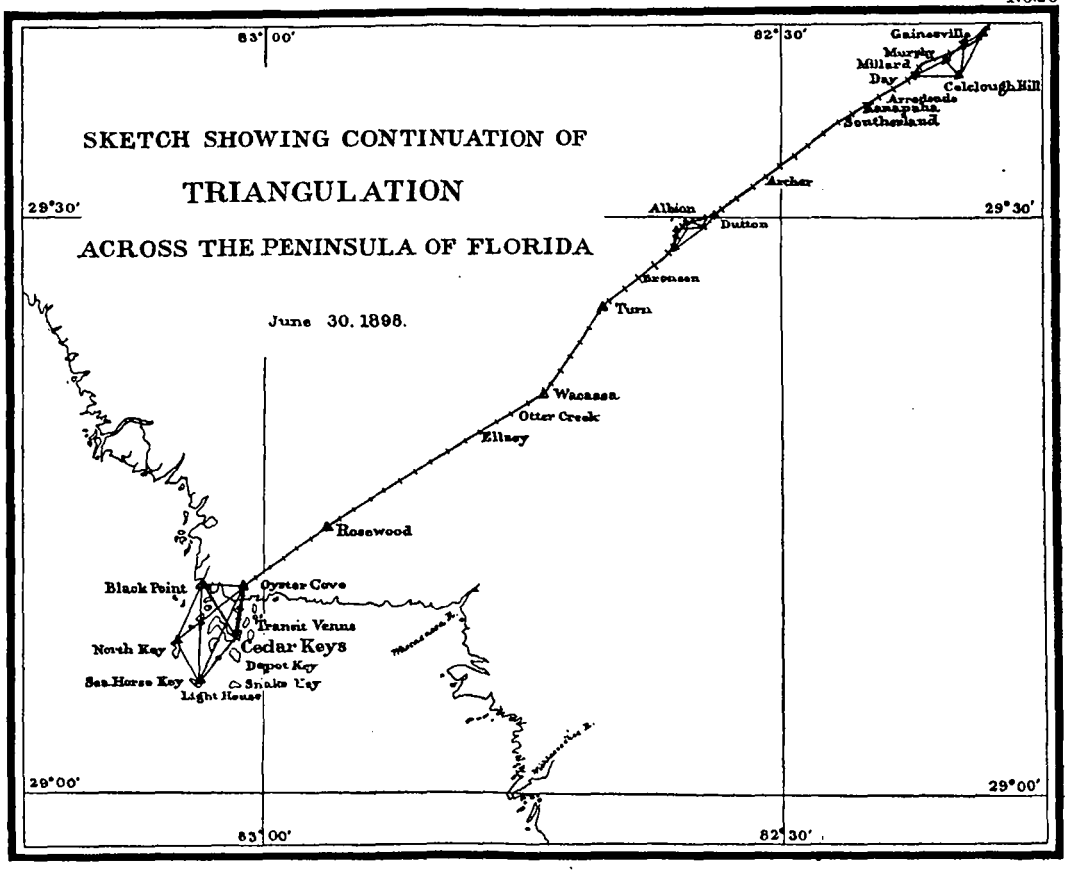
topographic operations, was employed in determining by triangulation the points necessary for the development of his topographic work north of Fairlee Creek, and the completion of the sheet assigned to him.

In April, 1898, Mr. F. W. Perkins, Assistant, Coast and Geodetic Survey, having been placed in charge of the execution of the main triangulation scheme for the resurvey of Chesapeake Bay, began operations at the head of the bay, and at the close of the fiscal year had completed the work to the south end of Tilghman Island (cuts Nos. 18 and 19).

As a necessary preliminary to beginning hydrographic and topographic surveys of

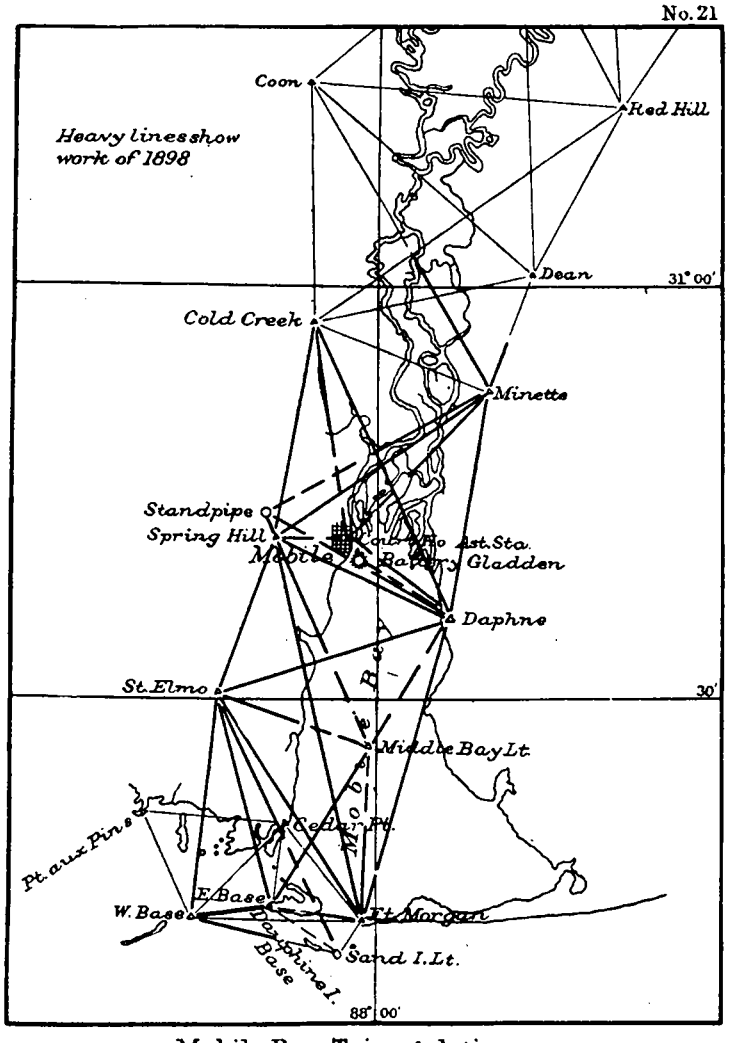
No.20



the Magothy River, which had been placed in his charge, Mr. J. B. Boutelle found it necessary to make a reconnoissance and triangulation to determine the points required for the sounding and plane-table operations. He was engaged in this preliminary work from June 7 to June 24, and the combined operations necessary for the completion of the survey of the river were in progress at the close of the fiscal year.

Having organized a party for the continuation of the direct measure across the State of Florida (cut No. 20), begun by him during the last fiscal year, Mr. H. G. Ogden, Assistant, Coast and Geodetic Survey, began field work early in January at

Cedar Keys and continued it steadily until its completion on April 16. This work, connecting the triangulations of the east and west coasts of Florida, had been previously carried from the termination of the triangulation at Baldwin to Gainesville, about half the distance to be measured. A single line of spirit levels was run over the road, the bench marks of the United States Coast and Geodetic Survey line of precise levels which ran parallel affording satisfactory checks. Curves in the railroad were passed by the



Mobile Bay Triangulation

measurement of short independent lines in combination with triangulation. The pier near Cedar Keys, occupied by Professor Eastman, U. S. N., on the Transit of Venus Expedition in 1882, was found and connected with the triangulation. Its geographic position, as thus determined, agrees satisfactorily with the determination by Professor Eastman.

The total length of line determined during the season is 90 kilometers, of which 74 kilometers were measured twice with the base tape and 16 kilometers were covered by triangulation from independent bases. For about 2 kilometers the tape measure was carried through lines opened in the forest, with the tape suspended on stubs.

To complete the triangulation along the oblique arc in Alabama, Mr. W. B. Fairfield, Assistant, Coast and Geodetic Survey, had taken the field in the latter part of March, 1897. Early in May Assistant Fairfield was instructed, upon the completion of the above work, to continue the triangulation to the westward of Fort Morgan, through Mississippi Sound, to connect with one or more of the old triangulation points of the work of 1847. This continuation is expected to lead ultimately to a prolongation of the oblique arc from Mobile to the mouth of the Mississippi, which will increase its length more than 100 miles.

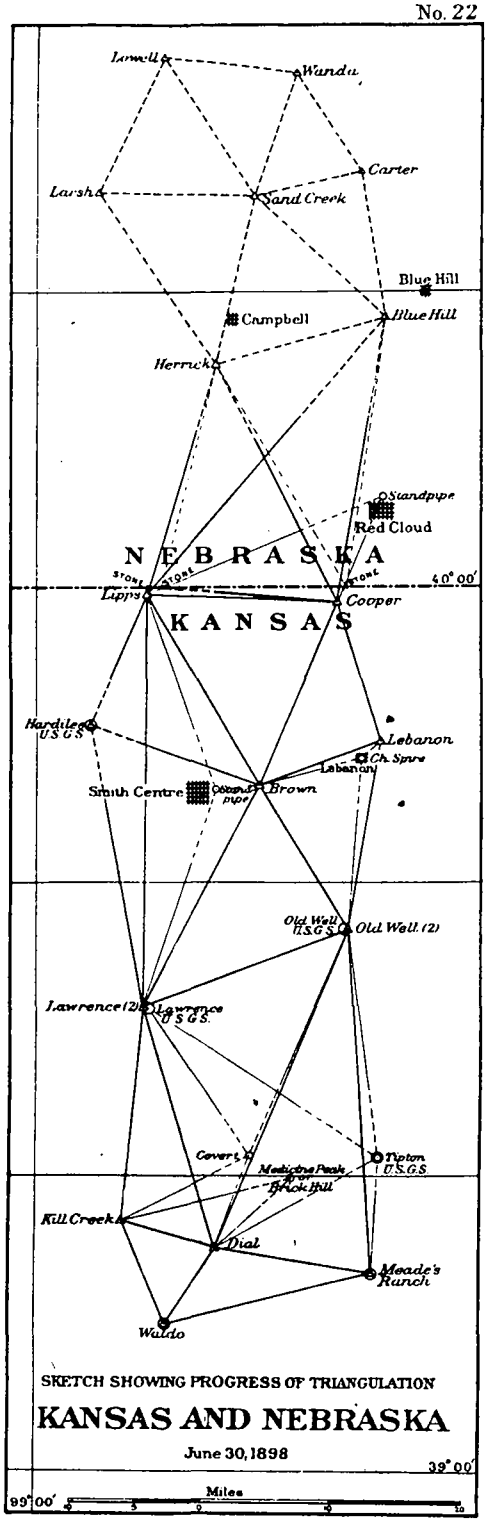
On June 23 he began the search for the old points, which proved a difficult one, but ultimately he was able to recover the stations at the ends of the Dauphin Island base (cut No. 21), and these he re-marked. Tripods and scaffolds were erected, and on August 1 observations were begun at East Base station. On the night of August 10 the signal at East Base station was destroyed by a storm and some of the instruments damaged beyond repair. The signal was at once rebuilt and observations resumed at East Base station on August 27. Observations at East Base and West Base were completed early in September, and the party had moved to Mobile, preparatory to the occupation of Fort Morgan, when it was found necessary, owing to the prevalence of yellow fever and the strict quarantine regulations adopted in consequence, to suspend field operations. From September 20 to January 9 Mr. Fairfield was at the Office in Washington, engaged in the computation of his recent work. On January 10 he left Washington for Mobile to take up the work where it had been abandoned in September and to finish the Dauphin Island connection. Fort Morgan, St. Elmo, and East Base were occupied, and on March 10 the work was completed and the party disbanded.

While observations were in progress at East and West Base stations, Dauphin Island, some of the old reference marks were found apparently undisturbed and agreeing exactly with the original descriptions furnished by the Office. Careful measurements from these points to the triangulation stations effectually tie the stations of 1897 to the old ones of 1847. The ends of the base were well and permanently re-marked and the granite monuments put back into position. In order to avoid cutting lines of sight and to lessen expense, the lights at several of the stations were elevated above the tripods; at Spring Hill 24 feet, at St. Elmo 45 feet, and at Fort Morgan 35 feet. The total heights above the ground were as follows: Spring Hill 144 feet, St. Elmo 165 feet, and Fort Morgan 80 feet.

MIDDLE DIVISION.

Mr. P. A. Welker, assistant, Coast and Geodetic Survey, in compliance with instructions to resume work on the survey of Lake Pontchartrain, Louisiana (cuts Nos. 6 and 7), organized his party at New Orleans, and on January 8, 1898, the party, with the schooner *Quick* and naphtha launch, sailed from New Orleans to South Point, at the eastern end of the lake. A base line was selected in this locality, and by the 13th of the month the ends had been marked, the signals erected, and the measurement of the line completed. Two measurements of the line, which is 5 663·46 meters in length,

No. 22



were made with a 50-meter steel tape along the outer rail of the railroad track, with satisfactory results. As no triangulation signals could be erected over the rail, the measurements were transferred to points on the shore of Lake Pontchartrain. These points, as well as the ends of the base, were securely marked. A sufficient number of signals for beginning the triangulation, topographic, and hydrographic work having been erected, one party began triangulation operations at the east end of the lake, another took up the work in the vicinity of Pontchartrain light-house, and a third party continued the erection of signals and the occupation of stations along the north shore from Big Point to Pass Manchac. By February 13 the triangulation was completed, and the party took up the hydrographic and topographic work, described under "Coast work."

At the beginning of the fiscal year the party under Mr. F. D. Granger, Assistant, Coast and Geodetic Survey, was preparing to occupy triangulation station Waldo, in Kansas, one of the stations of the transcontinental scheme for observations on new stations to the northward. These new stations, together with Waldo and Meades Ranch, the latter also a point in the transcontinental system, form a part of the scheme of triangulation along the ninety-eighth meridian laid out by Assistant Granger in the autumn of 1896 and the spring of 1897. This scheme extends northward through northern Kansas (cut No. 22) and thence across the State of Nebraska to within about 30 miles of its northern boundary, a distance of 225 miles. The scheme adopted included the stations Waldo, Meades Ranch, Old Well, Lawrence, and Kill Creek, these stations forming a pentagon with a central station, Dial. Although somewhat inferior to other schemes submitted, the one selected had the advantage of requiring only a moderate elevation of the theodolite, the points being intervisible from the ground, and its execution was attended with little expense and no delay. Observations were begun at Waldo on July 8 and completed on

July 11. The occupation of Meades Ranch followed, and observations were finished there on July 22. Stations Dial, Kill Creek, Lawrence, Old Well, and Lebanon were then successively occupied, the last-named station being completed on September 26, when the work closed. Circumstances were favorable throughout the season, and the work progressed rapidly.

Field work was resumed in April, when observing scaffolds, tripods, and signals were erected at stations Brown, Cooper, Blue Hill, Herrick, and Sand Creek; a 70-foot scaffold and tripod were built at Brown, and at Cooper a signal pole 108 feet in height was found necessary. By June 30 observations were completed at stations Brown, Lipps, and Cooper, and the party was preparing to move to station Blue Hill, in Nebraska. While at station Lipps three of the boundary monuments on the Kansas and Nebraska State line were found and connected with the triangulation.

During the interval between the field seasons Mr. Granger was engaged in the computation of the triangulation.

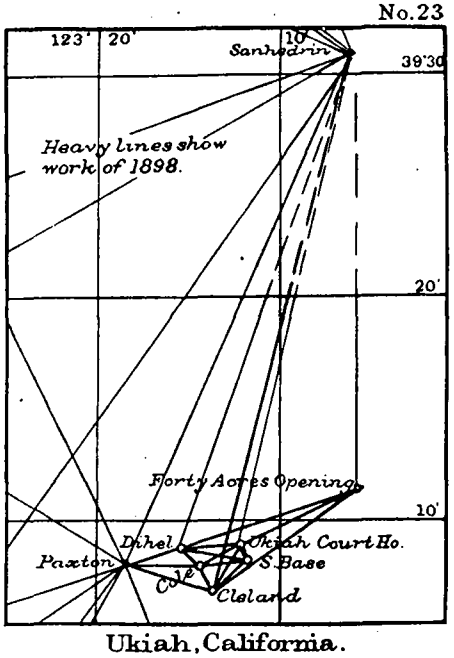
WESTERN DIVISION.

After the selection of the stations in the first quadrilateral of the scheme for the triangulation which was to extend northward from the Salt Lake basin, through Idaho, Mr. P. A. Welker, Assistant, Coast and Geodetic Survey, who was in charge of the work, suspended the reconnoissance and proceeded to occupy the base stations Pilot Peak, Nevada, and Ogden Peak, Utah. The party arrived at Tecoma, Nev , on July 16, and arrangements were commenced for the reoccupation of Pilot Peak, in Nevada, 45 miles distant. The trail to Pilot Peak is rough and difficult, and considerable work was necessary to put it in condition for the use of the pack animals. The outfit arrived at the foot of the mountain on July 24, and by the end of the month everything was at the summit and the party was ready to commence observations. As Pilot Peak had been occupied before, it was necessary to observe only four directions in order to continue the primary triangulation to the northward. The points observed upon were Reference Mark, distant about 2 miles; Oxford, distant 134 miles; Ogden, distant 112 miles; and Cache, distant 83 miles. Observations were prevented on twelve days by unfavorable atmospheric conditions, and by the inexperience of the heliotroper at the most distant station. The party left Pilot Peak on August 22 and reached Ogden station on September 3, but on account of unfavorable weather it was impossible to commence observations before September 6. By September 16 all observations at this station were completed, with satisfactory results. By September 25 the records and computation were completed, the triangulation outfit stored, and the party was ready to recommence the work upon the reconnoissance, which has already been described under the appropriate heading.

In conformity with instructions directing him to connect the longitude stations at Genoa, Carson City, Virginia City, and Verdi, Nev., with the transcontinental triangulation, Mr. C. H. Sinclair, Assistant, Coast and Geodetic Survey, proceeded to Carson City, and on his arrival on August 13 began to secure the necessary teams and to organize the parties which were to be employed in the work. After the intervisibility of certain mountain peaks had been determined, the line Freel Peak to Folsom was selected as a base. This was afterwards strengthened by the introduction of the line East Peak to Folsom. In addition to these stations the main scheme embraced Anderson, Hot Springs Mountain, Overlook, Prison Hill, Mount Davidson, Mount Rose (or

Washoe), Peavine 1893, Verdi Peak, and the smaller stations at Virginia City and Verdi. A continuous scheme was thus laid out to cover the entire region in which the four longitude stations are located, signals were erected at Genoa Peak and Folsom, and Freel Peak (about 11 200 feet above the sea) was occupied between August 21 and 26. East Peak, Genoa Peak, and Folsom were then occupied by Assistant Sinclair, in the order named.

In the meanwhile Mr. A. L. Baldwin, Assistant, Coast and Geodetic Survey, with a subparty, was engaged in connecting the longitude station at Virginia City with Mount Davidson and making a reconnoissance for connecting the longitude station at Verdi with Peavine triangulation station. He then moved to the south end of Carson Valley and occupied Anderson and Hot Springs Mountain, Mr. Sinclair occupying Prison Hill at the same time. The parties then occupied Peavine and Verdi Peak. The stations in the small scheme were then occupied. Three of the stations established by Prof. George Davidson, Assistant, Coast and Geodetic Survey, in 1872, during his determination of the one hundred and twentieth meridian, were recovered and incorporated in the work, giving a satisfactory check upon the triangulation. All observations were finished by September 18, and by September 21 the instruments and outfit had been moved back to Carson City and stored. Assistant Sinclair then proceeded to Ukiah, Cal., to connect the courthouse, whose astronomical position was afterwards determined with the primary triangulation, and to complete the other work, which is described in the account of the astronomical operations (cut No. 23).



Ukiah, California.

For the base of the triangulation scheme to connect the astronomical station with the triangulation, the line Paxton to Mount Sanhedrin was used. Forty Acre Opening, determined from this, and Cleland, Cole 2, and Dihel were put in for the final connection. A base line 1 264·8 meters in length was measured along the railroad with a steel tape as a check on the work. The reconnoissance, erection of signal, observation of angles, and the erection of a pier for azimuth observations at Paxton were completed by October 20. The base line was measured while the longitude and latitude observations at Ukiah were in progress, and horizontal angles were measured at North Base, South Base, and at the magnetic station established in 1897, during the same time. All the geodetic work in this vicinity was completed by December 3.

In May, 1898, Assistant Sinclair resumed the work of connecting astronomical stations in California and Nevada with the triangulation of the transcontinental arc. Arriving at Marysville, Cal., on May 10 a base line was selected and a scheme of triangulation was laid out to connect the astronomical station at that point with the pri-

mary triangulation station Marysville Butte, and the base measurement, triangulation, and astronomical operations were all brought to a successful conclusion in the same month.

The next longitude station to be connected with the triangulation was Austin, Nev. Here the line Toiyabe Dome to Mount Callahan was taken as a base, a point Vegus was established across the valley, 7 miles west of Austin, and the scheme gradually reduced in coming toward Austin. The occupation of all the stations was completed by June 17. The old foundation of the longitude pier at Austin was recovered and connected with the triangulation, as was also the Wheeler Stone of 1871. The point on Mount Prometheus or Lander Hill, 1 mile northeast of Austin, was permanently marked. Assistant Sinclair then proceeded to Eureka, Nev., selecting for the base at this place the line Prospect Peak to Diamond Peak. A signal was erected at the latter station, a point established in the valley to the westward, and the scheme gradually decreased to include Eureka. The foundation of the longitude station was recovered, connected with the triangulation, and securely marked; the Catholic church and the court-house flagstaff were included in the connection. The necessary field work for the connection at Eureka was completed in five days. After completing the records of his work Mr. Sinclair started for Salt Lake City and arrived at that point June 30.

On the completion of reconnoissance operations in southern California Mr. A. T. Mosman, assistant, Coast and Geodetic Survey, who was in charge of the party, made preparations to take up the triangulation. He organized a double party and arranged for the simultaneous occupation of the stations Santa Barbara and Santa Cruz E. Having made all the requisite arrangements, one party was made ready for work at Santa Barbara on June 12. The other party was engaged in the erection of signals and establishing heliotropes at Chaffee, Laguna, and Santa Clara, but owing to continual unfavorable weather this was not accomplished until June 27, and, the same conditions prevailing up to the close of the month, no observations for horizontal directions had been obtained up to the end of the fiscal year.

Mr. J. J. Gilbert, Assistant, Coast and Geodetic Survey, at the beginning of the fiscal year was bringing to completion the triangulation covering the islands of Washington Sound, and on the completion of this work commenced the surveys previously described in the account of the "Coast work" operations.

DIVISION OF ALASKA.

The triangulation in southeastern Alaska was continued during the field season of 1897 by the party on the steamer *Patterson*, Lieut. Commander E. K. Moore, U. S. N., Assistant, Coast and Geodetic Survey, commanding.

On July 15 the survey in the vicinity of Sitka was finished, including the outside work from Salisbury Sound to Sitka Sound, and the gap was closed between the triangulations of 1896 and 1893, thus completing the connection of the two principal astronomical stations, of the southeastern Alaska work, Port Simpson, British Columbia, and Sitka, via Dixon Entrance, Clarence Strait, Frederick Sound, Stephens Passage, Lynn Canal, Chatham and Peril straits. The vessel was then moved to Point Gardner and operations resumed where they had been discontinued at the close of the field season

in 1895. The triangulation was carried from Point Gardner 13 miles into Frederick Sound and connected with that of 1892. It was then carried from Point Gardner 45 miles down Chatham Strait to Point Harris, within 12 miles of Cape Ommaney, the southern extremity of Baranof Island. The work of the party then was confined to hydrographic and topographic operations.

The topographical survey of the Pribilof Islands, made by the party under direction of Mr. Will Ward Duffield, Assistant, Coast and Geodetic Survey, was based on a triangulation which covered all the islands of the group. The principal base on St. Paul Island was a line 4 422·112 meters in length, which was measured three times with a steel tape. The measurement of this line and the occupation of the twelve triangulation stations on the island were executed between June 15 and June 23, 1897. On July 12 the stations on Walrus Island, and on July 13 those on Otter Island, were occupied. On St. George Island the triangulation was based on a line 2 630·84 meters in length, which was measured twice with a steel tape. The fifteen stations on St. George Island were occupied between September 25 and October 4. To provide points for the detailed surveys of seal rookeries, seven small bases were measured on St. Paul Island and five small ones were measured on St. George Island, and from these, by a tertiary triangulation, several hundred prominent rocks, suitably marked for identification, were determined.

(*d*) HYPSOMETRY.

EASTERN DIVISION.

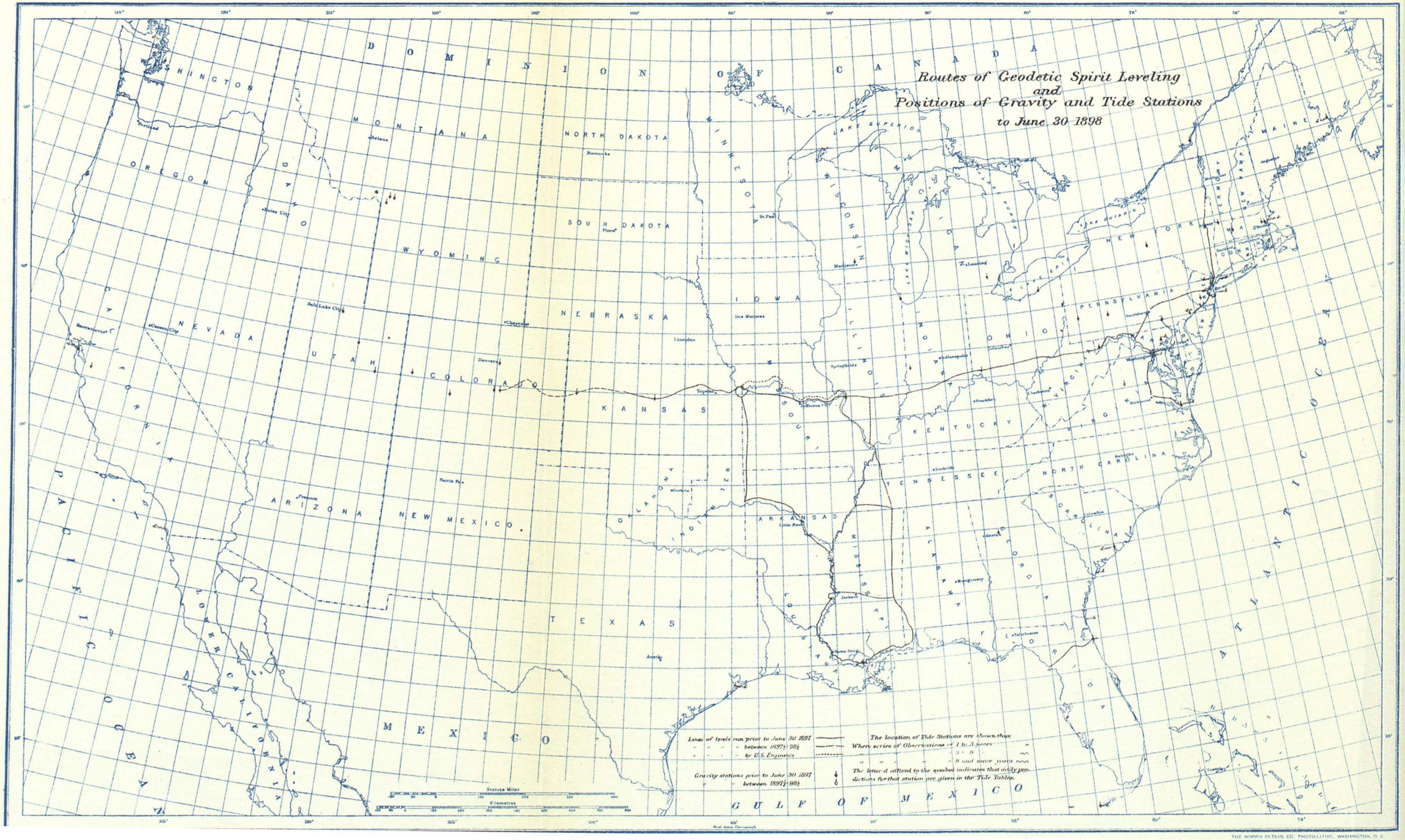
In accordance with the general practice of the Survey, regular sets of vertical angles for the determination of heights were measured on every point to which horizontal directions were observed. This plan was followed at all the stations occupied by Assistants Mosman and Fairfield in the primary work executed by them and described in the section of this report giving account of the "Triangulation" operations.

The heights of the stations selected by Mr. F. W. Perkins, Assistant, Coast and Geodetic Survey, in his reconnoissance for the connection of the Blue Ridge and south Atlantic coast triangulation schemes, depend upon the vertical angles measured in the course of the work. Conclusions as to the height of signals necessary to overcome intervening obstructions are based on the same data.

The spirit leveling in this division was executed by the party under the direction of Mr. H. G. Ogden, Assistant, Coast and Geodetic Survey, in connection with the measurement of the geodetic connection between the triangulations of the east and west coasts of Florida. A single line of Y-levels 56 miles in length was run between Cedar Keys and Gainesville to determine grades in tape measurements. The bench marks of the precise levels across the peninsula from St. Augustine to Cedar Keys, were found in position along the whole length of Mr. Ogden's line and afforded a most satisfactory check.

MIDDLE DIVISION.

The trigonometrical leveling in this division was executed by Mr. F. D. Granger, Assistant, Coast and Geodetic Survey, in connection with the extension of the triangulation northward through Kansas into Nebraska; by Mr. R. L. Faris, Assistant, Coast and Geodetic Survey, in the course of the reconnoissance for a triangulation southward from the Versailles Base, through Missouri, and by Mr. S. Forney, Assistant, Coast



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and Geodetic Survey, in connection with the reconnoissance for the triangulation through Texas and northward toward junction with the initial base for Mr. Granger's work.

The precise leveling operations along the transcontinental arc were resumed by the party under Mr. I. Winston, Assistant, Coast and Geodetic Survey, at Ellis, Kans., on June 11, 1897 (cut No. 24). The route follows the line of the Union Pacific Railroad, Kansas division. The plan of operations was to run a simultaneous double line over the route, using two rods. Permanent bench marks were established at towns and villages on the route whenever practicable. Through the courtesy of the railroad officials this party has been permitted to use velocipede cars for transportation to and from work, a privilege which has greatly facilitated the progress of the work and materially lessened its expenses. The observing tent on wheels, designed by Assistant Winston and constructed in the instrument division under the supervision of Assistant J. F. Pratt, has also greatly aided the rapid advancement of the work, affording complete protection to the instrument from the wind and the sun.

Connection was made with two stations of the transcontinental arc in Colorado, the height of which had been previously determined from the Pacific coast by vertical angle measures.

The work was closed for the season at Hugo, Colo., on November 17, 1897, the statistics of results being:

Number of miles of leveling completed	230·52
Number of bench marks established	29

Assistant Winston was engaged in completing the computation of his season's work at the Office until the middle of April, 1898, when he resumed leveling operations at Hugo. Work was continued with little interruption to the close of the fiscal year, when the party had reached the vicinity of Palmer, Colo. During June levels were run to connect with two of the stations of the primary triangulation. Temporary delay was caused by an accident to the observing tent, which was struck by a passing train, thereby disabling the observer and damaging the leveling instrument.

The number of miles completed to June 30, 1898, was 92·38.

WESTERN DIVISION.

The elevations of the stations selected by Mr. P. A. Welker, Assistant, Coast and Geodetic Survey, for the extension of the primary triangulation northward from the transcontinental arc into Idaho, are based upon the heights of the base stations Pilot Peak, Nevada, and Ogden, Utah. As a preliminary to the prosecution of the reconnoissance, these stations were occupied for the measurement of the horizontal directions and vertical angles to the northern stations, and from these the distances and heights of the stations in the projected scheme were determined.

To satisfy hypsometric requirements of the transcontinental arc between the Atlantic and Pacific coasts, Mr. J. J. Gilbert, Assistant, Coast and Geodetic Survey, was directed in May, 1898, to commence the work of determining trigonometrically the height of certain stations in the main triangulation. The elevations along the thirty-ninth parallel triangulation from the Pacific to Pikes Peak depend on trigonometric leveling. The observations already made not yielding results of sufficient accuracy, it

was proposed to repeat the work across the Sacramento Valley, which was presumably the weakest, by introducing an intermediate station and making additional observations which should be reciprocal and simultaneous. In the course of this work Mr. Gilbert, occupying Pine Hill station, measured the double zenith distances of stations Jackson, Sacramento, Vaca, Monticello, Mount Lola, and Round Top; reciprocal simultaneous observations on Pine Hill being made at each point, except in the case of Round Top, by Mr. F. Morse, Assistant, Coast and Geodetic Survey. Mr. Gilbert's instructions were to obtain five days' observations at all stations except Pine Hill, unless the completion of the fifth day should necessitate more than five days' occupation of any of these stations. On the fifth day of the reciprocal observations between Pine Hill and Jackson the weather became unfavorable, and it was deemed advisable to close work on that line with the last day's observations not quite complete. On June 30 the observations were completed at all the stations specified in the instructions.

Mr. A. T. Mosman, Assistant, Coast and Geodetic Survey, while engaged in the extension of the reconnoissance for the primary triangulation in southern California, carried along a system of vertical angle measurements for the determination of the heights of his stations and for the investigation of the obstacles which affected the intervisibility of the desirable points in his scheme. The locality and extent of this work is described in the account of the reconnoissance operations.

DIVISION OF ALASKA.

The hypsometric determinations of the party on the steamer *Patterson*, under command of Lieut. Commander E. K. Moore, U. S. N., Assistant, Coast and Geodetic Survey, which was engaged in the surveys in southeastern Alaska, noted in the review of the Coast and Geodetic work, were all trigonometric in character; 111 stations were occupied for vertical measures and 428 elevations were determined.

The topographic survey of the Pribilof Islands, executed by the party under the charge of Mr. W. W. Duffield, Assistant, Coast and Geodetic Survey, was based on a trigonometric survey which determined the vertical and horizontal coordinates of all notable points in the islands comprising the group.

(*e*) ASTRONOMICAL WORK.

EASTERN DIVISION.

The observations for latitude and azimuth at Cape Henlopen, Delaware, made by Mr. O. B. French, Assistant, Coast and Geodetic Survey, between September 5 and 13, 1897, complete the field work at the Atlantic end of the transcontinental arc. The azimuth observations were made with a 12-inch theodolite. Fifty series were obtained in seventeen positions of the horizontal circle. Seven nights' observations were required to obtain this number of series, as the clouds and a hazy atmosphere interfered somewhat with the work. Observations for time were secured on nearly every night when azimuth observations were made, and on September 13 for use in the determination of the value of the micrometer screw for latitude work. Twenty pairs of stars were observed for latitude on four nights.

The completion of the triangulation between Atlanta, Ga., and Mobile, Ala., in this fiscal year, made it necessary to secure certain latitudes and azimuths at stations near the southern end of this oblique arc, and Assistant O. B. French was assigned to this duty. The first station occupied was Coon triangulation station, where a latitude was determined, but as it was impracticable to observe an azimuth here without much expense and delay, none was attempted. Kahatchee triangulation station was next visited, and here a latitude and azimuth were observed, the azimuth of Horn triangulation station being determined. At Etheridge triangulation station the azimuth of Lovers' Leap triangulation station was observed. On the completion of work at this station Mr. French returned to Washington, reporting at the Office on June 29.

On the line between Fernandina and Cedar Keys, which connects the triangulation of the Atlantic and Gulf coasts of Florida, the party under Mr. H. G. Ogden, Assistant, Coast and Geodetic Survey, measured an astronomical azimuth at Bronson, Fla. A general account of the other operations of this party is given in the report of "Triangulation work."

MIDDLE DIVISION.

In connection with the survey of Lake Pontchartrain by the party under the direction of Mr. P. A. Welker, Assistant, Coast and Geodetic Survey, an azimuth was measured at Southwest Base and connected with the triangulation scheme of the lake. In the accounts of the Coast and Triangulation Work other details covering the operations completing the survey of the lake by this party are described.

WESTERN DIVISION.

The latitude, longitude, and azimuth operations in California were undertaken to satisfy the requirements of the transcontinental arc along the thirty-ninth parallel, connecting the Atlantic and Pacific coast triangulations, the field work on which is now completed. After completing the connection of the longitude stations with this arc (described in the account of "Triangulation work"), Mr. C. H. Sinclair, Assistant, Coast and Geodetic Survey, proceeded to Paxton triangulation station, and measuring an azimuth there connected it with the triangulation through Mount Sanhedrin. The astronomical station in the scheme (containing Paxton and Mount Sanhedrin) was in Ukiah, Cal. The latitude of this station was determined by five nights observations with a meridian telescope, and the longitude was secured through exchange of time signals with San Francisco on November 17, 23, 25, and 27, and after the observers had exchanged stations, on December 1, 2, and 3. Mr. Sinclair resumed field work in May, and after completing the necessary operations for the connection of the point selected for an astronomical station at Marysville, Cal., with the primary triangulation, a pier was built and the latitude of the station determined by 61 observations on 14 pairs of stars. The work of connecting astronomical stations with the transcontinental triangulation was then resumed and occupied Mr. Sinclair for the remainder of the fiscal year.

DIVISION OF ALASKA.

In the course of the survey of the Pribilof Islands, completed in this fiscal year by the party in charge of Mr. W. W. Duffield, Assistant, Coast and Geodetic Survey, astronomical stations were established on St. Paul and St. George islands. Latitudes

and azimuths were measured at these stations, and the longitude of the group was determined by reciprocal chronometric expeditions between the islands and the United States Coast and Geodetic Survey astronomical station on Unalaska Island.

(*f*) GRAVITY WORK.

The gravity work of the fiscal year was confined to the operations in Bering Sea. The party under Mr. W. W. Duffield, Assistant, Coast and Geodetic Survey, which made the survey of the Pribilof Islands, was equipped with a standard set of pendulums and made the requisite observations on St. Paul Island.

3. MAGNETIC WORK

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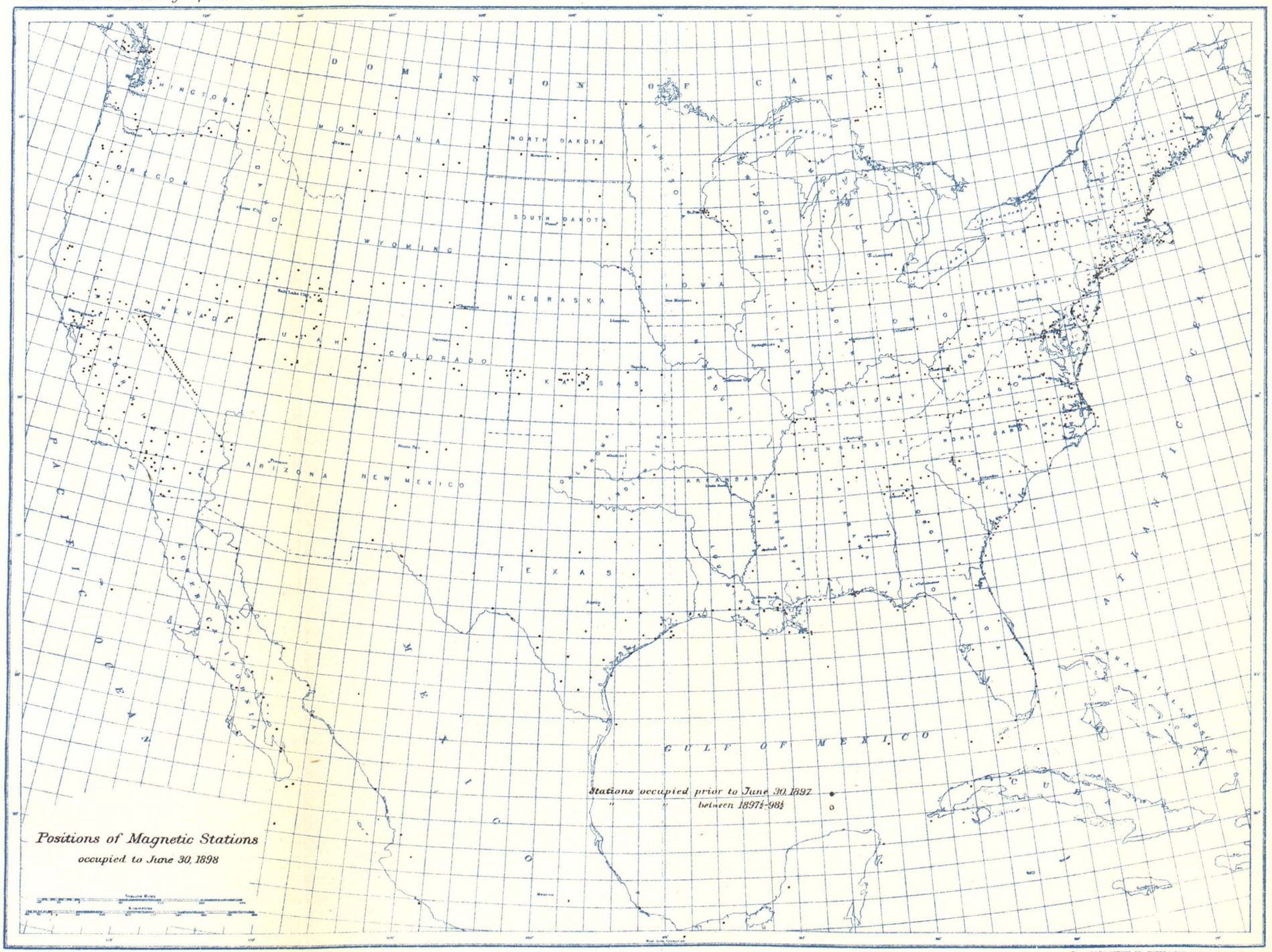

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II. THE SCIENTIFIC AND TECHNICAL RESULTS.

3. MAGNETIC WORK.

(Cut No. 25.)

(*a*) GENERAL STATEMENT.

Work in this important field of inquiry constitutes one of the chief functions of the Survey. No other class of work touches the interests of the people at large more intimately and appeals to them more strongly. Thus, for example, since land boundaries have been in the past, and still are, to a great extent referred to a line—the compass north and south line—which is subject both to progressive and to spasmodic fluctuations, it becomes a matter of paramount importance to have some means for ascertaining the changes taking place during a given interval of years for various localities throughout our dominions. The precise allowance to be made for these changes is the factor which usually causes the surveyor the greatest perplexity. An erroneous estimation will result in the tracing out of a totally different area from that of the original survey, and thus arise the overlappings of areas and the presence of gores and quadrangles between areas surveyed with the compass at various times and by various surveyors. The innumerable and costly litigations over disputed land areas are the inevitable outcome of the lack of proper precautions having been taken in the past. The extreme usefulness of the magnetic work of the Survey in this particular—the supplying of the necessary data for determining the amount of secular change in the compass line—has now become so thoroughly recognized that in the courts throughout the country the Survey is considered as the ultimate authority.[1]

Another extremely important feature of the magnetic work is the supplying of compass data to the mariner. Our world-wide commerce could not exist for a day without the aid of the compass. By day and by night the trembling bit of magnetized steel serves to guide our ships across the trackless seas. It thus becomes absolutely essential for the safety of our passenger and our commercial traffic that the magnetic declination, or the "variation of the compass," as the mariner calls it, be determined whenever opportunity presents itself. And as the amount of "variation" at any one

[1] For the eastern part of the United States the present annual change of declination is about 3 minutes on the average. In twenty years this would amount to 1 degree, which would correspond to a displacement of 92 feet at a distance of 1 mile. In parts of Alaska where the annual change is twice the above amount, or even more, the displacement would be correspondingly increased.

point varies by an appreciable quantity in a comparatively few years, we must ever be in a position to correct the data on our charts. For certain regions the correction in five years will amount to a whole degree.

With this general statement of the character and purposes of the magnetic work we pass to a brief résumé of the field operations.

(*b*) DETAILS OF FIELD WORK.

Observations for the determination of the magnetic declination (variation of the compass), the magnetic inclination, and of the intensity of the earth's magnetic force were made at various stations distributed over Maryland, the District of Columbia, Virginia, West Virginia, Ohio, North Carolina, California, Washington, and Alaska.

When the geographical positions of the stations occupied were not known with the desired degree of accuracy, special observations were made for this purpose.

The instruments principally used for the determination of magnetic declination and intensity are of the combined theodolite and magnetometer type, as illustrated in Appendix No. 8, Report for 1881, pl. No. 36, or Appendix No. 8, Report for 1894, Pl. No. III. The Kew Dip Circle (see illustration in Appendix 8, Report for 1881, pl. No. 37) is the one generally used by the Survey for determining the dip of the magnetic needle.

In conformity with the desire of the Survey to make its work as directly useful as possible, the endeavor was made, first, to make the observation in the vicinity of some generally frequented place, such as a county seat, and, secondly, to mark permanently at that place, by stone monuments, a true north-and-south line for the use of surveyors. Surveyors are thus enabled to determine precisely for themselves the amount of the deviation of the needle from the true north-and-south line, and, by repeating the measurements at some future time, the precise amount of change for the elapsed interval of time. Such standard reference lines are thus of inestimable value.

Mention of the magnetic work in Maryland, conducted by Dr. L. A. Bauer, under the auspices of the Maryland geological survey, might properly be made in this connection, as it is being carried out in cooperation with the Survey. It is the understanding that in return for the loan of the instruments the Survey is to have access to the results when desired.

The following paragraphs contain a more specific reference to the stations occupied:

EASTERN DIVISION.

Assistant O. B. French, between July 7 and August 14, observed the magnetic elements at the following-named county seats in Virginia: Fairfax Court-House, Culpeper, Charlottesville, Houston, Abingdon, Christiansburg, Lexington, and Woodstock. At all these places, with the exception of Houston, meridian lines were established and permanently marked by stone monuments.

Mr. Edwin Smith, extra observer, after occupying the base magnetic station at the Coast and Geodetic Survey Office for the purpose of determining the amount of annual change of the magnetic elements, proceeded next to Gaithersburg, Md., where he made observations on two days. He also, at this station, made an examination as to the availability of various sites for the location of a geodetic observatory where systematic

observations would be made for the purpose of determining the latitude variation in cooperation with the International Geodetic Association. Having carried out the Superintendent's directions in this particular, he resumed his magnetic work and completed observations for declination, intensity, and dip at the following points:

In Virginia: Bristol, Wytheville, Marion, and Tazewell.

In West Virginia: Dunlow, Wayne, Huntington, Alderson, Charleston, Parkersburg, Harrisville, Clarksburg, and Sutton.

In Ohio: Athens.

All of these places were county seats except Bristol, Alderson, and Dunlow, and meridian lines were permanently marked at all the stations, with the exception of Washington, Gaithersburg, and Alderson. Mr. Smith's work was still in progress at the close of the fiscal year.

Assistant J. B. Baylor was engaged upon a magnetic survey of North Carolina, in cooperation with the State geological survey. The precise arrangement under which this important work is being carried out is that the Survey shall furnish the instruments and the observer and provide for his salary, while all field expenses shall be borne by the State of North Carolina. The field work was commenced in March and is still in progress. The county seats at which observations have been made and where permanent meridian marks have thus far been established are: Hillsboro, Durham, Roxboro, Oxford, Warrenton, Plymouth, Windsor, Edenton, Elizabeth City, Currituck, Manteo, Swanquarter, Washington, and Greenville. Magnetic stations were likewise established at Chapel Hill (the seat of the State university), at Chicamicomico, and Cape Hatteras. Because of the isolated positions of the last two stations the observations made at them will have special value.

Assistant C. C. Yates, in April, 1898, was detailed to Morehead City, N. C., in order to establish at that point a self-registering tide gauge. Advantage was taken of this detail and Mr. Yates instructed to reoccupy the station, Beaufort, N. C., at which observations had been made by the Survey in 1880. Thus a fine opportunity was utilized for determining the change in the magnetic elements for the elapsed time.

WESTERN DIVISION.

Assistant H. P. Ritter, on August 23, 1897, began a magnetic campaign, designed to investigate the magnetic conditions in California, which was continued until January 11, 1898. The magnetic work had to be temporarily discontinued from November 12 to December 12, as Mr. Ritter was instructed to make a telegraphic determination of difference of longitude between San Francisco and Ukiah, Cal., in cooperation with Assistant C. H. Sinclair. At the same time Mr. Ritter examined various sites for a geodetic observatory, to be established for the same purpose as the one at Gaithersburg, mentioned above. As a result of Mr. Ritter's work, magnetic observations were made and meridian lines permanently marked at the county seats enumerated, viz: San Rafael, Ukiah, Fairfield, Nevada City, Auburn, Placerville, Sacramento, Marysville, Yuba City, Oroville, Red Bluff, Redding, Willows, Colusa, Woodland, and Napa. After completing the computations of the magnetic observations at the above points, Mr. Ritter reoccupied the Survey magnetic base station at Presidio, San Francisco, and thus determined the amount of annual change.

Assistant J. J. Gilbert, while engaged in the survey of Washington Sound, determined the magnetic elements at Cattle Point, San Juan Island, Washington.

DIVISION OF ALASKA.

Assistant Will Ward Duffield having been instructed to carry on magnetic observations while his party was engaged in a comprehensive survey of the Pribilof Islands, Assistant G. R. Putnam determined the magnetic elements on St. Paul and St. George islands. The work of the topographical party indicating marked irregularity in the distribution of the earth's magnetism in this region, advantage was taken of a delay in the arrival of the vessel which was to carry the party to San Francisco, and an exhaustive investigation of the magnetic conditions of the southeastern portion of St. George Island carried out. Twenty-four stations were occupied and some interesting results obtained, for an account of which the reader is referred to Appendix 5 of this volume.

The above account is sufficient evidence of the earnest with which the Survey is conducting the magnetic work. That not more has been accomplished must be ascribed to the extremely limited allotment for this work.

4. SPECIAL OPERATIONS.

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II. THE SCIENTIFIC AND TECHNICAL RESULTS.

4. SPECIAL OPERATIONS.

(*a*) EASTERN DIVISION.

SPECIAL OPERATIONS IN CONNECTION WITH SPEED TRIALS OF NEWLY CONSTRUCTED VESSELS FOR THE NAVY.

In compliance with requests from the Navy Department, Lieutenant-Commander Dunlap, U. S. N., Assistant, Coast and Geodetic Survey, was directed to hold the steamer *Blake* in readiness to give every possible assistance in the operations necessary for testing the speed of the new torpedo boats, which were tried over the Chesapeake Bay course established by the party on the *Blake* in the last fiscal year. Ten days in the latter part of July and first part of August, 1897, were devoted to these trials by the *Blake*.

On November 8, Mr. D. B. Wainwright, Assistant, Coast and Geodetic Survey was directed to verify the positions of the buoys marking the above-mentioned speed trial course, preparatory to its use for the trial of other vessels. The light-house tender *Maple* was placed at Mr. Wainwright's service on November 10, and by the 13th he had determined the positions of the south terminal buoy, four intermediate ones, the "Mile" buoy and north terminal buoy. All of these were found to be in position except one of the intermediate buoys, to the eastward of Cove Point light-house; this one proved to be 140 meters southeast of its former position. Owing to the high wind and rough sea it was impracticable to shift it.

On July 16, 1897, in accordance with instructions, Lieut. Commander W. J. Barnette U. S. N., Assistant, Coast and Geodetic Survey, in command of the steamer *Bache* moved the steamer to Irvington, on the Hudson, to locate a statute and a nautical mile for a speed-trial course. Considerable difficulty and delay in the completion of this work were caused by the disappearance of nearly all the old triangulation marks in the vicinity. However, the measurement and permanent marking of the courses were successfully finished on August 9, and tracings of the sheets were supplied to the representative of the Navy Department and of the other party interested.

DETERMINATION OF MAGNETIC CHANGES AND REVISION OF DOCK LINES, NEW YORK HARBOR.

On November 22, 1897, Assistant D. B. Wainwright was directed to take the field for the determination of points in the vicinity of New York, to be used as ranges for correcting compasses on vessels; and when this was done to make a reconnoissance and

examination of the harbor lines in the vicinity of Harlem River, in order to bring the chart of that locality up to date. Assistant Wainwright was engaged in this duty until December 23.

DETERMINATION OF THE BOUNDARY LINE BETWEEN THE STATES OF MARYLAND AND VIRGINIA IN TANGIER AND POCOMOKE SOUNDS.

At the request of the State authorities, Messrs. W. C. Hodgkins and J. B. Baylor, Assistants, Coast and Geodetic Survey, were detailed in the latter part of November, to act in conjunction with commissioners appointed by the governors of Maryland and Virginia, in marking the boundary line between those States in Tangier and Pocomoke sounds.

A conference was held at Crisfield, Md., on December 9, 1897, between Col. W. S. Hodson, commissioner for Maryland, Maj. B. T. Gunter, commissioner for Virginia, and Assistants Hodgkins and Baylor, of the Coast and Geodetic Survey, attached to the commissions for Maryland and Virginia, respectively.

A general plan of operations having been decided upon, field work was at once begun and was continued, with a brief intermission during the holidays, until its completion in January.

SPECIAL HYDROGRAPHIC EXAMINATION OF THE TYBEE SUBMERGED BREAKWATER, MADE AT THE REQUEST OF THE WAR DEPARTMENT.

At the request of the honorable Secretary of War, Messrs. H. L. Marindin and F. A. Young, Assistants, Coast and Geodetic Survey, were directed on March 28, 1898, to report to Col. Thomas F. Barr, assistant judge-advocate-general, U. S. A., at Savannah, Ga., for such service as he might require.

Upon reporting to Colonel Barr, on March 29, the party was directed to make an examination of the Tybee submerged breakwater. Two surveys had been made of this breakwater, one by the Government engineers and the other by Messrs. Wisner and Ripley, civil engineers, for Capt. O. M. Carter. A comparison of the results indicated some disagreement, which it was deemed necessary to explain, if possible. The breakwater being 3 miles offshore and no part of it projecting above the surface of the water, the examination was attended with considerable difficulty. It was necessary first to locate the breakwater and then to buoy its ends and angles. The length is about 700 feet, with a projected width of 100 feet. About 47 cross sections and from 3 to 5 longitudinal sections were determined.

The positions of the soundings were obtained by two observers at stations on shore, supplemented in many cases by sextant angles at the sounding boat.

At the beginning of the work a board of survey had been appointed, consisting of Captain Gaillard, Corps of Engineers, U. S. A., and Assistants Marindin and Young, United States Coast and Geodetic Survey; Captain Gaillard was recalled to Washington and Captain Townsend, Corps of Engineers, U. S. A., who was appointed in his stead, accompanied the sounding boat while the depths were measured. The plat of the cross sections was made at the United States Engineer Office at Savannah by a draftsman who had no connection with the court-martial, and in the presence of Captain Townsend and Assistants Marindin and Young.

On April 23 the results of the survey, accompanied by a plan of the cross and longitudinal sections, were placed by Assistant Marindin before the court-martial by order of Colonel Barr, the judge-advocate. All the records of the survey were deposited in the United States Engineer Office at Savannah, in charge of Captain Gillette, Corps of Engineers, U. S. A.

SERVICES ON MISSISSIPPI RIVER COMMISSION.

In addition to other duties in the field and Office, Mr. H. L. Marindin, Assistant, Coast and Geodetic Survey, served throughout the year as a member of the Mississippi River Commission and attended the meetings of the commission when called upon.

HYDROGRAPHIC SURVEYS AT KEY WEST AND TORTUGAS, MADE AT THE REQUEST OF THE NAVY DEPARTMENT, AND SPECIAL SERVICE IN CONNECTION WITH THE NAVY.

On December 7, 1897, the steamer *Bache*, under command of Lieut. Commander W. J. Barnette, U. S. N., Assistant, Coast and Geodetic Survey, left New York and proceeded to the Dry Tortugas, Florida, and arriving at the latter place on December 14, at once began the resurvey of Tortugas Harbor and approaches, as requested by the Navy Department. During the progress of this survey two rocks, designated the "Texas rock" and the "Iowa rock," were discovered.

After February 16, by direction of the Superintendent, the vessel was placed at the disposal of the Navy Department and was used in transferring divers and helpers to Havana and the injured men of the *Maine* from Havana to Tortugas. The survey in the vicinity of Tortugas was continued as opportunities occurred. On April 12 Lieut. A. H. Davis, U. S. N., Assistant, Coast and Geodetic Survey, relieved Lieutenant Commander Barnette of the command of the vessel, and afterwards continued the work until May 25. Early in June the *Bache* was taken to the Washington Navy-Yard, and on June 12 Lieutenant Davis was relieved in command by Mr. P. A. Welker, Assistant Coast and Geodetic Survey, and shortly afterwards the vessel was taken to Baltimore for repairs.

Upon completion of repairs at Baltimore the steamer *Blake*, under command of Commander A. Dunlap, U. S. N., Assistant, Coast and Geodetic Survey, started for Key West, Fla., on March 21, 1898, for the purpose of making special hydrographic survey asked for by the Navy Department. On her arrival at the latter place the commander in chief of the North Atlantic station requested the location of an anchorage ground suitable for the larger ships of war, inside the outer line of reefs at the entrance of the southern channel to Key West from the Gulf. The requirements for the anchorage were an entrance with least depth of 30 feet and least width of 300 feet, and an anchorage depth of no less than 36 feet. The charts indicated such a locality inside the entrance to the main ship channel and between the outer and inner lines of reefs, and an exceedingly close survey was made covering about 3 square miles, with special attention to the main channel. Numerous coral heads found in the western part of the area reduce the available anchorage to about 1 square mile, the general depth being between 40 and 42 feet. The main channel entrance as then buoyed was found to be impracticable, the fairway being narrowed to a spot about 150 feet long by 25 feet wide. However, a good channel with no less than 32 feet depth and 400 feet width was developed to the eastward of the old channel. The new channel and the anchorage were marked by speci-

buoys, the results platted and sheet and tracing furnished to the commander in chief. Commander Dunlap was detached from the *Blake* by order of the Navy Department in the latter part of April, and Ensign J. H. Reid, U. S. N., Assistant, Coast and Geodetic Survey, succeeding him in command, remained in charge of the party until the above-described work was finished, when he brought the vessel to the navy-yard at Washington, D. C., arriving there on June 27, when he was detached by order of the Navy Department.

OPERATIONS UNDERTAKEN IN COMPLIANCE WITH SPECIAL ACT OF CONGRESS.

SPECIAL HYDROGRAPHIC SURVEY OF THE BAR AT THE ENTRANCE TO BRUNSWICK HARBOR, GEORGIA.

On November 6, 1897, Mr. H. L. Marindin, Assistant, Coast and Geodetic Survey, was directed to report to the honorable the Secretary of War for duty in connection with a survey of Brunswick Outer Bar, Georgia, required by the act of Congress of June 3, 1896, relating to the improvement of Brunswick Harbor.

He reported in person to the Secretary of War, was supplied with the necessary instructions and data, and having organized a party for the work, proceeded to Brunswick, arriving there on November 18. A small tugboat was chartered for the sounding work. All expenses of the survey, except the salaries of the Coast and Geodetic officers engaged, were borne by the War Department.

Owing to the exposed nature of the bar and the extreme accuracy required, progress in the work was necessarily slow. As the survey progressed limited areas were found having a less depth than that required by the act of Congress. This information, by authority of the War Department, was communicated to the contractors, who applied to the Department for permission to dredge these spots before the completion of the examination. Permission being granted, the requisite dredging was done, the survey being suspended in the interval. In consequence of this dredging it became necessary to survey portions of the channels over the bar no less than three times. The examination was finally completed on February 14, 1898, and the results were communicated to the War Department in a report by Assistant Marindin, dated April 24.

The act of June 3, 1896, before referred to, requires that the Coast and Geodetic Survey officer making the survey shall make to Congress a report in detail of the work done, its cost, and value to the Government. Assistant Marindin's report to the Secretary of War related more specifically to the results obtained in the navigable channels, the questions of cost and value to the Government not being touched upon. Assistant Marindin has begun the collection of the data bearing on these questions.

(*b*) DIVISION OF ALASKA.

EXPLORATIONS IN THE VICINITY OF MOUNT ST. ELIAS, ALASKA.

As mentioned in the last Annual Report, Mr. E. B. Latham, Assistant, Coast and Geodetic Survey, was detailed in the spring of 1897 to accompany a party, under the charge of Prof. H. G. Bryant, of Philadelphia, having in view the exploration of the region in the vicinity of Mount St. Elias, Alaska.

On July 1 the party had made a landing on the north side of Yakutat Bay, established a supply camp, and started to cross the Malaspina Glacier. The Indian packers insisted on returning after the delivery of their loads at the edge of the ice, and when the party reached the western flank of the Samovar Hills one of the men was stricken with an illness of such severity that it was absolutely necessary to leave him in charge of another member of the expedition. The remainder of the party, now reduced to four men, continued for a time the arduous labor of advancing the supplies to the foot of St. Elias, but the condition of the snow and the great diminution in force finally made the task an impossible one and the project for the ascent of the mountain had to be abandoned. While detained near the Samovar Hills topographic sketches were made of country visible from the summits in the vicinity of the camp. These were supplemented by a reconnoissance of the region to the southwest of Mount St. Elias.

The conclusions reached by the party are: That the snow is in the best condition for travel in April or May, and that a party starting into the interior should be at Yakutat early in April; the best landing from which to reach Mount St. Elias is in the vicinity of the Yahtse River, about 20 miles from the Samovar Hills; Indians should be employed to make landings, as their light boats are more easily managed in the surf than other boats; a party intending to make the ascent of Mount St. Elias should not consist of less than ten persons.

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5. PUBLICATION OF RESULTS.

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II. THE SCIENTIFIC AND TECHNICAL RESULTS.

5. PUBLICATION OF RESULTS.

(*a*) GENERAL STATEMENT.

Publication is, in a scientific survey, a more complicated and particular branch of work than is usually comprehended under that term. In the first place, to transform the scientific data acquired in geodetic, hydrographic, and topographic operations into terms of a plane surface requires the use of the highest skill of geometric science. It demands that the refinements of mathematics, astronomy, and geodetics shall be adjusted to the narrow limitations of paper and ink. Different styles of projection must be taken into account. Add to all this the difficulties to be overcome in the very paper upon which the chart is to be printed—the expansion, the character of the surface, and many other problems connected with the paper maker's art, which, if not taken into account, may neutralize a vast deal of scientific accuracy—and it will be seen that the task here to be taken up has little in common with the ordinary methods of printing and publishing. The corrections alone, which must constantly be made, multiply the difficulties of the problem. It is for these reasons that the Survey, from the very beginning, has been compelled to retain under its immediate supervision, and as a distinct branch of its work, an engraving and printing establishment, with a force of men skilled in the cartographic art.

The work, whether begun on the slopes of the Rockies or on the coast of the Atlantic, can not be considered complete until it has been incorporated into one of the numerous publications of the Survey. When a chart is ready for use in the captain's cabin, then only are the ends satisfied for which that particular field work was commenced. The scientific results of the investigation of the form of the earth, or of the progress of the tidal wave, or of the declination of the needle, or of the oscillation of the pendulum—although all of these operations involve an enormous amount of observation, compilation, computation, and discusssion—only satisfy their complete purpose when they are laid in printed form before the scientific world. The importance of prompt publication was for these and other reasons early appreciated, and almost simultaneously with the organization of the Survey appear the reports, charts, and special publications which have in the intervening fifty-six years assumed the proportions indicated in the last bibliography of the Survey's publications of an octavo volume of 118 pages. The editorial labors connected with the issue of these publications are delegated by the Superintendent to two boards—one the chart board, the other the publication board—each having jurisdiction over their respective fields. Before them are passed in review all additions and changes as to form or matter.

The charts and topographic sheets are drawn, engraved, electrotyped, and printed by the drawing and engraving division. Charts are issued free only to Congressmen, Government departments, and exchange institutions. They are sold to the general public through the Survey Office itself, or through the medium of agents designated for that purpose in each of the principal cities and seacoast towns of the country.

The textual publications are printed by the Public Printer and are distributed through the miscellaneous division.

Copies of all of the charts and publications as printed are preserved in the library and archives.

(*b*) CHARTS.

The first catalogue of charts was issued by the Survey in 1843 and consisted of a small folio containing a list of eight charts. This comprised all of the charts issued between the years 1835 and 1842. At the beginning of the civil war this list had grown to 6 pages quarto, containing a description of 278 Coast-Survey maps, preliminary charts and sketches geographically arranged. Two decades later, in 1880, a 45-page quarto catalogue described 409 charts, and in 1897 this had assumed the proportions of a 142-page quarto catalogue with 501 maps and charts. The average number of copies of these charts issued for each year from 1889 to 1897 inclusive was 55 331, of the average annual value of $23 574. The total number printed during the present fiscal year is 110 398, valued at $43 773·20.

PROCESSES EMPLOYED IN CHART PRODUCTION.

The construction and publication of charts of the United States Coast and Geodetic Survey is peculiarly the work of the drawing and engraving division. With few exceptions the charts are published on the polyconic projection and on a scale smaller than the original field sheets. Upon the completion of the field work covering a certain area a scheme for a chart in the locality is proposed which shows roughly the projection, scale, and amount of detail required for the chart. Upon this scheme any alterations or changes deemed necessary by the Office are made, and, the scheme having been finally decided upon, the drawing itself is begun in the drawing section. At the completion of the drawing all details of the field work are shown consistent with the scale to which the reduction is made, the reduction being made by proportional squares from the field sheets. It very rarely occurs that a chart is published on a scale larger than the field sheet, although 1–10 000 scale are frequently used for both field work and chart publication. The details of the drawing includes houses, roads, forest, cultivated land, fences, contours of elevation, and indeed all topographic features, while on the water only such soundings are selected from the original sheets as will show the characteristic features of the bottom, and curves of varying depths are used in a similar manner to the contours of elevation on the land. To publish all soundings shown on the original hydrographic sheets would merely lead to confusion, therefore only the characteristic ones are selected from the thousands on the original. On most of the published charts of the United States Coast and Geodetic Survey the water is sanded to a depth of 18 feet, after which the varying depths are shown by standard fathom curves. This sanding process serves to bring out more distinctly the deep-water channels by contrast of the white unshaded portions with the sanded areas.

As the process of engraving charts on copper is a slow one, the chart is usually published first by photolithography and is continued in that form until the engraved plate is completed. It frequently occurs that a chart is issued of a region whose survey is not entirely completed, and which depends for a large part of the data upon our reconnoissance work or sources outside of this Survey. In cases of this kind the chart is usually continued as a photolithograph until this Survey has completed its work in the region of the chart. This is necessitated on account of the numerous and radical changes occurring on such charts as new data is received from year to year, and which it would be impossible to show on copper plates.

Most of the charts of the coast of the United States proper, however, are now published from engraved copper plates. This produces, of course, a much finer chart in appearance than a photolithograph. Even on these standard charts changes are constantly occurring, owing to improvements on land, railroads, city surveys, the work of the Corps of Engineers, United States Army, in dredging channels, widening and improving harbors, etc., together with the constant changing and shifting of aids to navigation, such as lights, buoys, sailing lines, etc. Where such changes affecting the copper plates are not too extensive the printing plate itself is corrected by bumping up and erasing the old work and reengraving the new work in its proper position. Where the changes are of large extent it is customary to make them by erasing from the alto plate (referred to later) before making a new basso plate, thus avoiding distortion of the plate by too much bumping.

Lithograph charts are usually printed by contract in editions of 300 copies, and changes occurring from time to time are made by hand in the chart section of the inspector of charts division. The copper plates, however, are printed in the printing section of the drawing and engraving division in editions of from 30 to 50 copies at a time, and before each print the plate is corrected to date, thus eliminating to a large extent the hand corrections and thereby improving the appearance of the chart. Whenever the changes on the lithograph chart become too extensive for hand corrections, the charts on hand are canceled and a new edition published. When similar changes occur on copper-plate charts the charts are also made new editions and new basso plates for same brought up to date.

Charts are rarely printed to any extent from the original plates, as it is advisable that these be preserved in the vaults of the Office for future reference. As soon as the engraving of the plate is completed and a few charts are published, a thin alto is made by the ordinary electrotyping process, and from this alto a basso or printing plate is made, similar in every detail to the original plate as engraved. This basso becomes the standard printing plate, and the original engraved plate is retired. Each basso plate is capable of printing from 2 000 to 5 000 impressions, according to the fineness and detail of work shown thereon. As soon as the plate begins to grow faint from wear, a new basso or printing plate is made from the original alto, only such changes being made as are necessitated by the causes previously referred to. If these changes have been extensive, before the second basso plate is used as a printing plate, a new alto is made from it, which now becomes the standard for that chart, and the original alto is retired. This second basso, being made from the original alto, has all the strength of the original plate, and the new work being engraved, the second alto is as strong as the original. This process

is continued indefinitely. Some of the older or standard charts have already passed through a series of from four to ten altos. Each basso or printing plate, as it becomes worn out, is also retained and kept in the vaults of the Office. This process enables the Office to reproduce at any time a chart showing its condition at any date, save for the minor corrections of aids to navigation.

In the printing section of the drawing and engraving division four large power presses are used, capable of printing from plates up to 36 by 44 inches in size. The process is as follows:

Owing to the unequal thickness and inequalities of the plates, resulting from numerous corrections and other causes, it is first necessary to thoroughly pack the plate. An impression is first taken, which shows the weak portions resulting from this inequality in thickness. A bed is then formed by packing with paper under the thin portions until the plate surface is brought in perfect contact with the roller, when the impression will be strong and distinct throughout. The plates are inked and wiped entirely by hand, and it usually requires on an average about five minutes for each impression. A day's output of charts on each press, employing two men, varies from 40 to 60 charts, depending on the size of the plate.

The paper on which the charts are printed is wet and allowed to lie in piles for twenty-four hours, each sheet being once shifted and turned during this time in order to soften the surface, so that it will readily take the ink from the engraved plate. After printing they are allowed to dry, and are then calendered by hydraulic pressure, the pressure used being in the neighborhood of 600 tons. Remaining under this pressure for twelve hours, they come out hard and smooth, and are then ready for issue, save for the coloring of the buoys, light sectors, etc., which is done in the chart section.

It occasionally becomes necessary, owing to the large issue of a chart, to publish a lithograph edition of that chart by transfer from the copper plate. When this occurs the transfer is pulled in the printing section and sent to the lithographer. This is transferred direct to the stone and is used in lieu of the photolithograph process.

After an edition has been printed from a copper plate the plate is heated slightly and then covered with a thin coat of paraffine, on which tissue paper is spread before returning to the vaults. This prevents the plate from tarnishing or from being injured by scratches until used again.

(*c*) TEXTUAL PUBLICATIONS.

[For detailed lists of publications sent to printer, received from printer, and issued to the public see report of the miscellaneous division, under the head of "Administration."]

ANNUAL REPORTS AND SCIENTIFIC APPENDICES.

The two parts into which the report of last year was divided have now been combined in one. In order to provide institutions and individuals, who receive the reports in exchange or otherwise, with all of the scientific results of the Survey, a plan has been evolved of publishing in the report, as appendices, all of the papers of this character, whether issued separately afterwards or not.

BULLETINS.

One new bulletin, No. 36, entitled "Table of depths for channels and harbors, coasts of the United States," has been issued in quarto form.

NOTICE TO MARINERS.

These are circulars issued monthly, and are usually made up of chart corrections. For special purposes extra numbers appear.

TIDE TABLES.

Tide tables are published annually and now give the predicted time and height of every high and every low water throughout the year for seventy principal ports, of which twenty-five are within the territory of the United States. Predictions are extended to about 3,000 subordinate points, about one-third of which are home stations. Other information pertinent to the subject is incorporated in these publications, such as a brief treatise on tides, general information as to the saving of life, weather and temperature signals, times of sunrise and sunset, etc.

COAST PILOT.

The publication of the Coast Pilot was commenced in 1850. Its preparation, except when discontinued during the civil war and Spanish-American war, has been regularly carried on to the present time. As their title indicates, they are issued almost exclusively to mariners and must, in the nature of the case, be constantly corrected to meet the changes of buoys, light-houses, and shore points. Nine volumes have now been issued, of which two are for the Pacific Coast and Alaska.

SPECIAL PUBLICATIONS.

Special Publication No. 1, "Magnetic ranges for determining the deviation of the compass, San Francisco Bay," has been issued during the year.

Seventeen catalogues of charts have been published up to the present time. The last edition, that of March, 1898, having 2,614 copies. These catalogues contain a list of about 500 charts and maps.

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SECTION III.

THE ADMINISTRATION.

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SECTION III.

THE ADMINISTRATION.

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THE ADMINISTRATION.

1. GENERAL STATEMENT.

The preceding pages present the actual results, both scientific and practical, achieved by the different branches of the Survey. Only incidental mention has been made of the general organization by which the observations in the field, scientific and practical deductions, and the publication to the world of these results have been brought about.

Although the divisions of the Survey may be, in a general way, grouped under the divisions of field and office, yet this is, after all, an insufficient characterization of the work, nor does it convey an accurate idea of the division of labor. Often, in the case of hurried work, a field party, after making observations, will proceed to compute upon the spot the results from the data obtained. On the other hand, the completion of field work is often reserved by field assistants for work in the Office during the less pressing parts of the season. The Assistants themselves are interchangeably assigned to work in the field, or to scientific or administrative duty in the various divisions, as exigency requires. It is therefore impracticable to draw any line between the work performed within or without the Survey headquarters, but rather to base the organization upon the actual character of the work in which the entire force is employed.

The Superintendent is, of course, the responsible head of the Survey, to whom all branches or divisions of the work, whether scientific or practical, are directly subordinate. He is assisted in his immediate office by an executive officer, who is also an Assistant, and by another Assistant in the management of the suboffice in San Francisco.

Other details of an executive character come under the cognizance of three offices, whose titles sufficiently indicate the scope of their work. The Assistant in charge of the office and topography; the offices of the hydrographic inspector; and the disbursing agent. The officers designated as Assistants compose the scientific staff, who have the immediate direction of operations in various parts of the country, or who are employed on other work essential to the completion of special scientific pursuits in which the Survey is engaged.

The computing offices include the geodetic and tidal divisions.

The publication office for charts comprises the drawing and engraving and the chart divisions

The accessory offices are the instrument, library and archives, and miscellaneous divisions, and the suboffice in San Francisco.

In the review that follows, the work of the different accessory divisions will be considered in connection with the administrative divisions to which they are immediately subordinate.

SUPERINTENDENCE.

Gen. W. W. DUFFIELD, Superintendent, July 1, 1897, to November 30, 1897.
Dr. HENRY S. PRITCHETT, Superintendent, December 1, 1897, to June 30, 1898.
Mr. E. D. PRESTON, Assistant, Coast and Geodetic Survey, executive officer, July 1, 1897, to June 30, 1898.
Mr. A. F. RODGERS, Assistant, Coast and Geodetic Survey, in charge of suboffice, San Francisco, July 1, 1897, to June 30, 1898.
Mr. E. F. DICKINS, Assistant, Coast and Geodetic Survey, acting in charge of suboffice.
Mr. W. B. CHILTON, clerk, July 1, 1897, to June 30, 1898.
Mr. A. H. BAILEY, confidential clerk, July 1, 1897, to December 5, 1897.
Mr. W. H. EMERY, confidential clerk, December 6, 1897, to June 30, 1898.
Mr. FRANK W. EDMONDS, clerk, July 1, 1897, to June 30, 1898.

The Superintendency of the Coast and Geodetic Survey at the beginning of the fiscal year was held by Gen. W. W. Duffield, and upon his resignation taking effect, the duties were assumed by the present Superintendent on December 1, 1897.

At the date of assumption of office by the present incumbent the first half of the fiscal year was drawing to its close; the work of the Survey in that period had been executed in conformity with the plans made by his predecessor, and as the appropriations for the Coast and Geodetic Survey for the fiscal year 1897–98 were made in accordance with General Duffield's estimates, the line of operations for the Survey during the remainder of the fiscal year was practically determined. New questions of moment afterwards disposed of were the preparation of plans of operation for the extensive surveys in Alaska provided for in the appropriation of 1898; the construction of the new steamer for Alaskan work; the change of plans for hydrographic operations necessitated by the sudden withdrawal of the naval officers from the Office and Coast and Geodetic Survey vessels; and the utilization of the resources of the Survey to furnish the greatest possible amount of assistance to the military authorities during the war.

The Superintendent's decisions on all matters connected with operations of the Survey are formulated by the executive officer, who attends to the details connected with the issue of instructions for all work, the organization of the field parties, and allotment of estimates. The official mail is received by him and he has charge of the letters, reports, and documents which comprise the record of the work of the Survey, as shown by the Superintendent's files. The duties of this position were executed by Mr. E. D. Preston, Assistant, Coast and Geodetic Survey, who continued to act as executive officer throughout the year.

The suboffice in San Francisco was in charge of Mr. A. F. Rodgers, Assistant, Coast and Geodetic Survey, from July 1, 1897, to September 8, 1897, and from October 22, 1897, to June 30, 1898. Mr. E. F. Dickins, Assistant, Coast and Geodetic Survey, was in charge of this Office from September 8, 1897, to October 22, 1897. In addition to furnishing information in reply to the many requests from Government officials and private individuals, attending to the storage and issue of the Government property in the suboffice, Assistant Rodgers prepared estimates and made arrangements and plans for the erection of an automatic tidal indicator in San Francisco Bay; attended to the preparation of instruments and equipment for the Alaskan parties, and supervised the construction of the steam launch *Taku* and the outfitting of the steamer *Gedney*. On the detachment from service in the Coast and Geodetic Survey of the naval officers on

the *McArthur*, the steamer was placed under Assistant Rodgers's charge, as were also the Steamers *Patterson* and *Gedney* on their retransfer to the Treasury Department. His duties also embraced the supervision of the tidal stations and the topographical operations in San Francisco Bay.

2. ASSISTANTS.

In order to present a full list of the Assistants employed between July 1, 1897, and June 30, 1898, they are printed below, although their work is of so varied a character and they are so frequently interchanged from one class of operations to another that the duties of each can not be definitely stated. Reference must be made to the pages on hydrography and topography for a description of the work they have performed in the field, and to administration for a statement of the assistance they have rendered in the compilation and publication of results. A schedule showing the details to field duty is given on a subsequent page.

ASSISTANTS.

Names.	Occupation at end of fiscal year.
C. A. Schott	In charge of computing division.
A. F. Rodgers	In charge of suboffice, San Francisco.
O. H. Tittmann	Assistant in charge of office, Washington.
A. Braid	In charge of office of weights and measures, and of publications.
A. T. Mosman	Primary triangulation, southern California.
H. G. Ogden	Inspection of field work, Chesapeake Bay.
W. W. Duffield	Chief of drawing and engraving division.
E. D. Preston	Executive officer.
C. H. Sinclair	Field work, California and Nevada boundary.
W. Eimbeck	Acting chief of library and archives.
F. D. Granger	Field work, Kansas.
F. W. Perkins	Field work, Maryland.
J. J. Gilbert	Field work, California.
H. L. Marindin	Field work, Chesapeake Bay.
J. F. Pratt	Field work, Alaska, mouth of Yukon River.
E. F. Dickins	Field work, San Francisco Bay.
D. B. Wainwright	Field work, Baltimore Harbor.
L. Winston	Field work, Colorado.
W. C. Hodgkins	Field work, Marthas Vineyard, Massachusetts.
P. A. Welker	Field work, Chesapeake Bay.
J. B. Baylor	Field work, North Carolina.
J. A. Flemer	Field work, Alaska.
S. Forney	Field work, Texas.
J. Nelson	Field work, Alaska.
F. Morse	Field work, California.
G. Bradford	In charge of chart division and acting hydrographic inspector.
W. B. Fairfield	Field work, southern California.
W. J. Vinal	Field work, Chester River, Maryland.
C. T. Iardella	Died October 27, 1897.
H. M. Clapp	Detailed to supervising special agent's office.
G. R. Putnam	Field work, Alaska.
F. A. Young	Field work, Alaska.
F. Westdahl	Field work, San Francisco Bay.
E. B. Latham	Field work, Alaska.
A. L. Baldwin	Field work, Alaska.
H. P. Ritter	Field work, Alaska.
R. L. Faris	Field work, Alaska.
G. L. Flower	Field work, Chesapeake Bay.
O. B. French	Office work, Washington.
C. C. Yates	Field Work, Chesapeake Bay.

AIDS.

Names.	Occupation at end of fiscal year.
H. C. Denson	Field work, Alaska.
A. F. Zust	Office duty.
R. B. Derickson	Field work, Alaska.
W. Bowie	Field work, Chesapeake Bay.
H. F. Flynn	Field work, Chesapeake Bay.

Only a small number of aids are on the permanent force of the Survey. The method of appointing for temporary service on particular expeditions and surveys has been found eminently satisfactory. Their duties are such as require, for the higher classes of work, technical training and education. For this reason appointments have been made largely from young men, graduates or students at the colleges, or from those who have in previous connection with the Survey exhibited special fitness for this class of work.

3. DETAILS OF FIELD OPERATIONS.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, and in the interior of the United States during the fiscal year ending June 30, 1898.

1. EASTERN DIVISION.

STATES EAST OF THE MISSISSIPPI RIVER.

1. Maine.
2. New Hampshire.
3. Vermont.
4. Massachusetts.
5. Rhode Island.
6. Connecticut.
7. New York.
8. New Jersey.
9. Pennsylvania.
10. Delaware.
11. Maryland.
12. District of Columbia.
13. Virginia.
14. North Carolina.
15. South Carolina.
16. Georgia.
17. Florida.
18. Alabama.
19. Mississippi.
20. Michigan.
21. Wisconsin.
22. Ohio.
23. Indiana.
24. Illinois.
25. West Virginia.
26. Kentucky.
27. Tennessee.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
Vermont, New York, and Canada.	1	Triangulation	A. T. Mosman, Assistant	Completion of observations for the connection of Mount Royal, near Montreal, with the primary triangulation in Vermont and New York.
Massachusetts	2	Topography	W. I. Vinal, Assistant	Continuation of the topographical survey of Marthas Vineyard and the adjacent islands.
Massachusetts	3	Topography	W. C. Hodgkins, Assistant	Continuation of the topographical survey of Marthas Vineyard.
Massachusetts	4	Hydrography	Lieut. Commander W. J. Barnette, U. S. N., Assistant.	Hydrographic survey of the "Haulover," Nantucket Harbor, and hydrographic examinations at Gloucester Harbor.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, etc.—Continued.

1. EASTERN DIVISION—Continued.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
Massachusetts	5	Hydrography	Lieut. G. C. Hanus, U. S. N., Assistant.	Continuation of the hydrographic survey of Buzzards Bay.
Massachusetts	6	Hydrography	Lieut. Commander C. T. Forse, U. S. N., Assistant.	Hydrographic survey of Buzzards Bay and examinations of reported changes along the coast.
Rhode Island	7	Triangulation	D. B. Wainwright, Assistant.	Continuation of determinations of geographical positions of light-houses in Narragansett Bay and Providence River, Rhode Island.
Rhode Island, Connecticut, and New York.	8	Hydrography	Lieut. Commander W. J. Barnette, U. S. N., Assistant.	Hydrographic examinations off the coasts of Long Island and Block Island.
New York	9	Tidal observations.	J. G. Spaulding, tidal observer.	Continuation of the tidal record and the automatic tidal indicator at Fort Hamilton tidal station, New York Harbor.
Delaware	10	Azimuth	O. B. French, Assistant	Determination of an azimuth at Cape Henlopen, Delaware.
Delaware	11	Tidal observations.	Dr. R. M. Woodward, U. S. Marine-Hospital Service.	Continuation of the tidal record and the automatic tidal indicator at Reedy Island, Delaware River.
Maryland	12	Inspection of field work.	H. G. Ogden, Assistant	Inspection and general charge of field work; resurvey of Chesapeake Bay.
Maryland	13	Topography	J. W. Donn	Resurvey of Chesapeake Bay; topography in vicinity of Baltimore.
Maryland	14	Hydrography	D. B. Wainwright, Assistant.	Hydrographic resurvey of Chesapeake Bay to the northward of Tolchester Beach.
Maryland	15	Hydrography	Lieut. Commander A. Dunlap, U. S. N., Assistant.	Resurvey of Chesapeake Bay; hydrography of entrance to Baltimore Harbor.
Maryland	16	Hydrography	Lieut. Commander C. T. Forse, U. S. N., Assistant; Lieut. E. Simpson, U. S. N., Assistant; D. B. Wainwright, Assistant.	Hydrography, Baltimore Harbor.
Maryland	17	Hydrography	Lieut. G. C. Hanus, U. S. N., Assistant; Lieut. M. E. Hall, U. S. N., Assistant; Ensign H. A. Wiley, U. S. N., Assistant; H. L. Marindin, Assistant.	Resurvey of Chesapeake Bay; hydrography in the vicinity of Baltimore.
Maryland	18	Current observations.	Lieut. E. H. Tillman, U. S. N., Assistant; R. L. Faris, Assistant.	Observations of currents in Chesapeake Bay.
Maryland	19	Topography	William Bowie, Aid	Resurvey of Chesapeake Bay; topography of north shore of Patapsco River and Middle River and of Patapsco Neck and vicinity.
Maryland	20	Topography	H. G. Ogden, Assistant; O. B. French, Assistant.	Resurvey of Chesapeake Bay; topography from Gibson Island and north shore of Magothy River to and including the Patapsco River as far as Colgate Creek.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, etc.—Continued.

1. EASTERN DIVISION—Continued.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
Maryland	21	Triangulation, topography, and hydrography.	J. B. Boutelle	Survey of Magothy River.
Maryland	22	Triangulation and topography.	J. A. Flemer, Assistant	Resurvey of Chesapeake Bay and tributaries, and topography of Chester River.
Maryland	23	Hydrography	W. I. Vinal, Assistant	Resurvey of Chesapeake Bay; hydrography of Chester River.
Maryland	24	Triangulation and topography.	John Nelson, Assistant	Triangulation and topography of the eastern shore of Chesapeake Bay.
Maryland	25	Triangulation	F. W. Perkins, Assistant	Triangulation of Chesapeake Bay.
District of Columbia	26	Tidal observations.	Tidal division, U. S. Coast and Geodetic Survey Office.	Continuation of the tidal record at the tidal station at the United States navy-yard, Washington, D. C.
Virginia	27	Magnetic observations.	O. B. French, Assistant	Magnetic observations and establishment of meridian lines at stations in Virginia.
North Carolina	28	Magnetic and tidal observations.	Chas. C. Yates, Assistant	Magnetic observations at Beaufort, and establishment of tidal station at Morehead City.
North Carolina	29	Magnetic observations.	J. B. Baylor, Assistant	Magnetic observations and establishment of meridian lines at stations in North Carolina.
North Carolina	30	Tidal observations.	Harry V. Webb, tidal observer.	Tidal observations commenced at the automatic tide-gauge station at Morehead City, N. C.
South Carolina and Georgia.	31	Reconnoissance	F. W. Perkins, Assistant	Reconnoissance for triangulation along the Savannah River to connect the Blue Ridge primary work with the coast triangulation.
Florida	32	Tidal observations.	B. W. Weeks, tidal observer.	Tidal observations continued at the tidal station at Fernandina, Fla.
Florida	33	Tape measure, triangulation, leveling and astronomical work.	H. G. Ogden, Assistant	Geodetic connection of the Atlantic and Gulf coasts of Florida.
Alabama	34	Triangulation	W. B. Fairfield, Assistant	Continuation and completion of the triangulation along the oblique arc in Alabama and its connection with the triangulation of the Gulf coast.
Alabama	35	Latitude and azimuth.	O. B. French, Assistant	Determination of latitude and azimuth at stations at the southern end of the oblique arc in Alabama.
Ohio, Virginia, West Virginia, Maryland, and District of Columbia.	36	Magnetic observations.	Edwin Smith	Observations of the magnetic elements and establishment of meridian lines at stations in Ohio, Virginia, and West Virginia, and magnetic observations at Gaithersburg, Md., and Washington, D. C.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, etc.—Continued.

II.—MIDDLE DIVISION.

STATES AND TERRITORIES BETWEEN THE MISSISSIPPI RIVER AND THE ROCKY MOUNTAINS.

28. Minnesota.
29. North Dakota.
30. South Dakota.
31. Iowa.
32. Nebraska.
33. Missouri.
34. Kansas.
35. Arkansas.
36. Indian Territory.
37. Oklahoma Territory.
38. Louisiana.
39. Texas.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
Missouri	37	Reconnoissance	R. L. Farris, Assistant	Reconnoissance for triangulation in central Missouri.
Kansas and Nebraska.	38	Triangulation	F. D. Granger, Assistant	Geodetic work; continuation of the triangulation along the ninety-eighth meridian in Kansas and Nebraska.
Kansas and Colorado.	39	Precise leveling	Isaac Winston, Assistant	Continuation of the line of precise leveling from Ellis, Kans., to Hugo, Colo., and from Hugo toward Colorado Springs, Colo.
Louisiana	40	Triangulation, topography, and hydrography.	P. A. Welker, Assistant	Completion of the survey of Lake Pontchartrain, Louisiana.
Texas	41	Reconnoissance	Stehman Forney, Assistant.	Reconnoissance for primary triangulation along the ninety-eighth meridian northward from San Antonio and Seguin.

III. WESTERN DIVISION.

STATES AND TERRITORIES BETWEEN THE ROCKY MOUNTAINS AND THE PACIFIC.

40. California.
41. Oregon.
42. Washington.
43. Idaho.
44. Montana.
45. Wyoming.
46. Nevada.
47. Utah.
48. Colorado.
49. Arizona Territory.
50. New Mexico Territory.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
California	42	Reconnoissance	A. T. Mosman, Assistant	Reconnoissance for primary triangulation in southern California.
California	43	Vertical angles	J. J. Gilbert, Assistant; F. Morse, Assistant.	Trigonometric determination of heights in California.
California	44	Magentic observations.	H. P. Ritter, Assistant	Determination of the magnetic elements and establishment of meridian lines at stations in California.
California	45	Hydrography	Lieut. Commander A. P. Osborn, U. S. N., Assistant.	Hydrographic resurvey of San Francisco Bay and hydrographic examinations along the coast of California.
California	46	Hydrography	Lieut. Commander J. M. Helm, U. S. N., Assistant; F. Westdahl, Assistant; E. F. Dickins, Assistant.	Hydrographic resurvey of southern part of San Francisco Bay.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, etc.—Continued.

III. WESTERN DIVISION—Continued.

States.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
California	47	Tidal observations.	A. F. Rodgers, Assistant; H. S. Ballard, tidal observer.	Tidal observations continued at the automatic tide gauge station at Sausalito and at the new station, Fort Point, San Francisco Bay.
California	48	Triangulation and topography.	A. F. Rodgers, Assistant; E. F. Dickins, Assistant; F. Westdahl, Assistant.	Topographical resurvey of San Francisco and San Pablo bays.
California and Nevada.	49	Triangulation longitudes, azimuths, etc.	C. H. Sinclair, Assistant; A. L. Baldwin, Assistant; H. P. Ritter, Assistant.	Connection of longitude stations in California and Nevada with the triangulation. Latitude, longitude, and azimuth determined at triangulation stations in California.
California, Nevada, and Utah.	50	Triangulation and astronomical work.	C. H. Sinclair, Assistant	Triangulation and astronomical work in California, Nevada, and Utah.
Washington	51	Tidal observations.	F. O. Maxon	Tidal record continued at the self-registering tide-gauge station at Bremerton, Wash.
Washington	52	Triangulation and topography.	J. J. Gilbert, Assistant	Triangulation and topography of Washington Sound, Washington.
Utah, Idaho, and Nevada.	53	Geodetic work	P. A. Welker, Assistant	Reconnoissance and triangulation in Utah, Idaho, and Nevada.

IV. DIVISION OF ALASKA.

INCLUDING ITS COASTS BORDERING ON THE PACIFIC OCEAN, ON BERING SEA, AND ON THE ARCTIC OCEAN; ALSO ITS INLETS, SOUNDS, BAYS, AND RIVERS, AND THE ALEUTIAN AND PRIBILOF ISLANDS.

Territory.	Parties.	Operations.	Persons conducting operations.	Localities of work, etc.
Alaska	54	Hydrography, and general surveys.	Lieut. Commander E. K. Moore, U. S. N., Assistant	Continuation of hydrographic and general surveys in southeastern Alaska.
Alaska	55	Triangulation and topography.	J. A. Flemer, Assistant; John Nelson, Assistant.	Togographical reconnoissance at the head of Lynn Canal.
Alaska	56	Topography and hydrography.	A. F. Rodgers, Assistant	Special examinations at Dyea and Skagway, head of Lynn Canal.
Alaska	57	Triangulation and topography.	H. P. Ritter, Assistant	Reconnoissance in the vicinity of the mouth of the Copper River.
Alaska	58	Triangulation, topography, hydrography, astronomical work, etc.	J. F. Pratt, Assistant	Survey of the mouth of Yukon River.
Alaska	59	Triangulation, topography, and astronomical.	Will Ward Duffield, Assistant.	Survey of the Pribilof Islands and detailed survey of the seal rookeries on the islands of St. Paul and St. George.

Distribution of the field parties of the Coast and Geodetic Survey upon the Atlantic, Gulf of Mexico, and Pacific coasts, etc.—Continued.

V. SPECIAL OPERATIONS.

States.	Parties.	Persons conducting operations.	Localities of work.
New York	60	D. B. Wainwright, Assistant	Determination of magnetic ranges and revision of dock lines, New York Harbor.
Maryland	61	D. B. Wainwright, Assistant; John Ross, Nautical Expert.	Determination of the position of buoys for a speed trial course on Chesapeake Bay.
Maryland and Virginia.	62	W. C. Hodgkins, Assistant; J. B. Baylor, Assistant.	Demarcation of the boundary line between the States of Maryland and Virginia in Tangier and Pocomoke sounds.
Georgia	63	H. L. Marindin, Assistant; F. A. Young, Assistant.	Special hydrographic examination of the Tybee submerged breakwater made at the request of the War Department.
Georgia	64	H. L. Marindin, Assistant; F. A. Young, Assistant; C. C. Yates, Assistant; H. C. Denson, Aid.	Special hydrographic survey of the bar at the entrance to Brunswick Harbor, Georgia.
Florida	65	Lieut. Commander A. Dunlap, U. S. N., Assistant; Ensign J. H. Reid, U. S. N., Assistant.	Hydrographic surveys at Key West Harbor made at the request of the Navy Department.
Florida	66	Lieut. Commander W. J. Barnette, U. S. N., Assistant; Lieut. A. H. Davis, U. S. N., Assistant.	Hydrographic surveys at Key West and Tortugas made at the request of the Navy Department, and special service in connection with the Navy.
Alaska	67	E. B. Latham, Assistant	Explorations in vicinity of Mount St. Elias, Alaska.

4. OFFICE OF ASSISTANT IN CHARGE OF OFFICE AND TOPOGRAPHY.

Mr. O. H. TITTMANN, Assistant, Coast and Geodetic Survey, in charge, July 1, 1897, to June 30, 1898.
Mr. A. B. SIMONS, clerk, July 1, 1897, to June 30, 1898.
Mr. E. B. WILLS, clerk, July 1, 1897, to June 30, 1898.
Miss SOPHIE HEIN, clerk, July 1, 1897, to June 30, 1898.
Miss KATE LAWN, writer, July 1, 1897, to June 30, 1898.

Mr. O. H. Tittmann, Assistant, Coast and Geodetic Survey, served throughout the year as Assistant in Charge of Office and Topography. His duties embraced the supervision of the operations of the computing, publication, and accessory divisions, and he directed the disbursement of the sums allotted for their maintenance. As the responsible custodian, the proper care of all the archives and property in the Office at Washington must be provided for by him. The projections of the field sheets for topography are verified by him and the completed work passes under his examination before it receives the Superintendent's approval for enrollment in the archives. His presidency of the chart and publication board insures his immediate personal supervision of all the publications of the Survey. The work in the Office executed to satisfy the requirements of the military authorities after the outbreak of hostilities with Spain was prosecuted under his direction.

(*a*) COMPUTING DIVISION.

Mr. C. A. SCHOTT, Assistant, Coast and Geodetic Survey, Chief of Division, July 1, 1897, to June 30, 1898.

PERSONNEL.

Permanent force.—Edward H. Courtenay, Myrick H. Doolittle, Daniel H. Hazard, John B. Boutelle, Lilian Pike, Francis W. Clay, William H. Dennis, John F. Hayford, Ernest J. Sommer, and George A. Fairfield.

Temporary force.—J. B. Baylor, A. L. Baldwin, H. F. Flynn, F. A. Young, C. C. Yates, W. Bowie, I. Winston, G. R. Putnam, P. V. Dolan, and R. L. Faris.

The temporary force enumerated above, with the exception of Mr. P. V. Dolan, are field officers temporarily detailed for duty in the computing division.

The charge of this division throughout the year remained with Mr. C. A. Schott, Assistant, Coast and Geodetic Survey, who, in addition to the general operations of the division, gave his immediate personal attention to the advancement of the computations of the transcontinental triangulation from Cape May, N. J., to Point Arena, Cal., and the preparation of the explanatory text of the report of the measurement of this arc, embracing almost fifty degrees in amplitude. Despite the magnitude of this work, the computing force was able to keep pace with the field work, of which latter but little remains to complete the whole undertaking. The work so far accomplished includes a full account of the ten base lines and of the adjustments of the base nets; the completion of the final adjustment of the several triangulations connecting these base lines, from the Atlantic coast to Salina Base, in Kansas; abstracts of results of 25 determinations of telegraphic longitudes, and abstracts of results for astronomic azimuths at 73 stations. The latitudes at 103 stations are also computed, but these still need a revision on account of the improvement in the star places.

In compliance with a request from the International Geodetic Association, Mr. Schott prepared statistics covering the period 1895–1898 of the following operations of the Survey: The measure of primary base lines and the determination of astronomic latitudes, longitudes, and azimuths. A wall diagram was also furnished, showing on an equivalent or homolographic projection the present state of the arc measures for the determination of the earth's shape and size.

The adjustment of the recent triangulation results of the Massachusetts State survey by one of the staff engaged on that work continued in this Office between January 28 and April 22, 1898, with the cooperation of the computing division, which insured a coordination of the new work with that already executed in Massachusetts by the Coast and Geodetic Survey.

The discussion of the result from magnetic observations was kept up to date.

The official correspondence referred to this division is quite heavy, and much labor is required for preparing the answers and furnishing the information desired, particularly for those calls from the field parties demanding geographical positions and the description of trigonometrical and astronomical stations. Whenever available, the services of officers of the Survey, pending their assignment to duty in the field, have been utilized; but these employments are necessarily of short duration.

The following statement gives in detail the results of the labors of the division for the year:

Triangulation results.—The triangulation between Kent Island and Cape May, 1896–97, and the base nets connecting Salt Lake Base and El Paso Base with main triangulations adjusted; final adjustments made of the several chains of triangulation connecting the base lines of the transcontinental arc between the capes of Delaware Bay and the Salina Base, in Kansas, with computation of the geographical positions of all the principal stations within these limits. This last adjustment involved an immense amount of labor, and the direct solution of the great number of normal equations involved could only be successfully carried out within a reasonable space of time by the methods devised by the computer, Mr. Doolittle. The greatest numbers of normal equations simultaneously solved by him were 65 and 77. The latter—between the Versailles and the Salina Base—were solved in fourteen working days.

The probable errors of the resulting sides of the several base nets of the transcontinental and of some of the intervening chains of triangulation were determined. The horizontal directions of the triangulation between the Salina and El Paso bases were reduced to sea level. Geodetic (geographical) positions of astronomical stations in the transcontinental triangulation were also computed. Abstracts were made of the horizontal directions at stations of the primary triangulation along the oblique arc in Alabama. The computations of triangulations in the following localities were completed: San Francisco Bay, 1897; Blackwater Bay, Florida, 1872; Upper Chesapeake Bay, 1896–97; mouth of Patapsco and Chester rivers; vicinity of Cape Charles, Virginia. The positions of light-houses in Rhode Island and the length of trial speed lines in the Hudson River and in Chesapeake Bay were computed. The adjustment of the reconnoissance triangulation in Southeastern Alaska, based on standard astronomical stations established by the Survey, was taken up by this division in April 28, and is now in progress.

Hypsometry.—Abstracts of vertical angles at the principal triangulation stations in Colorado prepared; a complete adjustment made of the trigonometrical measures for height of all stations of the transcontinental triangulation between Colorado Springs, Colo., and the crest of the Sierra Nevada, California; height of stations between Kit Carson and Colorado Springs computed from vertical angle measures.

Precise spirit-leveling work between Holliday, Kans., and Hugo, Colo., computed.

Observations for declination, inclination, and intensity at magnetic stations computed.

Astronomical results.—Latitude: Mean places prepared for all stars used in the latitude computations of the year; mean places of stars revised for the latitude stations along the transcontinental arc, which show larger deviations from mean results than are warranted by the probable errors. Latitudes computed: Dover, Del., 1897; Cape Henlopen, Del., 1897; Pilot Peak, Nev.; Ibepah, Mount Nebo, and Ogden Peak, Utah; Kadiak, Alaska, 1896; St. Paul and St. George, Alaska, 1897, and Ukiah, Cal., 1897.

Longitude: Telegraphic difference of longitude between San Francisco and Ukiah, Cal., 1897, and chronometric difference of longitude between Unalaska and St. Paul Island, Alaska, computed.

Azimuth: The azimuths of stations at Baldwins, Fla., Waldo, Fla., Paxton, Cal., St. George and St. Paul, Alaska, were computed.

Prepared for publication.—The abstract of results for station adjustment at the stations of the transcontinental triangulation; abstracts of vertical angles at the principal triangulation stations in Colorado; abstracts of telegraphic longitudes along the transcontinental arc; abstracts of azimuth results at stations on the transcontinental arc; descriptions of trigonometric stations forming the base net of the transcontinental triangulation, and account of the method of local adjustment of the horizontal directions as followed in the computation of the primary triangulation of the Survey prepared for the report on the transcontinental arc, and three appendices on spirit leveling for the regular Annual Report; miscellaneous operations.

Besides the foregoing, the following incidental work was performed: Proof reading, description of stations, geographical positions furnished to field parties, and letters prepared in reply to requests for information.

(*b*) TIDAL DIVISION.

Mr. HENRY L. MARINDIN, Assistant, United States Coast and Geodetic Survey, chief of division, July 1, 1897, to May 16, 1898.
Mr. L. P. SHIDY, computer, acting chief of division, November 17, 1897, to May 16, 1898, and chief of division, May 17 to June 30, 1898; was employed the whole year.
Mr. F. M. LITTLE, computer, was employed the whole year.
Mr. R. A. HARRIS, computer, was employed the whole year.
Mr. D. S. BLISS, writer, was employed the whole year.
Miss ALICE G. REVILLE, clerk, was employed the whole year.
Mrs. VIRGINIA HARRISON, writer, was employed July 1, 1897, to May 10, 1898.
Mr. ERNEST WHITEHEAD, on extra labor roll, was employed July 1, 1897, to September 6, 1897.
Mr. L. W. ERICKSON, on extra labor roll, was employed November 5 to 8, 1897.
Mr. E. PHILLIPS MOULTON, tidal predictor, was employed November 9, 1897, to May 26, 1898.
Mrs. ELLA P. ELLIS, writer, was employed November 20, 1897, to May 4, 1898.
Mr. ARTEMAS MARTIN, computer, was employed March 1 to June 30, 1898.
Miss MARY E. CAMPBELL, writer, was employed May 10 to June 30, 1898.
Mrs. MARY A. GRANT, writer, was employed May 27 to June 30, 1898.

The following field officers have assisted in the work during the year:

Mr. E. B. LATHAM, Assistant, United States Coast and Geodetic Survey, from October 13 to November 30, 1897.
Mr. F. A. YOUNG, Assistant, United States Coast and Geodetic Survey, from February 25 to March 18, 1898.
Mr. HUGH C. DENSON, Aid, United States Coast and Geodetic Survey, from February 18 to March 18, 1898.
Mr. ALBERT F. ZUST, Aid, United States Coast and Geodetic Survey, from July 1 to August 28, 1897, and from September 13, 1897, to February 28, 1898.

Assistant Marindin was chief of division at the beginning of the fiscal year, but on account of other official duties he was absent from the office most of the time between November 16, 1897, and May 16, 1898, during which period Mr. L. P. Shidy was acting chief. On May 17 Mr. Shidy was appointed chief, and since that date has been in charge.

The predictions for the Tide Tables for 1899 were made with the Ferrel tide machine for the 30 stations remaining at the close of the last fiscal year. The manuscript copy of these tables was completed, submitted for publication, read and revised in proof, and the printed volume issued in April, 1898. The predictions for 53 stations for the Tide Tables for 1900 have been made with the tide machine, and most of them have been checked by differencing or other means, so as to correct accidental errors.

The preparation of the manual of tides has been continued and considerable progress made; three parts out of the five parts contemplated have now been completed. A number of auxiliary tables for saving labor on certain portions of tidal work were computed.

Tidal notes have been prepared for 170 stations on 51 charts. Requisitions from 26 field parties have been filled, requiring the descriptions of 97 bench marks and tidal data for 15 stations. Tidal information has been called for by 64 persons not connected with the Survey, the response to which necessitated the preparation of 43 descriptions of bench marks, current tables for 31 stations, and tidal data for 201 stations, together with the preparation of technical letters explaining tidal phenomena.

There have been received, examined, and registered in the tidal division an aggregate of about six years of record from automatic tide gauges, together with 91 original and 94 duplicate volumes of tidal observations made by 15 hydrographic parties, as well as records of the currents at 6 stations. About three years of tabulated hourly heights of the sea, with the times and heights of high and low waters, were also received.

The automatic tide gauge in Washington has remained in charge of this division throughout the year, members of the force giving it all necessary personal supervision.

(*c*) DRAWING AND ENGRAVING DIVISION.

PERSONNEL.

The personnel of the division for the fiscal year was as follows:

WILL WARD DUFFIELD, Assistant, United States Coast and Geodetic Survey, chief of division, from July 1, 1897, to June 30, 1898.

STEHMAN FORNEY, Assistant, United States Coast and Geodetic Survey, acting chief of division, from July 1, 1897, to November 22, 1897. Was attached to division from November 23, 1897, to March 5, 1898.

JOHN H. SMOOT, clerk, from July 1, 1897, to June 30, 1898.

JAMES M. GRIFFIN, writer, from July 1, 1897, to June 30, 1898.

Drawing section.—E. H. Fowler, chief draftsman, H. Lindenkohl, draftsman, A. Lindenkohl, draftsman, from July 1, 1897, to June 30, 1898; F. Westdahl, draftsman, from July 1, 1897, to November 8, 1897; D. M. Hildreth, draftsman, from July 1, 1897, to June 30, 1898; E. J. Sommer, draftsman, from July 1, 1897, to November 16, 1897, and from February 19, 1898, to June 30, 1898; C. H. Deetz, draftsman, E. P. Ellis, draftsman, P. von Erichsen, draftsman, Harlow Bacon, draftsman, from July 1, 1897, to June 30, 1898; B. E. Tilton, draftsman, from January 4, 1898, to June 30, 1898; J. P. Keleher, draftsman, from March 5, 1898, to June 30, 1898; C. A. Weckerly, draftsman, from July 1, 1897, to August 1, 1897; Charles Mahon, from July 1, 1897, to June 30, 1898.

Engraving section.—W. A. Thompson, H. M. Knight, Theo. Wasserbach, W. H. Davis, E. H. Sipe, W. F. Peabody, H. L. Thompson, W. A. Van Doren, A. H. Sefton, P. H. Geddes, H. R. McCabe, William Mackenzie, George Hergesheimer, F. G. Wurdemann, W. H. Holmes, H. E. Franke, R. H. Ford, from July 1, 1897, to June 30, 1898.

Electrotyping and photographing section.—L. P. Keyser, foreman, Roy Thomas, assistant electrotyper, from July 1, 1897, to June 30, 1898.

Printing section.—D. N. Hoover, foreman, from July 1, 1897, to June 30, 1898; C. J. Harlow, printer, from July 1, 1897, to May 10, 1898, when he resigned to enter volunteer army; J. L. Smith, Eberhard Fordan, Frank C. Gohre, printers; C. F. Locraft, W. M. Conn, C. W. Buckingham, L. L. Williams, printer helpers, from July 1, 1897, to June 30, 1898; F. R. Dulin, A. O'Neill, E. F. Campbell, temporary laborers, from April 2, 1898, to June 30, 1898; J. E. Buckingham, Kirk McMurtrie, C. E. Zurhorst, temporary laborers, from April 2, 1898, to June 15, 1898; W. A. Harlow, temporary laborer, from April 2, 1898, to June 2, 1898; A. D. Levi, temporary laborer, from June 10, 1898, to June 30, 1898; F. P. Reinhart, temporary laborer, from May 1, 1898, to June 15, 1898; A. P. Madeira, temporary laborer, from April 2, 1898, to May 21, 1898; R. F. Le Mat, temporary laborer, from April 25, 1898, to June 30, 1898; R. J. Fondren, extra laborer, from July 1, 1897, to December 31, 1897, and from February 24, 1898, to June 30, 1898; J. A. Williamson, laborer, from July 1, 1897, to June 1, 1898; Frank Thomas, laborer, from July 1, 1897, to August 3, 1897, and from June 1, 1898, to June 30, 1898; George Newman, John W. Reed, messengers, from July 1, 1897, to June 30, 1898; Hans Bowdwin, laborer, from July 1, 1897, to June 30, 1898.

At the beginning of the fiscal year, owing to the absence of Assistant Will Ward Duffield, chief of the division, on official business in Alaska, Assistant Stehman Forney was acting chief; on November 23 Assistant Duffield resumed active charge of the division. Assistant Forney remained attached to the division, at work on a graphic index of all the original hydrographic sheets.

DRAWING SECTION.

During the year the drawing section prepared the drawings for 34 charts, and had in progress drawings for 7 charts which were to be reproduced by photolithography or copper engraving; 338 charts were revised, corrected, and verified; 7 topographic sheets were inked; the sketches and drawings for illustrating the Superintendent's Annual Report, with accompanying Appendixes and Coast Pilot, were made; 37 topographic and 55 hydrographic projections were constructed for field parties, and 7 projections on copper plates were made; 16 large wall maps have been compiled for the use of the President and Congress, besides numerous other drawings for the various departments. The following tabulated statements give the lists of the charts for which drawings were completed, or are in progress.

TABLE I.—*List of drawings completed during fiscal year for charts.*

Chart No.	Title.	Scale.
E.	Straits of Florida and approaches	1-1 200 000
316b	Kennebec River, Court-House Pt. to Augusta	1-10 000
482	Cuba	1-1 200 000
541	Anchorage chart, New York Bay	1-10 000
571	Port Royal Sound, South Carolina	1-40 000
3091	Territory of Alaska, Southeast Section	1-1 200 000
3092	Territory of Alaska, Southwest Section	1-1 200 000
3093	Territory of Alaska, Northwest Section	1-1 200 000
3094	Territory of Alaska, Northeast Section	1-1 200 000
3098	Yukon River, Alaska	1-1 200 000
3099	Klondike region, Alaska	1-900 000
3100	Route map from Juneau to Porcupine River	1-1 200 000

TABLE I.—*List of drawings completed during fiscal year for charts*—Continued.

Chart No.	Title.	Scale.
3215	Reef, Gorbatch, and Ardiguen Rookeries, St. Paul Island, Alaska	1–2 000
3216	Lukanin and Kitovi Rookeries, St. Paul Island, Alaska	1–2 000
3217	Tolstoi Rookery, St. Paul Island	1–2 000
3218	Zapadni Rookery, St. Paul Island	1–2 000
3219	Little Zapadni and Zapadni Reef Rookeries, St. Paul Island.	1–2 000
3220	Polovina, Polovina Cliffs, and Little Polovina Rookeries, St. Paul Island	1–2 000
3221	Morjovi Rookery, St. Paul Island	1–2 000
3222	Vostochni Rookery, St. Paul Island	1–2 000
3223	Lagoon Rookery, St. Paul Island	1–2 000
3224	St. George Island, Alaska	1–20 000
3225	Zapadni Rookery, St. George Island	1–2 000
3226	North Rookery, St. George Island	1–2 000
3227	Staraya Artil and Little East Rookeries, St. George Island	1–2 000
3228	East Rookery, St. George Island	1–2 000
5052	San Francisco to Strait of Juan de Fuca	Mercator.
6140	Columbia River Entrance	1–40 000
6444	Port Orchard, Washington	1–20 000
8154	Zarembo Island and Vicinity	Various.
8170	Wrangell Strait	1–20 000
8283	Peril Strait, Alaska	1–40 000
8881	Islands and harbors off the Alaska Peninsula	Various.
	Compass chart, San Francisco Bay Entrance	1–40 000

TABLE II.—*List of drawings in progress at end of fiscal year for charts.*

Chart No.	Title.	Scale.
252	New Bedford Harbor	1–20 000
274	Harlem River	1–10 000
3067	East Shore, San Francisco Bay	1–20 000
3214	St. Paul, Otter, and Walrus Islands	1–20 000
5531	San Francisco Bay	1–50 000
7002	Strait of Juan de Fuca to Dixon Entrance	Mercator.
8160	Zarembo Island, Alaska	1–80 000

ENGRAVING SECTION.

The engraving section completed 13 original plates and has in hand 9 plates for original charts which were in process of execution on July 1, 1897, and 7 original plates begun in this fiscal year; 531 chart plates were corrected for printing; the correction of 40 chart plates, for new editions, was commenced and 30 of them were completed; 15 plates, including 5 begun in the last fiscal year, remain to be finished. Work was commenced on the correction of the plates for the new edition of the map of the District of Columbia, and was completed on 3 sections, leaving five to be brought up; the number of sketches and illustrations engraved was 3; 16 are in process of completion.

The details of the original plate work are tabulated as follows:

Original plates on which engraving was completed during the fiscal year 1897–1898.

Chart No.	Plate No.	Title.	Scale.
350	2499	New Bedford Harbor	1-40 000
352	1033	Port of Providence	1-10 000
353	2502	Narragansett Bay	1-40 000
431	2306	Charleston Harbor	1-30 000
438	2277	Beaufort River	1-40 000
440	1934	Tybee Roads, Savannah River, etc	1-40 000
446	1312	Doboy and Altamaha Sounds	1-40 000
471a	1475	Tortugas Harbor and Approaches	1-40 000
520	1993	Galveston Entrance	1-40 000
6400	2133	Sea Coast and Interior Waters of Washington	1-300 000
	2529	Triangulation across Peninsula of Florida	1-600 000
	2535	Standard Notes	
	2539	Standard Compass and Scale Plate	

Original plates on which engraving was begun, but remains uncompleted on July 1, 1898.

Chart No.	Plate No.	Title.	Scale.
246	2437	Boston Harbor, West Part	1-20 000
246	2438	Boston Harbor, East Part	1-20 000
272	2488	New Rochelle to Throgs Neck	1-10 000
281	2513	Hudson River, New York to Haverstraw	1-40 000
281	2514	Hudson River, Haverstraw to Hamburg	1-40 000
337	2495	Boston Harbor	1-40 000
381	2439	Schuylkill River, Philadelphia Water Front, Top	1-9 600
381	2440	Schuylkill River, Philadelphia Water Front, Bottom	1-9 600
445	2479	Charleston Harbor and Vicinity	1-20 000
490	2517	Entrance to Pensacola Bay	1-30 000
5002	2507	San Diego to Point St. George	Mercator.
5052	2527	San Francisco to Cape Flattery	Mercator.
5525	2463	Mare Island Strait	1-10 000
6185	2464	Willapa Bay, Washington	1-40 000
6303	2465	Port Angeles	1-10 000
8240	2414	Sitka Sound, Alaska	1-80 000

PRINTING SECTIONS.

The number of chart plates printed from for the chart division was 1 307; the number of impressions printed was 78 995.

The exceedingly large output in the printing division is due mainly to the extraordinary demand for our charts of the Atlantic coast made by the War and Navy Departments, because of the outbreak of hostilities with Spain.

During the last quarter of the fiscal year the force in the printing section was increased by the employment of additional skilled laborers, and an output of nearly 38 000 charts was the result. For six weeks this section was run double time, with both day and night shifts, and to provide for the night work it became necessary to introduce electric lights, which have proven eminently satisfactory and enabled the Office to accomplish fully as much work at night as was done during the day. The presses were kept constantly going from 8.30 a. m. until 10.30 p. m. (including Sundays) on every day during this period of emergency.

ELECTROTYPING AND PHOTOGRAPHING SECTION.

In addition to the preparation of all the electrotypes from the engraved copperplates required for the production of the chart publications of this Bureau, a number of electrotype copies from steel dies furnished by various bureaus of the Government were satisfactorily produced by this section.

The number of basso plates made was	26
The number of alto plates made was	29
Total number of plates produced	55

In the photographic laboratory, besides the prompt and satisfactory execution of the routine duties of the section, a notable success has been met with in the production of a great many prints from original plane table sheets, many of which were extremely difficult to reproduce by photography. The following statement gives a summary of the work done in the laboratory during the year:

Number of negatives made	196
Number of prints	1 767
Number of films developed	48

(*d*) CHART DIVISION.

GERSHOM BRADFORD, Assistant, United States Coast and Geodetic Survey, Chief of Division, July 1, 1897, to June 30, 1898.

PERSONNEL.

Miss L. A. MAPES, Mr. H. R. GARLAND, Mr. A. G. RANDALL, Mr. NEIL BRYANT, Miss M. L. HANDLAN, Mr. ARCHIE UPPERMAN, Mr. O. E. MCNEILL, Mrs. F. I. MATHEWS, Mr. EDWARD BELFORD, Mr. F. C. LARIMORE, Mr. J. W. DRUM, Mr. P. V. DOLAN, Mr. ISAAC BASSETT, Mr. A. B. SIMONS, Jr., Mr. F. P. REINHART, Mr. HENRY WARRINGTON, Mr. JAMES R. LONG.

Assistant Bradford remained in charge of this division throughout the year, acting in addition as Hydrographic Inspector from May 12 to the date of this Report.

There have been delivered to this division for issue during the year 27 new charts and maps, all printed by lithography, viz:

TABLE I.—*New charts and maps delivered.*

Date.	Catalogue No.	Title.
1897.		
July 3.	244	Salem Harbor and Approaches, Massachusetts.
Aug. 25.	3100	Juneau to Porcupine River, Alaska.
Sept. 17.	8154	Harbor charts, Zarembo Island and Vicinity, Alaska.
Oct. 8.	8302	Lynn Canal from entrance to Point Sherman, Alaska.
1898.		
Feb. 3.	3098	Yukon River, Alaska.
Apr. 19.	3090	Territory of Alaska, in four sheets.
Apr. 26.	3091	Territory of Alaska, Southeast Section.
Apr. 26.	3092	Territory of Alaska, Southwest Section.
Apr. 26.	3093	Territory of Alaska, Northwest Section.
Apr. 26.	3094	Territory of Alaska, Northeast Section.

TABLE I.—*New charts and maps delivered*—Continued.

Date.	Catalogue No.	Title.
1898.		
Apr. 28.	3059	Territory of Columbia (Ellicott), D. C.
May 11.	541	New York Harbor, Upper Bay and Narrows (Anchorage Chart).
May 27.	3223	Lagoon Rookery, St. Paul Island, Alaska.
May 27.	3225	Zapadni Rookery, St. George Island, Alaska.
May 27.	3226	North Rookery, St. George Island, Alaska.
June 6.	8170	Wrangell Strait, Alaska.
June 6.	3227	Staraya-Artil and Little East Rookeries, St. George Island.
June 6.	3228	East Rookery, St. George Island.
June 10.	3215	Reef, Gorbach, and Ardiguen Rookeries, St. Paul Island.
June 10.	3216	Lukaniv and Katovi Rookeries, St. Paul Island.
June 10.	3218	Zapadni Rookery, St. Paul Island.
June 10.	3221	Morjovi Rookery, St. Paul Island.
June 10.	3222	Vostochni Rookery, St. Paul Island.
June 10.	3224	St. George Island, Alaska.
June 16.	3217	Tolstoi Rookery, St. Paul Island.
June 16.	3219	Little Zapadni and Zapadni Reef Rookeries.
June 23.	8283	Peril Strait, Hooniah Sound to Chatham Strait.

Thirty new copperplate editions of charts and 23 new lithographic editions, 53 in all, have been received for issue.

The receipts, issue, and general distribution of charts are given in the following tables:

TABLE II.—*Charts issued.*

How disposed of.	July 1, 1897, to June 30, 1898.	
	No.	Value.
Sales agents	32 405	$13 405·95
Sales by Office and chart division	3 055	1 122·25
Congressional account	6 166	2 524·65
Hydrographic Office, Navy	43 646	17 289·45
Light-House Board	1 884	729·35
Coast and Geodetic Survey Office	5 070	1 992·25
Executive Departments	7 128	2 740·15
Foreign governments	1 310	496·80
Libraries	1 213	387·05
Miscellaneous	1 711	531·65
Totals	103 588	41 219·55
Condemned	6 768	2 544·55
Total issued and condemned	110 356	43 764·10

TABLE III.—*General statement.*

Charts on hand and received.	No.	Value.
On hand, by count, July 1, 1897	35 835	$14 188·15
Received from drawing and engraving division	73 329	29 948·95
Received from lithographers	52 476	18 315·05
Returned	2 232	905·20
Total on hand and received	163 872	63 357·35
Total issued and condemned	110 356	43 764·10
On hand, by book, July 1, 1898	53 516	19 593·25
Difference between book and count	42	9·10
On hand, by count, July 1, 1898	53 474	19 584·15

The following table represents in brief the more important features of the relation of the chart issue of this year to that of the nine years next preceding, practically, since the division was established.

TABLE IV.—*Comparison of issues of charts during the fiscal years noted below.*

Fiscal year.	Totals.		Free distribution.		Gross sales.		Net sales.	
	Copies.	Values.	Copies.	Values.	Copies.	Values.	Copies.	Values.
1889	49 312	$20 096	21 088	$8 266	28 224	$11 830	26 540	$11 280
1890	63 152	26 178	30 112	12 121	33 040	14 057	31 806	13 575
1891	52 959	23 457	20 811	8 846	32 148	14 611	28 473	13 141
1892	52 675	23 041	23 451	9 831	29 224	13 209	27 214	12 506
1893	55 026	24 215	27 310	11 805	27 716	12 409	25 366	11 605
1894	51 671	22 476	27 702	11 845	23 969	10 631	21 230	9 595
1895	51 456	22 280	24 892	10 507	26 564	11 773	23 136	10 405
1896	64 541	26 440	36 516	14 037	28 025	12 403	25 278	11 249
1897	57 188	23 987	31 977	12 820	25 211	11 166	21 673	9 731
1898	103 588	41 219	68 128	26 691	35 460	14 528	33 276	13 645

The total issue is 87 per cent greater than the average for the previous nine years, the period during which this division has had a separate existence; the free distribution is 151 per cent greater; and the sales have increased in number of charts sold 30 per cent, and in value received 19 per cent, as compared with the average for the same period.

The remarkable results above noted are due to the phenomenal conditions that have prevailed during the year. Owing to the excitement aroused in the public mind by the gold discoveries in Alaska and the adjoining British Northwest Territory, there was an exceedingly large demand for charts and maps of that region, which began in July and continued until December. Hardly had this slackened when the probability of war with Spain, and its subsequent prosecution, caused an extraordinary demand for charts for the use of the military authorities—principally the Navy Department. Because of this demand, which at first employed all of our resources, and for prudential reasons connected with the national welfare, the sale of charts for the Atlantic and Gulf coasts was suspended and so remains.

It is gratifying to state that after the first rush the Office was able to supply charts to the Navy Department without unreasonable delay.

The edition of the Chart Catalogue for 1897 was received in January, and 1 766 copies have since been distributed.

The correspondence for the year has amounted to 5 811 letters written; 1 251 circulars have been filled out and mailed in the same period.

(*e*) INSTRUMENT DIVISION.

Mr. J. F. Pratt was in charge of this division at the beginning of the fiscal year, and was detached on April 30 to take charge of the surveys in the vicinity of the mouth of the Yukon River. He was succeeded by Mr. E. G. Fischer.

The instrument division has charge of the instruments and general property of the Survey, and the change in its direction necessitated an inventory and transfer of all such articles.

In addition to his duties as chief of the division, Assistant Pratt, between January 1 and April 30, designed and personally supervised the construction of one 75-foot and two 32-foot steam launches, two 24-foot whaleboats and four dingeys; he also made the plans for a 30-foot tidal indicator to be erected in San Francisco Harbor.

TABLE I.—*Summary of instruments, apparatus, and machinery repaired during the year.*

Instrument.	Number.	Instrument.	Number.
Alidades, ship's	2	Pantographs	1
Alidades, plane table	32	Parallel ruler	1
Anemometers	1	Pendulum apparatus	2
Azimuth circles, marine	3	Plane tables	33
Barometers, aneroid	2	Plane-table side clamps	20
Beam compasses	6	Plate-printing presses	4
Binoculars	12	Position stands	2
Camera, photographic	1	Proportional dividers	2
Chartometer	1	Press, engraver's	1
Clocks	36	Protractors, three-arm	36
Chronographs	7	Pyrometer	1
Comparator (Bessel)	1	Scales, metric	16
Compass declinometers	6	Section liner	1
Compasses (liquid), mariner's	11	Sextants	46
Compass ruling machine	1	Sextant mirrors, resilvered	704
Current meter	1	Spring balance	1
Dip circles	5	Stamp, printing	1
Drawing instruments, cases	3	Straightedges, steel	3
Dynamo	1	Tapes, steel	12
Gas engines	2	Telemeters, pairs	20
Hair frames, reducing	4	Telescopes, draw	2
Heliotropes	20	Telescopes, reconnoitering	6
Lamps, dark-room	3	Telescope, reading	1
Levels, geodetic	3	Theodolites	72
Levels, wye	5	Tide gauges, self registering	5
Leveling rods	23	Tide-predicting machine (Ferrel)	1
Magnifying glasses	3	Transits, astronomical	3
Magnetometers	7	Transits, station	5
Meridian telescopes	4	Transits, engineer's	3

TABLE I.—*Summary of instruments, apparatus, and machinery repaired during the year*—Continued.

Instrument.	Number.	Instrument.	Number.
Vertical collimator	1	Steel tapes	15
Vertical circles	9	Steel metre	1
Zenith telescopes	2	Sugar tubes	585
REPAIR WORK FOR OFFICE OF STANDARD WEIGHTS AND MEASURES.		Standard bottles, marking	172
		Thermometer comparator	1
		Troy weights, sets	2
Apparatus for marking standard bottles	1	Weights for sugar-testing apparatus	22
Balances	4	Wheatstone Bridge	1
Bench standard	1	REPAIR WORK FOR UNITED STATES MARINE-HOSPITAL SERVICE.	
Comparator (Saxton)	1		
Copper conductors for Wheatstone Bridge	2		
Gold-plating apparatus	1	Photo-copying arc lamps	2
Grain weights, set	1	X-ray induction coil	1
Level rods	3	Stand for germ specimens	1
Polariscopes	14	Total number of instruments, apparatus, and machines repaired	2 092
Quartz plate tubes	36		
Reading microscopes	2		

TABLE II.—*Summary of new instruments, apparatus, and machines constructed during the year.*

Instrument.	Number.	Instrument.	Number.
Awls for tape measurement	2	Telemeters, pairs	3
Appliance for photo-engraving	1	Telemeter targets	2
Appliances for war maps, Executive Mansion		Theodolites, 12-inch, position, work begun	3
Battery cells for electroplating rooms	6	Tide gauges, completed	7
Bookcases, special design	2	Tide staffs	29
Bulletin board	1	Tide-predicting machine work, continued	1
Case for card catalogue	1	Topographic cameras, completed	6
Case for storing instruments	1	Tripods for instruments	24
Cases for sounding clocks	2	Wetting boards	4
Cases for specimen bottles	8	NEW WORK FOR OFFICE OF STANDARD WEIGHTS AND MEASURES.	
Chart stand	1		
Color screens	6		
Desk case	1	Case for apparatus and instruments	1
Drawing boards	2	Coil for compensating apparatus for Treasury Department	1
Frames for electroplating baths	7	Glass reading scale for galvanometers	1
Grindstone frame	1	Oil damper	1
Hair frames, reducing	7	Quartz plate tubes	36
Heliotropes, begun	12	Rubber washers for sugar tubes	550
Ink roller	1	Standard bars, 70-inch, preparing for graduation	3
Letter gauges	39	Temperature box for standard cells	1
Negatives, photographic, of instruments	12	Total number of instruments and apparatus constructed	342
Patterns for casting	63		
Punches, engravers'	6		
Station marks	36		
Seal, United States Coast and Geodetic Survey, for Omaha Exposition	1		

TABLE III.—*Instruments, apparatus, and machinery purchased during the year.*

Instrument.	Number.	Instrument.	Number.
Anemometer	1	Opisometers	6
Binoculars	18	Parallel rulers	44
Binoculars, "Trieder"	2	Printing frames	12
Beam compass fixtures	8	Protractors, three-arm	13
Bow-pens	4	Plate holders	50
Bow-pencils	4	Psychrometers	2
Bow-pens, drop	17	Ray filters	6
Cameras, photographic	3	Rain gauge	1
Chartometers	2	Ruling pens	6
Clocks, sounding	36	Saws, circular, for metal	8
Color screens	4	Scale, boxwood	1
Compasses, "Alteneder"	6	Scales, steel	26
Current floats	2	Shutters, camera	2
Curves, ship's	3	Sextants	12
Developing boxes	6	Spacing dividers, standard	2
Distance measure	1	Stamps, steel, alphabet and numbers, number of sets	3
Dividers, hairspring	31	Taffrail logs	3
Dividers, spring, bow	8	Tapes, steel	12
Dividers, pocket	19	Telescopes, draw, for heliotropes	18
Enameling oven	1	Thermometers, maximum and minimum, number of sets	3
Eyepieces	12	Thermometers	12
Funnels	3	Theodolites, 7-inch	2
Gauges, gear tooth, sets	2	Trays, hard rubber	33
Graduates, glass	3	Type, printing, fonts	6
Knife-grinding machine	1	Triangles, celluloid	30
Lamps, dark room	3	Watches, nickel	12
Lamps, acetyline gas	2	Total number of instruments, apparatus, and machines purchased	319
Magnifying glasses, engravers'	6		
Objectives, microscope	6		
Objectives, photographic	8		
Objectives for magnetometers	4		
Objectives, telescope	5		

TABLE IV.—*Instruments repaired outside the shops.*

Instrument.	Number.	Instrument.	Number.
Azimuth circle	1	Telescope, reconnoitering	1
Barometers, aneroid	3	Theodolite	1
Barometers, mercurial	2	Transit, surveyors'	1
Chronometers	14	Watches	17
Compasses, liquid	2	Total number of instruments repaired outside of shops	45
Levels, wye	2		
Sextants	2		

The work of packing, receiving, and unpacking instruments and general property sent to and received from the field, including the making and repairing of packing cases, does not appear in the foregoing tables. The statistics of the work are as follows:

Number of instruments cleaned, adjusted, and forwarded to the field	1 327
Number of instruments received from the field and elsewhere	1 833
Number of articles of general property packed and sent to the field	833
Number of articles of general property received from the field	582
Total number of instruments in the field	5 532
Total number of instruments in the office	2 415
Total number of instruments owned by the Survey	7 947

As heretofore, the two gas engines furnishing power for the instrument and carpenter shops, elevator, hydraulic press, and the printing presses were attended to and kept in good running order. The pneumatic time-distributing system, the call-bell circuits, and a small dynamo were also attended to and kept in order.

The repairs of the office buildings and furniture have been kept, as usual, by the employees of the division.

Fifty-two working days were lost to the division by the detail of one instrument maker for duty in the printing office while that section was running at night and on Sundays.

The main part of the work in the instrument and carpenter shops is in the line of repairs and reconstruction, but most of the new work is of special design for the specific and peculiar needs of the Survey. The following account epitomizes the principal features of the new work and important remodeling of instruments undertaken during the year:

The destruction of the 12-inch direction theodolite No. 145 in a hurricane left the Survey in possession of only one good instrument of that class. The reconstruction of that instrument was therefore begun, together with two new ones of the same design, to be known as Nos. 167 and 168. Only a few parts of No. 145 can be used, so that practically three new instruments are being built. The press of routine and other work, however, allowed but little progress to be made toward their completion.

Seven new self-recording tide gauges, begun in the previous fiscal year after designs and working drawings made in the instrument shop, were completed. They are Nos. 61 to 67, inclusive. All but one have been issued for use in the field. The screws moving the pencil back and forth with the rise and fall of the water run in ball bearings; thus, by reason of reduced friction, assuring increase in accuracy of record, especially at the time of slack water. The float pulleys of all the gauges were made interchangeable, so that a change of scale can be quickly made. By an adjusting device the true relation to the tide staff can readily be established. The hour-break attachment, previously applied in the form of a separate movement, now forms part of the time clock; the latter and the driving clock are protected by a substantial metal case. The whole is more compact, stronger, and less liable to get out of order than the models previously used.

In order to avoid the great expense of engraving by hand the 14 clock dials required for these tide gauges, the process of photo-engraving was employed, perhaps the first instance of that kind of work.

To satisfy the need of the Survey for a topographic camera, the requirements of photographic topography and the apparatus so far put on the market for carrying on that class of surveying were carefully studied, after which a design was elaborated in in the division according to which six instruments were constructed. The camera proper is made of aluminum, protected by a strong but light wooden case. The lens, Zeiss Anastigmat, No. 3, Series V, enables six views, on plates measuring 5 inches by 8 inches, to complete the horizon. The focal plane of the lens can easily be brought in coincidence with the film plane of the dry plate without distorting the latter. Adjustment for horizontality and verticality can be quickly made. The lens is placed some distance from the center, so that the camera, to be mounted either erect or inverted in the horizontal position or on end, can be used on stations elevated much above or depressed below the surrounding country without inclining the focal plane. Three of the cameras were fitted to form parts of 4-inch theodolites, while the others are to be used independently. A new and very convenient form of folding tripod was designed for these cameras. Five of them were issued for use in the survey of Alaska, where they will receive a thorough test.

The glass covers which shielded the needles of the compass declinometers in use on the Survey often became strongly electrified and made the instruments unreliable. To correct this it was decided to replace the glass by metal covers and also to improve the manner of raising and lowering the needles. Seven of the 11 declinometers owned by the Survey were thus remodeled.

But little progress was made in the construction of the new tide-predicting machine. Increasing demands upon the division for fitting out field parties, the construction of special apparatus which can not be purchased, changing and remodeling old instruments nearly always requiring immediate attention made it impossible to keep even one mechanician constantly employed on that complicated and delicate machine. Only 133 working days for one man could be devoted to it during the year.

f. Library and Archives Division.

Dr. Artemas Martin, chief of division, July 1, 1897, to February 15, 1898.
Mr. W. C. Hodgkins, assistant, Coast and Geodetic Survey, acting chief of division, February 16, 1898, to March 4, 1898.
Mr. W. I. Vinal, chief of division, March 5, 1898, to March 31, 1898.
Mr. W. Eimbeck, assistant, Coast and Geodetic Survey, acting chief of division, June 1, 1898, to June 30, 1898.
Permanent force.—Mr. Edward F. Lopez, writer, July 1, 1897, to March 8, 1898; Mr. A. F. Zust, writer, March 1, 1898, to June 30, 1898.
Temporary force.—Miss Fannie Martens, July, 1897, three days; Mr. B. A. Lynch, writer, September, 1897, four days; Mr. H. H. Warrington, June 22, 1898, to June 30, 1898.

Dr. Artemas Martin was in charge of the division from July 1, 1897, to February 15, 1898; Assistant W. C. Hodgkins acted as chief of division in the interval between the date of Dr. Martin's and Mr. Vinal's incumbencies, and Assistant Eimbeck assumed charge as acting chief on the retransfer of Mr. Vinal to the field force of the Survey and his departure for work in the field.

All new material received and registered in this division is of two kinds, the unpublished original records of the Survey and published literature from whatever source.

This discrimination is very strictly adhered to. The former are placed upon the shelves of the archives, the latter of the library.

ACCESSIONS DURING THE FISCAL YEAR 1897-98.

ARCHIVES.

Observations, original records:	
Volumes (12mo)	782
Cahiers (8vo)	76
Tidal rolls	66
Sheets, etc	65
Observations, duplicate records:	
Volumes	550
Cahiers	101
Sheets	101
Computations:	
Original field cahiers	83
Original office cahiers	139
Sheets:	
Topographic sheets	61
Hydrographic sheets	30
Descriptive reports of sheets	7
Miscellaneous hydrography:	
Log books of Coast and Geodetic Survey vessels	38
Specimens of sea bottom	85
Photographs, negatives, and prints, etc.:	
Negatives	33
Prints, mounted	69
Prints, unmounted	40
Blue prints, mounted	39

The observations are, almost exclusively, made by parties in the field and are sent in duplicate to the office. Only the originals are filed in the archives, the duplicate being sent to the different divisions concerned. Some of the original tidal observations are referred, immediately after registering, to the tidal division, where they are permanently retained.

LIBRARY.

Books:	
By purchase	110
By gift and exchange	360
Total	470
Serials and pamphlets:	
By purchase	739
By gift and exchange	1 913
Total	2 652
Maps and charts:	
By purchase	17
By gift and exchange	1 186
Total	1 203

In cataloguing the archives the "Personal accounts" (author catalogue) has been continued, and various registers for different classes of records, as tides, monograms,

soundings, etc., kept up. The card catalogue of books and pamphlets has been maintained, as well as a catalogue of miscellaneous maps and charts. During the year a card catalogue of the titles of the topographic sheets was prepared and arranged in alphabetical order, and a similar catalogue of the hydrographic sheets was begun and almost half finished. A numerical index was prepared of the hydrographic office charts and of nearly all the British Admiralty charts. The purpose of this was to show at a glance what numbers in the printed catalogues of these charts are on file in the chart room.

The "fixed-shelf" system of numbering was continued for the shelving of the books. The Dewey system of classification originally introduced was approximately adhered to, although necessarily in an unsatisfactory way, as it is impracticable to combine a fixed and relative system of shelf arrangement. Nine thousand charts of the Hydrographic Office and of the foreign admiralties were classified and shelved in numerical order, 100 charts to the drawer.

For the growing collection of specimens of sea bottom, heretofore stored in the original shipment boxes, a well-arranged and commodious cabinet of drawers was designed and constructed. This permits the specimens to be classified by States and filed in a form easy of access.

The maregrams and current observations have been arranged and shelved in a special room in the fireproof building.

Two hundred and sixty-two volumes of computations were arranged and prepared for the binder by Mr. E. H. Courtenay, who was detailed from the computing division for this purpose.

g. Miscellaneous Division.

Mr. W. P. Ramsey, Chief of Division, July 1, 1897, to June 30, 1898.
Mr. F. R. Green, July 1, 1897, to June 30, 1898.

Mr. W. P. Ramsey has been in charge of this division throughout the fiscal year. The duties of the division include the correspondence with sales agents relating to the supply and sale of charts, Coast Pilot, and tide tables, and keeping the accounts connected therewith; the purchase, custody, and issue of stationery used in the Office and by the field parties, and all miscellaneous supplies for the Office, and the keeping of accounts of all expenditures for these purposes; the supervision of the printing and issue of the Annual Reports and all other publications of the Office, including all record books, blank forms, etc., used in the transaction of the work of the Office and field parties; the care and general supervision of the Office buildings, the direction of the messenger service, and similar duties of a miscellaneous nature.

Publications sent to press during the fiscal year 1897–98.

Annual Report of the Superintendent for the fiscal year ending June 30, 1897.
United States Coast Pilot, Atlantic Coast, Part V.
Supplement to United States Coast Pilot, Atlantic Coast, Parts I, II, III, IV, V, and VII.
Supplement to Pacific Coast Pilot, Alaska, Part I.
Tide Tables for the Year 1899.
Special Publication No. 1.—"California, Bay of San Francisco, Magnetic Ranges for Determining the Deviation of the Compass, with short explanations of how to find the Deviation and Error of the Compass."
Notice to Mariners, Nos. 221 to 233, inclusive.

Publications received from the Public Printer during the fiscal year 1897–98.

	Number of copies.
Report of the Superintendent of the United States Coast and Geodetic Survey for the fiscal year ending June 30, 1896	2 000
Appendix No. 1.—Report for 1896, "Distribution of the magnetic declination in the United States for the epoch January 1, 1900"	1 000
Appendix No. 2.—Report for 1896, "Heights from geodetic leveling between Old Point Comfort and Richmond, Va., in the years 1884-1891 and 1892"	500
Appendix No. 3.—Report for 1896, "Heights from geodetic leveling between Richmond, Va., and Washington, D. C., in the years 1883, 1884, 1886, and 1895"	500
Appendix No. 4.—Report for 1896, "Heights from geodetic leveling between Washington, D. C., and Hagerstown, Md., in 1883"	500
Appendix No. 5.—Report for 1896, "Heights from geodetic leveling between Jefferson City, Mo., and Holliday, Kans., in 1891"	500
Appendix No. 6.—Report for 1896, "Establishment of the United States Naval Observatory Circle and the determination of the geographical position of the center of the clock room"	50
Appendix No. 7.—Report for 1896, "A new solution of a principal geodetic problem"	50
Appendix No. 9.—Report for 1896, "Field method of reducing portable transit time observations"	250
Appendix No. 10.—Report for 1896, "Determination of the constant of aberration from latitude observations with the Zenith telescope at Honolulu, Hawaiian Islands, and at San Francisco, Cal	200
Appendix No. 11.—Report for 1896, "General information relating to the vicinity of Chatham and Peril straits, from a recent survey by the United States Coast Survey steamer *Patterson*, Lieut. Commander E. K. Moore, U. S. N., commanding, and Cooks Inlet and the region to the westward, by W. H. Dall, United States Geological Survey"	1 000
Appendix No. 12.—Report for 1896, "Logarithms, their nature, computation and uses, with logarithmic tables of numbers and circular functions to ten places of decimals"	750
Tide Tables of the Pacific Coast of the United States for the year 1898	2 500
Tide Tables for the year 1899	2 082
Tide Tables of the Pacific Coast of the United States, 1899	5 035
United States Coast Pilot, Atlantic Coast, Part V, "From New York to Chesapeake Bay Entrance"	650
Supplement to First Edition United States Coast Pilot, Atlantic Coast, Parts I–II, "From St. Croix River to Cape Ann"	400
Supplement to First Edition United States Coast Pilot, Atlantic Coast, Part III, "From Cape Ann to Point Judith"	600
Supplement to Second Edition United States Coast Pilot, Atlantic Coast, Part IV, "From Point Judith to New York"	600
Supplement to First Edition United States Coast Pilot, Atlantic Coast, Part V, "From New York to Chesapeake Bay Entrance"	200
Supplement to First Edition United States Coast Pilot, Atlantic Coast, Part VII, "From Chesapeake Bay Entrance to Key West"	650
Supplement to United States Coast Pilot, Atlantic Coast, Parts I–II, III, IV, V, VI, VII, VIII, "Rules of the road at sea and in harbors, rivers, and inland waters (except the Great Lakes and their connecting and tributary waters as far east as Montreal, and the Red River of the North and rivers emptying into the Gulf of Mexico and their tributaries)"	1 500
Supplement to Third Edition Pacific Coast Pilot, Alaska, Part I, "Dixon Entrance to Yakutat Bay with Inland Passage from Strait of Fuca to Dixon Entrance"	800
Catalogue of Charts, Coast Pilots, and Tide Tables, 1897	2 512
Bulletin No. 36, "Table of depths for channels and harbors, coasts of the United States"	2 000
Special Publication No. 1, "California, bay of San Francisco, magnetic ranges for determining the deviation of the compass, with short explanations of how to find the deviation and error of the compass	2 000

Publications received from the Public Printer during the fiscal year 1897-98—Continued.

	Number of copies.
Notice to Mariners, No. 220, June, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 221, July, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 222, August, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 223, September, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 224, October, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 225, November, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 226, December, 1897. "Chart corrections during the month"	4 400
Notice to Mariners, No. 227. "Index to Notice to Mariners, 1897"	4 400
Notice to Mariners, No. 228, January, 1898. "Chart corrections during the month"	4 400
Notice to Mariners, No. 229, February, 1898. "Chart corrections during the month"	4 400
Notice to Mariners, No. 230, March, 1898. "Chart corrections during the month"	4 400
Notice to Mariners, No. 231, April, 1898. "Chart corrections during the month"	4 400
Notice to Mariners, No. 232, May, 1898. "Chart corrections during the month"	4 400

Publications issued during the fiscal year 1897-98.

Annual Reports	2 841
Appendices to Annual Reports	1 826
Tide Tables	7 568
United States Coast Pilot, Atlantic Coast	1 557
Pacific Coast Pilot, Alaska, Part I	303
Pacific Coast Pilot, "California, Oregon, and Washington"	60
Bulletins	878
Notice to Mariners	42
Miscellaneous publications	145
Special publications	1 529
Charts sent to sales agents	32 405

The number of requisitions during the year for printing and binding was 110; those for stationery filled 457, and for miscellaneous supplies and repairs attended to 875. Two hundred and ninety-one quarterly statements of sales agents were verified and 24 circulars were issued to sales agents. The number of letters written in connection with work executed in the division was 3 893.

h. Disbursing Division.

Scott Nesbit, disbursing agent, chief of division, July 1, 1897, to June 30, 1898.
Mr. Nicholas G. Henry, clerk, July 1, 1897, to June 30, 1898.
Miss Ida M. Peck, clerk, July 1, 1897, to June 30, 1898.
Mrs. Jennie H. Fitch, clerk, July 1, 1897, to June 30, 1898.

This division throughout the year has remained in charge of Mr. Scott Nesbit, disbursing agent.

Summarized and detailed statements of the disbursements are given in the following tables:

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898.

[Prepared pursuant to act approved March 3, 1853.]

SALARIES—PAY OF FIELD OFFICERS.

To whom paid.	Time employed.	Amount.
SUPERINTENDENT.		
W. W. Duffield	Five months	$2 078·80
Henry S. Pritchett	Seven months	2 921·20
ASSISTANTS.		
Charles A. Schott	One year	4 000·00
Aug. F. Rodgers	do	4 000·00
Otto H. Tittmann	do	3 200·00
Andrew Braid	do	3 000·00
A. T. Mosman	do	3 000·00
Herbert G. Ogden	do	3 000·00
Will Ward Duffield	do	3 000·00
Erasmus D. Preston	do	2 500·00
Cephas H. Sinclair	do	2 500·00
William Eimbeck	do	2 500·00
Frank D. Granger	do	2 500·00
Frank Walley Perkins	do	2 044·57
J. J. Gilbert	do	2 200·00
Henry L. Marindin	do	2 200·00
John F. Pratt	do	2 200·00
Edmund F. Dickins	do	2 200·00
Dallas B. Wainwright	do	2 200·00
Isaac Winston	do	2 200·00
William C. Hodgkins	do	2 000·00
Philip A. Welker	do	2 000·00
James R. Baylor	Eleven months and sixteen days	1 918·43
John A. Flemer	One year	2 000·00
Stehman Forney	do	2 000·00
John Nelson	do	2 000·00
Fremont Morse	do	2 000·00
Gershom Bradford	do	1 800·00
Walter B. Fairfield	do	1 800·00
W. Irving Vinal	Nine months and four days	1 363·30
Charles T. Iardella	Three months and twenty-seven days	517·39
Harry M. Clapp	Two months and twenty-five days	426·70
George R. Putnam	One year	1 600·00
Fred A. Young	do	1 600·00
Ferdinand Westdahl	Seven months and twenty-three days	1 034·80
E. B. Latham	One year	1 400·00
Albert L. Baldwin	do	1 400·00
Homer P. Ritter	do	1 400·00
Robert L. Faris	do	1 200·00
George L. Flower	do	1 200·00
Owen B. French	do	1 200·00
Chas. C. Yates	do	1 200·00
AIDS.		
Hugh C. Denson	One year	900·00
Albert F. Zust	Eight months	597·50
R. B. Derickson	One year	900·00
William Bowie	do	900·00
Harry F. Flynn	Four months	302·50
Expenditures		90 105·19
Appropriation		90 400·00
Expenditures		90 105·19
Unexpended balance		294·81

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SALARIES—PAY OF OFFICE FORCE, 1898.

To whom paid.	Time employed.	Amount.
DISBURSING AGENT.		
Scott Nesbit	One year	$2 200·00
GENERAL OFFICE ASSISTANT.		
Walter P. Ramsey	One year	1 800·00
CHIEF OF DIVISION OF LIBRARY AND ARCHIVES.		
Artemas Martin	Eight months	1 195·00
W. Irving Vinal	Two months and twenty-seven days	436·70
Harry M. Clapp	Five days	24·73
CLERKS.		
William B. Chilton	One year	1 647·76
Nicholas G. Henry	do	1 650·00
John H. Smoot	do	1 400·00
William C. Maupin	do	1 400·00
Freeman R. Green	do	1 400·00
Eugene B. Wills	do	1 200·00
Frank W. Edmonds	do	1 200·00
J. Henry Roeth	do	1 200·00
Asa G. Randall	do	1 200·00
A. H. Bailey	Five months and five days	515·20
Sophie S. Hein	One year	1 200·00
William H. Emery	Six months and twenty-six days	684·78
Adelbert B. Simons	One year	1 000·00
Jennie H. Fitch	do	991·85
Alice G. Reville	do	1 000·00
Fannie I. Matthews	Eight months and four days	678·31
Patrick V. Dolan	Three months and eighteen days	299·99
CHART CORRECTORS.		
Edward H. Wyvill	One year	1 200·00
Ida M. Peck	do	1 200·00
Henry R. Garland	do	900·00
Archie Upperman	do	720·00
Mary L. Handlan	do	720·00
WRITERS.		
Lily A. Mapes	One year	900·00
Virginia Harrison	Ten months and nine days	771·45
Mary E. Campbell	One month and twenty-two days	128·60
Kate Lawn	One year	800·00
Deane S. Bliss	do	720·00
Marie L. Fout	Nine months	540·00
Edward F. Lopez	Seven months and twenty days	462·00
James M. Griffin	One year	720·00
Fannie I. Matthews	Eight days	15·65
Buford Lynch	Two months and nineteen days	123·83
Ella P. Ellis	Five months and twenty-four days	289·33
Albert F. Zust	Four months	242·00
Henry Warrington	Two months and eighteen days	156·30
Mary A. Grant	One month and six days	59·39

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SALARIES—PAY OF OFFICE FORCE, 1898—Continued.

To whom paid.	Time employed.	Amount.
BUOY COLORIST.		
Edward Belford	Ten months and twenty-seven days	$665·33
DRAFTSMEN.		
Edwin H. Fowler	One year	2 400·00
Henry Lindenkohl	do	2 200·00
Adolph Lindenkohl	do	2 000·00
William C. Willenbucher	do	2 000·00
Ferdinand Westdahl	Four months and seven days	635·84
Ernest J. Sommer	Eight months and twenty-six days	1 334·86
Frank C. Donn	One year	1 800·00
David M. Hildreth	do	1 658·63
Charles H. Deetz	do	1 400·00
Edmund P. Ellis	do	1 326·61
John T. Watkins	do	1 087·49
Paul Erichsen	do	1 000·00
Harlow Bacon	do	941·40
Benjamin E. Tilton	Five months and twenty-eight days	442·50
James P. Keleher	Three months and twenty-seven days	292·50
Charles Mahon	One year	871·64
Charles A. Weckerly	One month	49·49
COMPUTERS.		
Edward H. Courtenay	One year	2 000·00
Myrick H. Doolittle	do	2 000·00
John B. Boutelle	do	1 600·00
Leland P. Shidy	do	1 600·00
Frank M. Little	do	1 600·00
Daniel L. Hazard	do	1 400·00
Rollin A. Harris	do	1 400·00
Lilian Pike	do	1 180·43
Artemas Martin	Four months	403·30
Harry F. Flynn	Eight months	796·70
Francis W. Clay	Ten months	829·67
Albert Baker	Five months and ten days	445·00
William H. Dennis	Four months and twenty-six days	408·32
George A. Fairfield	One month and twenty-seven days	156·58
COPPERPLATE ENGRAVERS.		
William A. Thompson	One year	2 000·00
Henry M. Knight	do	2 000·00
Theodore Wasserbach	do	2 000·00
William H. Davis	do	1 800·00
Edward H. Sipe	do	1 800·00
William F. Peabody	do	1 600·00
Harry L. Thompson	do	1 600·00
William A. Van Doren	do	1 400·00
Alfred H. Sefton	do	1 200·00
Peter H. Geddes	do	1 196·74
Harry R. McCabe	do	1 000·00
William Mackenzie	do	1 000·00
George Hergesheimer	do	900·00
Frank G. Wurdemann	do	900·00
William H. Holmes	do	900·00
Hugo Franke	do	900·00
Rowland H. Ford	Eleven months and fourteen days	480·64

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SALARIES—PAY OF OFFICE FORCE, 1898—Continued.

To whom paid.	Time employed.	Amount.
ELECTROTYPER AND PHOTOGRAPHER.		
Louis P. Keyser	One year	$1 800·00
ASSISTANT ELECTROTYPER AND PHOTOGRAPHER.		
Roy Thomas	One year	700·00
PLATE PRINTERS.		
D. N. Hoover	One year	1 600·00
Charles J. Harlow	Ten months and ten days	859·87
Eberhard Fordan	One year	1 000·00
Neil Bryant	do	1 000·00
James L. Smith	do	1 000·00
Frank C. Gohre	do	989·13
Charles F. Locraft	Two months	152·73
PLATE PRINTERS' HELPERS.		
Charles F. Locraft	Ten months	582·70
Louis L. Williams	One year	671·47
William M. Conn	do	700·00
Charles Buckingham	do	700·00
INSTRUMENT MAKERS.		
Ernest G. Fischer	One year	1 800·00
Clement Jacomini	do	1 200·00
William P. Whitman	do	1 000·00
Michael Lauxmann	do	1 000·00
Thomas A. Gibson	do	900·00
J. A. Clark	do	863·29
CARPENTERS.		
Horace O. French	One year	1 200·00
George W. Clarvoe	do	1 000·00
Charles N. Darnall	do	997·28
ENGINEER.		
P. J. Mullen	One year	1 000·00
WATCHMEN.		
David Parker	One year	880·00
John W. Drum	do	880·00
J. A. Dorsey	do	820·00
FIREMAN.		
Horace Dyer	One year	630·00
MESSENGERS.		
Edward D. Scott	One year	880·00
Charles Over	do	820·00
Charles H. Jones	do	820·00

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SALARIES—PAY OF OFFICE FORCE, 1898—Continued.

To whom paid.	Time employed.	Amount.
MESSENGERS—continued.		
Wm. R. McLane	One year	$820·00
Vicente Denis	do	820·00
Thomas McGoines	do	820·00
John W. Reed	do	700·00
George Newman	do	700·00
John W. Miner	do	640·00
John W. Hunter	do	640·00
Wm. H. Butler	do	640·00
Owen E. McNeille	do	550·00
PACKER AND FOLDER.		
Attrell Richardson	One year	630·00
LABORERS.		
J. H. Brown	One year	630·00
Frank Thomas	do	630·00
Hans Bowdwin	do	550·00
Boston Brown	One month	46·30
Jos. A. Williamson	One year	550·00
Charles H. Bryan	Eleven months	500·75
John Mason	One year	365·00
Virginia McGlincy	do	365·00
Expenditures		134 640·06
Appropriation		136 470·00
Expenditures		134 640·06
Unexpended balance		1 829·94

RECAPITULATION.

Pay of field officers	$90 105·19
Pay of office force	134 640·06
Expenditures	224 745·25
Total sum appropriated for salaries	226 870·00
Total sum expended for salaries	224 745·25
Unexpended balance	2 124·75

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898.

ATLANTIC COAST.

To whom paid.	On what account.	Amount.
J. B. Boutelle	Combined operations	$268·06
William Bowie	Topography	1 984·04
J. W. Donn	....do	132·39
A. Dunlap, U. S. N	Hydrography, steamer Blake	4 108·89
J. A. Flemer	Topography	1 334·67
C. T. Forse, U. S. N	Hydrography, steamer Endeavor	2 048·93
O. B. French	Topography	484·02
George W. Knox Express Co	Transportation	·50
M. E. Hall, U. S. N	Hydrography, schooner Eagre	714·63
G. C. Hanus, U. S. N	....do	1 107·46
W. G. Hodgkins	Topography	3 262·09
Henry L. Marindin	Hydrography, schooner Eagre	400·52
John Nelson	Topography	1 306·13
H. G. Ogden	Triangulation, topography, and outfit for Blake, Eagre, and Matchless.	4 624·69
F. W. Perkins	Triangulation	1 963·36
H. S. Pritchett	Commutation	10·00
W. B. Proctor	Telegrams	·55
J. H. Reed, U. S. N	Hydrography, steamer Blake	616·47
Revenue-Cutter Service	Flags and bunting	73·51
E. Simpson, U. S. N	Hydrography	681·51
Standard Oil Co	Oil for steamer Endeavor	17·21
E. D. Taussig, U. S. N	Hydrography, schooner Matchless	296·05
W. Irving Vinal	Topography and hydrography	2 013·99
D. B. Wainwright	Triangulation and hydrography, Endeavor, Matchless, and Eagre.	1 382·58
Henry A. Wiley, U. S. N	Hydrography, schooner Eagre	313·54
W. C. Willenbucher	Traveling expenses	109·85
Expenditures		29 255·64
Appropriation		30 000·00
Expenditures		29 255·64
Unexpended balance		744·36

GULF COAST, ETC.

To whom paid.	On what account.	Amount.
W. J. Barnette, U. S. N	Hydrography, steamer Bache	$805·97
Bureau of Equipment, Navy	Coal for steamer Bache	231·14
A. H. Davis, U. S. N	Hydrography, steamer Bache	261·21
W. B. Fairfield	Triangulation	2 281·36
R. L. Faris	Traveling expenses	38·90
J. K. Glennon & Co	Storage	15·00
J. H. Reed, U. S. N	Hydrography, steamer Blake	238·71
Revenue-Cutter Service	Flags and bunting	20·08
P. A. Welker	Combined operations	3 613·66
Amount disbursed		7 506·03
Railroad accounts referred for settlement		38·02
Expenditures		7 544·05
Appropriation		8 000·00
Expenditures		7 544·05
Unexpended balance		455·95

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

OFFSHORE WORK, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$4·80
W. J. Barnette, U. S. N	Hydrography, steamer Bache	3 697·25
Bureau of Equipment, Navy	Coal for steamer Bache	168·74
A. H. Davis, U. S. N	Hydrography, steamer Bache	259·74
Revenue-Cutter Service	Flags and bunting	24·93
P. A. Welker	Hydrography, steamer Bache	807·65
Expenditures		4 963·11
Appropriation		5 000·00
Expenditures		4 963·11
Unexpended balance		36·89

PACIFIC COAST.

To whom paid.	On what account.	Amount.
Charles R. Allen	Coal for steamer Gedney	$350·00
Bernham Mattress Co	Outfit for steamer Gedney	35·30
City of Paris Dry Goods Co	do	227·61
E. F. Dickins	Topography	2 122·31
C. & N. Dunham Co	Outfit for steamer Gedney	308·06
J. J. Gilbert	Triangulation and topography	1 880·32
J. M. Helm, U. S. N	Hydrography, steamers McArthur and Gedney.	4 058·68
Charles J. Hendry's Son & Co	Stores for Steamer Gedney	43·90
Herreschoff Manufacturing Co	Outfit for steamer Gedney	42·00
G. M. Josselyn & Co	do	487·17
Fremont Morse	Triangulation	637·63
A. T. Mosman	do	4 026·30
Nathan, Dohrman & Co	Outfit for steamer Gedney	36·75
A. P. Osborn, U. S. N	Hydrography, steamers McArthur and Gedney.	3 978·84
Revenue-Cutter Service	Flags and bunting	21·65
Aug. F. Rodgers	Triangulation and topography and hydrography, steamers McArthur and Gedney.	3 694·63
C. H. Sinclair	Triangulation	571·82
Standard Oil Co	Oil for steamer Gedney	55·00
Washburn Moen Manufacturing Co.	Outfit for steamer Gedney	23·25
F. Westdahl	Hydrography	601·84
Amount disbursed		23 203·06
Railroad accounts referred for settlement		276·85
Expenditures		23 479·91
Appropriation		25 600·00
Expenditures		23 479·91
Unexpended balance		2 120·09

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

ALASKA.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$27·45
Bureau of Equipment	Coal for steamer Patterson	53·00
Will Ward Duffield	Triangulation and topography	3 701·78
J. A. Flemer	Topography	3 526·15
C. T. Forse, U. S. N	Hyrography, steamer Patterson	1 688·04
E. K. Moore, U. S. N	....do	4 972·55
Revenue-Cutter Service	Flags	9·46
Aug. F. Rodgers	Reconnoissance and hydrography, steamer Patterson.	822·45
J. D. Spreckels & Bros. Co	Towing steamer Patterson	25·00
Amount disbursed		14 825·88
Railroad account referred for settlement		51·56
Expenditures		14 877·44
Appropriation		15 000·00
Expenditures		14 877·44
Unexpended balance		122·56

TIDES, ETC.

To whom paid.	On what account.	Amount.
R. L. Faris	Tidal observations, schooner Matchless	$588·00
H. L. Marindin	Washington tidal	3·66
E. K. Moore, U. S. N	Tidal observations, steamer Patterson	344·70
J. F. Pratt	Tidal observations	10·50
Aug. F. Rodgers	San Francisco tidal	1 142·93
L. P. Shidy	Washington tidal	11·08
J. G. Spaulding	Fort Hamilton tidal	1 012·88
E. D. Taussig, U. S. N	Tidal observations, schooner Matchless	38·69
E. H. Tillman, U. S. N	....do	242·89
O. H. Tittmann	Establishing tide gauge	25·79
H. V. Webb	Tidal observations	50·00
B. W. Weeks	Fernandina tidal	607·06
P. A. Welker	Tidal observations	167·71
C. C. Yates	....do	57·16
Expenditures		4 303·05
Appropriation		5 000·00
Expenditures		4 303·05
Unexpended balance		696·95

SAN FRANCISCO TIDAL INDICATOR.

To whom paid.	On what account.	Amount.
Appropriation		$2 500·00
Unexpended balance		2 500·00

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

COAST PILOT, ETC.

To whom paid.	On what account.	Amount.
A. P. Osborn	Steamer Gedney	$28·25
Talbot Pulizzi	Services	900·00
John Ross	do	1 649·12
Expenditures		2 577·37
Appropriation		3 300·00
Less 3 per cent transferred to leveling	$99 00	
Expenditures	2 577 37	
		2 676·37
Unexpended balance		623·63

MAGNETICS.

To whom paid.	On what account.	Amount.
Owen B. French	Magnetic observations	$188·40
Homer P. Ritter	do	970·14
Aug. F. Rodgers	do	18·05
Edwin Smith	do	579·78
United States Express Co	Transportation	1·50
C. C. Yates	Magnetic observations	56·38
Expenditures		1 814·25
Appropriation		2 000·00
Expenditures		1 814·25
Unexpended balance		185·75

LEVELING.

To whom paid.	On what account.	Amount.
G. D. Freed	Storage	$4·40
Isaac Winston	Precise leveling	1 499·97
Amount disbursed		1 504·37
Railroad accounts referred for settlement		33·70
Expenditures		1 538·07
Appropriation		1 500·00
Add 3 per cent from Coast Pilot, etc		99·00
		1 599·00
Expenditures		1 538·07
Unexpended balance		60·93

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

STATE SURVEYS.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$9·90
A. L. Baldwin	do	30·03
John Barlow	Pasturage	421·20
Central Vermont Railroad	Transportation	5·15
George A. Fairfield	Services	1 012·90
R. L. Faris	Reconnoissance	461·79
Stehman Forney	do	1 972·88
George W. Knox Express Co	Transportation	10·68
F. D. Granger	Triangulation, storage, and pasturage	4 193·96
Thomas Hughes	Storage	15·00
H. W. Lawrence	do	45·00
A. T. Mosman	Triangulation	1 276·97
F. Walley Perkins	Reconnoissance	212·97
United States Express Co	Transportation	4·05
P. A. Welker	Triangulation, storage, and pasturage	3 314·19
Frank Williams	Pasturage and storage	43·50
Amount disbursed		13 030·17
Railroad accounts referred for settlement		511·83
Expenditures		13 542·00
Appropriation		13 500·00
Add 5 per cent from objects not named		200·00
		13 700·00
Expenditures		13 542·00
Unexpended balance		158·00

GRAVITY, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$9·25
O. B. French	Latitudes	507·54
C. H. Sinclair	Triangulation, longitudes, and astronomical work.	2 035·86
Amount disbursed		2 552·65
Railroad accounts referred for settlement		12·66
Expenditures		2 565·31
Appropriation		2 500·00
Add 5 per cent from objects not named		200·00
		2 700·00
Expenditures		2 565·31
Unexpended balance		134·69

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

NAVY TRAVEL, ETC.

To whom paid.	On what account.	Amount.
W. J. Barnette, U. S. N	Mileage	$76·96
G. B. Bradshaw, U. S. N	do	260·80
Guy W. Brown, U. S. N	do	2·00
R. E. Coontz, U. S. N	do	76·64
John Craig, U. S. N	do	8·37
A. Dunlap, U. S. N	do	6·40
W. H. Faust, U. S. N	do	3·04
C. T. Forse, U. S. N	do	259·52
M. E. Hall, U. S. N	do	22·40
G. C. Hanus, U. S. N	do	21·76
A. B. Hoff, U. S. N	do	16·96
H. O. Jordan, U. S. N	do	4·30
N. A. McCully, U. S. N	do	154·88
H. G. Ogden	Special survey	25·98
C. F. Preston, U. S. N	Mileage	252·00
F. H. Schofield, U. S. N	do	278·00
J. E. Shepherd, U. S. N	do	7.30
E. Simpson, U. S. N	do	6·40
F. B. Sullivan, U. S. N	do	15·04
J. H. Sypher, U. S. N	do	251·20
E. D. Taussig, U. S. N	do	501·44
E. H. Tillman, U. S. N	do	6·08
D. B. Wainwright	Special survey	78·75
P. A. Welker	do	56·65
Roger Welles, jr., U. S. N	Mileage	287·84
Henry A. Wiley, U. S. N	do	298·48
Expenditures		2 979·19
Appropriation		3 400·00
Expenditures		2 979·19
Unexpended balance		420·81

OBJECTS NOT NAMED.

To whom paid.	On what account.	Amount.
Owen B. French	Astronomical observations	$138·51
George W. Knox Express Co.	Transportation	·25
J. H. Gore	Indexing publications	150·00
Charles Hansen	Services as ship keeper	79·03
G. C. Hanus, U. S. N	Hydrography, schooner Eagre	158·44
W. R. Hoag	Storage	8·75
A. B. Hoff	Subsistence	5·60
Charles Johnson	Services as ship keeper	367·86
M. P. Lagos	do	138·00
James Laird	do	10·00
N. A. McCully, U. S. N	Incidental expenses	5·83
George Olsen	Services as ship keeper	300·00
Frank Walley Perkins	Traveling expenses	13·25
Philadelphia, Wilmington and Baltimore R. R. Co.	Transportation	10·83
J. F. Pratt	Traveling expenses	282·85
H. S. Pritchett	do	65·90
G. R. Putnam	do	35·45

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

OBJECTS NOT NAMED—Continued.

To whom paid.	On what account.	Amount.
Aug. F. Rodgers	Transportation, astronomical, and drawing for tidal indicator.	$135.19
F. Springman	Transportation	7.53
E. D. Taussig, U. S. N	Stores for schooner Transit	64.19
D. B. Wainwright	Triangulation, topography, and traveling expenses.	226.52
Expenditures		2 203.98
Appropriation		4 000.00
Less 5 per cent transferred to State surveys	$200.00	
Less 5 per cent transferred to gravity, etc	200.00	
Expenditures	2 203.98	
		2 603.98
Unexpended balance		1 396.02

INTERNATIONAL GEODETIC ASSOCIATION.

To whom paid.	On what account.	Amount.
International Geodetic Association	Annual dues	$1 410.00
Appropriation		1 500.00
Expenditures		1 410.00
Unexpended balance		90.00

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Atlantic coast	$29 255.64
Gulf coast, etc	7 506.03
Offshore work, etc	4 963.11
Pacific coast	23 203.06
Alaska	14 825.88
Tides, etc	4 303.05
Coast Pilot, etc	2 577.37
Magnetics	1 814.25
Leveling	1 504.37
State surveys	13 030.17
Gravity, etc	2 552.65
Navy travel	2 979.19
Objects not named	2 203.98
International Geodetic Association	1 410.00
Amount disbursed	112 128.75
Railroad accounts referred for settlement	924.62
Expenditures	113 053.37
Total amount appropriated for party expenses, 1898	122 800.00
Total amount expended for party expenses, 1898	113 053.37
Unexpended balance	9 746.63

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1898—Continued.

CLASSIFICATION OF EXPENDITURES FOR PARTY EXPENSES, 1898.

On what account.	Amount.
Triangulation	$35 654·31
Topography	23 506·29
Hydrography	39 453·76
Coast Pilot	2 577·37
Leveling	1 538·07
Magnetics	1 814·25
Geographical positions	1 139·79
Tidal operations	4 303·05
Astronomical work	970·28
Annual dues to International Geodetic Association	1 410·00
Traveling expenses, transportation, etc	686·20
Total	113 053·37

REPAIRS OF VESSELS, 1898.

To whom paid.	On what account.	Amount.
W. J. Barnette, U. S. N	Steamer Bache	$1 045·38
J. B. Boutelle	Schooner Matchless	·80
A. Dunlap, U. S. N	Steamer Blake	14 441·69
C. T. Forse, U. S. N	Steamers Endeavor and Patterson	549·86
F. W. Grogan	Steamer Blake	2·50
M. E. Hall, U. S. N	Schooner Eagre	209·00
G. C. Hanus, U. S. N	do	419·83
Hay & Wright	Steamers Gedney and McArthur	1 516·27
J. M. Helm, U. S. N	do	1 723·77
Charles J. Hendry's Son & Co	Steamer McArthur	344·79
H. L. Marindin	Schooner Eagre	401·10
Marine Machine and Conveyor Co	Steamer McArthur	235.00
McKenzie, Oerting & Co	Schooners Spy and Transit	51.99
E. K. Moore, U. S. N	Steamer Patterson	635.55
Oakland Iron Works	Steamers Gedney and McArthur	1 418·75
H. G. Ogden	Steamer Blake and schooners Eagre and Matchless.	234·10
A. P. Osborn, U. S. N	Steamers Godney and McArthur	114·67
Charles Oulliber	Schooner Quick	26·00
Reeder & Sons	Steamer Endeavor	5 160·00
Aug. F. Rodgers	Steamer Gedney	5·54
J. H. Roeth	Traveling expenses	7·95
E. Simpson, U. S. N	Steamer Endeavor	41·47
E. D. Taussig, U. S. N	Steamer Endeavor and schooners Spy and Transit and traveling expenses.	676·76
E. H. Tillman, U. S. N	Schooner Matchless	45·00
D. B. Wainwright	Steamer Endeavor and schooner Eagre	693·47
P. A. Welker	Steamer Bache	1 250·15
J. A. Whelan & Bro	Steamer Patterson	1 530·00
Henry A. Wiley, U. S. N	Schooner Eagre	126·38
Charles C. Yates	Steamer Blake	825 00
Expenditures		33 732·77
Appropriation		35 000·00
Expenditures		33 732·77
Unexpended balance		1 267·23

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

REPAIRS OF VESSELS, 1898—Continued.

CLASSIFICATION OF EXPENDITURES FOR REPAIRS OF VESSELS.

Name of vessel.	Amount.
Steamer Bache	$2 295·53
Steamer Blake	15 315·39
Schooner Eagre	1 222·06
Steamer Endeavor	6 177·85
Steamer Gedney	791·63
Schooner Matchless	169·95
Steamer McArthur	4 567·16
Steamer Patterson	2 436·90
Schooner Quick	26·00
Schooners Spy and Transit	673·07
Mileage of Inspection officers	57·23
Total	33 732·77

PUBLISHING OBSERVATIONS, 1898.

To whom paid.	On what account.	Amount.
Ernest Whitehead	Services	$100·00
E. Phillips Moulton	do	439·22
J. B. Johnson	do	25·00
John F. Hayford	do	380·00
Expenditures		944·22
Appropriation		1 000·00
Expenditures		944·22
Unexpended		55·78

GENERAL EXPENSES, 1898.

INSTRUMENTS, INSTRUMENT SHOP, CARPENTER SHOP, DRAWING DIVISION, BOOKS, MAPS, CHARTS, AND SUBSCRIPTIONS.

To whom paid.	On what account.	Amount.
A. Lietz Co	Instruments and instrument shop	$74·75
American Engineer, Car Builder and Railroad Journal.	Books	2·00
American Journal of Science	do	6·00
D. Appleton & Co	do	5·00
Barber & Ross	Carpenter shop	9·77
Bausch & Lomb Optical Co	Instruments	423·21
Charles Becker	Carpenter shop	7·88
Benedict & Burnham Manufacturing Co.	Instrument shop	5·97
Billany & Cochran	Carpenter shop	·31
John Bliss & Co	Charts, instruments, books, and maps	78·95
R. P. Bowker	Subscriptions	5·00
W. Andrew Boyd	Books	25·00
John A. Breashear	Instruments	98·00

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

INSTRUMENTS, INSTRUMENT SHOP, CARPENTER SHOP, DRAWING DIVISION, BOOKS, MAPS, CHARTS, AND SUBSCRIPTIONS—Continued.

To whom paid.	On what account.	Amount.
Brentanos	Books	$2·00
Henry H. Brown	Instruments	45·75
W. T. Brown	Instrument shop	1·50
Brown & Sharp Manufacturing Co.	do	6·34
Buffington Light Co	do	5.25
Buff & Berger	Instruments	725·40
N. Bunch	Instrument shop	21·55
W. H. Butler	Carpenter shop	1·75
J. Carbutt	Instruments	5·40
Rufus P. Clark	Instrument shop, carpenter shop, and drawing division.	42·25
Clarke & Courts	Maps	1·00
M. G. Copeland & Co.	Instrument shop	·90
Cushman Chuck Co	do	8·64
Diamond Machine Co	do	13·00
Doremus & Just	do	8·00
M. Du Perow	Instrument shop and carpenter shop	17·35
H. C. Easterday	Instrument shop	·75
W. H. Echols	Books	2·00
Eimer & Amend	Instrument shop	16·11
Elwood Ivins Tube Co	do	11·25
E. Morrison Paper Co	Drawing division	93·28
George T. Ennis	Instrument shop	167·47
John B. Espey	Instrument and carpenter shops	267·55
William Gaertner & Co.	Instruments	35·00
W. A. Gahlenbeck	Instrument shop	4·50
Geological Publishing Co.	Books	3·50
Z. D. Gilman	Instrument and carpenter shops	24·34
Golding & Co.	Instrument shop	4·38
Henry J. Green	Instruments	85·33
Gustendorfer Bros.	Instrument shop	6·50
Harris & Shafer	Instruments	228·00
Louis Hartig	Carpenter shop	·20
H. B. Smith Machine Co.	do	8·40
A. Hurlemann	Instruments	475·55
George Isemann	Instrument shop	·75
The E. E. Jackson Co.	Carpenter shop and drawing division	32·65
M. E. Kahler	Instruments	81·00
J. Karr's Sons	do	4·00
W. H. Kemp & Co.	Instrument shop	11·39
J. B. Kendall	Carpenter shop	·50
Keuffel & Esser Co.	Instruments	808·20
James B. Lambie	Carpenter and instrument shops	29·99
Julius Lansburgh	Carpenter shop	·21
Lansburgh & Bro	do	17·00
Lemcke & Buechner	Books and subscriptions	40·37
J. S. Lentz's Son & Co.	Instrument shop	18·00
Lietz & Co.	do	5·00
Melville Lindsay	do	3·84
Leo Loeb	do	12·74
W. H. Lowdermilk & Co.	Books and maps	111·95
Mackall Bros. & Flemer	Instrument and carpenter shops	22·23
The Macmillan Co.	Books	2·50
Manhattan Brass Co.	Instrument shop	18·50
F. P. May & Co.	Instruments	3·00
William H. Mehler	do	4·00
Mercantile Printing Co.	Maps	·50

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

INSTRUMENTS, INSTRUMENT SHOP, CARPENTER SHOP, DRAWING DIVISION, BOOKS, MAPS, CHARTS, AND SUBSCRIPTIONS—Continued.

To whom paid.	On what account.	Amount.
W. B. Moses & Sons	Carpenter shop	$2·88
Munn & Co	Books	7·00
N. Murray	do	5·00
George F. Muth & Co	Instruments, instrument and carpenter shops, and drawing division.	418·79
T. S. & J. D. Negus	Instruments	40·50
Charles A. Orth & Co	Books	3·00
John C. Parker	do	5·00
The Pratt & Whitney Co	Instrument shop	81.68
Queen & Co	Instruments	81·60
William Ramsey	Instruments and instrument shop	47·75
Rand, McNally & Co	Maps	1·59
Hugh Reilly	Instrument shop	12·00
F. J. Reutlinger	do	33·10
E. S. Ritchie & Sons	do	4·25
Rochester Optical Co	do	222·60
Royce & Marean	Instruments	2·50
Rudolph, West & Co	Carpenter shop	134·17
Saks & Co	Instruments	9·44
Fred. A. Schmidt	Instruments, instrument shop, and drawing division.	532·61
Science	Books and subscriptions	5·15
Seth Thomas Clock Co	Instruments	108·00
George A. Shehan	Carpenter shop	354·50
M. Silverberg & Co	do	2·10
Thomas W. Smith	do	39·73
Standard Oil Co	Instrument shop	12·50
Gustav E. Stechert	Books	81·47
Sussfeld, Lorsch & Co	Instruments and instrument shop	192·20
J. de Mendizabel Tamborrel	Books	10·00
Terrestrial Magnetism	Subscriptions	2·00
S. Thaxter & Son	Charts	8·80
The Calvert Co	Books	1·50
The L. S. Starrett Co	Instruments	36·65
The University of Chicago	Subscriptions	4·00
T. M. Thorp	Maps	10·00
O. H. Tittmann	Drawing division	·70
United States Naval Institute	Subscriptions	3·50
William Wagner	Carpenter shop	·13
John Walker & Sons	do	2·70
Louis Weule	Instruments and instrument shop	125·75
Woodward & Lothrop	Instrument shop	·80
Amount disbursed		6 957·99
Accounts for stationery settled by Auditor		346·92
Expenditures		7 304·91
Appropriation		7 700·00
Received from United States Marine Hospital Service for work done for that Service		14·79
		7 714·79
Expenditures		7 304·91
Unexpended balance		409·88

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

COPPERPLATES, CHART PAPER, PRINTING INK; COPPER, ZINC, AND CHEMICALS FOR ELECTROTYPING AND PHOTOGRAPHING; ENGRAVING, PRINTING, PHOTOGRAPHING, AND ELECTROTYPING SUPPLIES; EXTRA ENGRAVING AND DRAWING; PHOTOLITHOGRAPHING AND PRINTING FROM STONE AND COPPER FOR IMMEDIATE USE.

To whom paid.	On what account.	Amount.
R. Carter Ballantyne	Engraving supplies	$7.50
D. Ballauf	Printing supplies	22.00
Charles E. Barrick	....do	9.45
Bausch & Lomb Optical Co	Engraving supplies	11.25
Henry H. Brown	Photographing supplies	19.46
Bureau of Engraving and Printing	Printing supplies	1 152.97
W. H. Butler	....do	10.50
Rufus P. Clark	....do	351.10
Clendenin Bros	Copper and copper plates	295.20
H. C. Easterday	Photographic supplies	38.67
Eimer & Amend	....do	12.74
E. Morrison Paper Co	Chart paper	5 042.87
J. G. Ergood & Co	Printing supplies	.27
John B. Espey	Engraving supplies	291.68
Thompson C. Gill & Co	Printing supplies	.99
Z. D. Gilman	Printing, photographing, engraving, and electrotyping supplies	1 119.17
Andrew B. Graham	Photolithographing	3 905.09
R. M. Harrover	Engraving supplies and zinc	13.25
A. Hoen & Co	Photolithographing	996.40
James B. Lambie	Engraving supplies	13.41
Julius Lansburgh	Printing supplies	.69
Mackall Bros. & Flemer	Photographing, printing, and electrotyping supplies.	100.96
Mackey Print Paper Co	Chart paper	37.13
Matthiessen & Hogler Zinc Co	Zinc	183.21
Robert Mayer & Co	Printing supplies	18.00
William S. McLeod	....do	144.20
W. H. Mehler	Printing supplies and zinc	19.97
Mount Holly Paper Co	Chart paper	1 232.90
George F. Muth & Co	Printing supplies	176.50
Peter Adams Paper Co	Chart paper	144.20
E. J. Pullman	Photographing supplies	9.69
Hugh Reilly	Printing supplies and zinc	2.70
Aug. F. Rodgers	Photographing supplies	2.04
Fred A. Schmidt	Photographing and electrotyping supplies	31.36
Shoemaker & Busch	Photographing and engraving supplies	10.03
The Scoville & Adams Co., of New York.	Printing supplies	2.35
Williams, Brown & Co	Chart paper	16.00
Amount disbursed		15 445.90
Accounts for engraving and printing supplies settled by Auditor		54.10
Expenditures		15 500.00
Appropriation		15 500.00
Expenditures		15 500.00

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

STATIONERY, TRANSPORTATION OF INSTRUMENTS AND SUPPLIES, OFFICE WAGON AND HORSES, FUEL, GAS, ELECTRICITY, TELEGRAMS, ICE, AND WASHING.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$77·75
C. F. Anderson	Washing	3·53
Herman Baumgarten	Stationery	20·70
J. Baumgarten & Sons	....do	1·27
James Connor	Office horse	31·25
E. Morrison Paper Co	Stationery	166·74
Felt & Tarrant Manufacturing Co.	....do	1·00
General Electric Co	Transportation	1·35
George W. Knox Express Co	....do	32·04
Z. D. Gilman	Office horse	·60
J. F. Dorman Co	Stationery	6·93
Johnson Bros	Fuel	1 176·99
Library Bureau	Stationery	37·31
Lutz & Co	Office horse and wagon	64·00
Mackey Printing Paper Co	Transportation	1·25
The McDermott Carriage Co	Office wagon	7·00
George F. Muth & Co	Stationery	15·20
John C. Parker	....do	61·20
People's Dispatch Co	Transportation	2·47
Postal Telegraph Cable Co	Telegrams	4·92
Purity Ice Co	Ice	193·70
Queen & Co	Stationery	10·00
Aug. F. Rodgers	Stationery and washing	12·52
Fred A. Schmidt	Stationery	46·93
B. F. Shaw	Office horse	243·00
Smithsonian Institution	Transportation	101·65
United States Electric Light Co.	Electricity	185·32
United States Express Co	Transportation	71·03
United States Typewriter Supply Co.	Stationery	1·60
Washington Gas Light Co	Gas	1 442·70
Western Union Telegraph Co	Telegrams	256·90
Lilian M. Yost	Washing	168·15
Amount disbursed		4 447·00
Accounts for stationery settled by Auditor		849·31
Expenditures		5 296·31
Appropriation		6 000·00
Expenditures		5 296·31
Unexpended balance		703·69

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

MISCELLANEOUS EXPENSES, CONTINGENCIES OF ALL KINDS, OFFICE FURNITURE, REPAIRS, EXTRA LABOR, AND TRAVELING EXPENSES (OFFICE).

To whom paid.	On what account.	Amount.
M. W. Beveridge	Miscellaneous	$6.94
Blum Bros	do	1.58
H. Boswell & Co	Repairs and miscellaneous	15.00
Boston Brown	Extra labor	42.00
O. Chanute	Miscellaneous	334.95
Chesapeake and Potomac Telephone Co.	Exchange rental	101.30
Walter Y. Clark	Extra labor	210.54
Rufus P. Clarke	Miscellaneous	67.87
Wm. D. Colt	do	14.50
M. DuPerow	do	95.25
J. C. Ergood	do	34.89
John B. Espey	do	4.95
Evening Star Newspaper Co	Advertising	3.60
J. R. Francis	Repairs	65.00
Frank Freeman	Miscellaneous	16.50
R. J. Fondren	Extra labor	508.93
General Electric Co	Repairs	12.33
Alfred Gilbert	Extra labor	215.48
Z. D. Gilman	Miscellaneous	2.50
B. F. Guy & Co	do	1.40
R. M. Harrover	Repairs	57.00
J. Hawkins	Extra labor	260.65
Henry A. Jones & Co	Miscellaneous	1.10
Jordan & Christie	do	15.67
The Julius Lansburgh Furniture and Carpet Co.	do	5.75
Thos. Keely	do	15.33
Julius Lansburgh	do	276.30
Frank C. Larimore	Extra labor	266.13
Melville Lindsay	Miscellaneous	1.25
Mackall Bros. & Flemer	do	2.20
W. H. Mehler	do	55.00
Edward Miller	Advertising	3.00
Mitchell & Reed	Miscellaneous	1.30
J. T. Mockabee	do	10.00
Moore Bros	do	34.50
W. B. Moses & Sons	do	168.80
Geo. F. Muth & Co	do	7.30
Otto Gas Engine Works	Repairs	14.03
John C. Parker	do	35.00
Rudolph, West & Co	Miscellaneous	32.13
Wm. G. Raymond	do	300.20
Revenue-Cutter Service	do	8.20
Aug. F. Rodgers	do	24.25
E. G. Schafer & Co	Repairs and miscellaneous	33.77
The Sextro Furniture Co	Office furniture	30.50
Shoemaker & Busch	Miscellaneous	10.01
Thomas Somerville & Son	do	5.10
Specialty Soap Manufacturing Co	do	19.50
Standard Oil Co	do	2.70
O. H. Tittmann	Office travel	46.75
United States Electric Light Co	Miscellaneous	20.10
John Walsh	Repairs	3.00
The Washington Post Co	Advertising	3.90
Jas. P. Willett	Post-office box rent	20.00

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

MISCELLANEOUS EXPENSES, CONTINGENCIES OF ALL KINDS, OFFICE FURNITURE, REPAIRS, EXTRA LABOR, AND TRAVELING EXPENSES (OFFICE)—Continued.

To whom paid.	On what account.	Amount.
Wilmarth & Edmonston	Miscellaneous	$3·66
B. M. Winters	Extra labor	85·48
O. L. Wolfsteiner	Repairs	4·00
Wyckoff, Seamans & Benedict	Miscellaneous and repairs	366·35
Amount disbursed		4 005·42
Accounts settled by Auditor for towels and repairs		125·58
Expenditures		4 131·00
Appropriation		4 200·00
Expenditures		4 131·00
Unexpended balance		69·00

RECAPITULATION.

[Showing expenditures in gross (by subitems) on account of appropriation for general expenses, 1898.]

Subitems.	Amount.
Instruments, instrument shop, carpenter shop, drawing division, books, maps, charts, and subscriptions	$6 957·99
Copper plates, chart paper, printing ink, copper, zinc, and chemicals for electrotyping and photographing; engraving, printing, photographing, and electrotyping supplies; photolithographing and printing from stone and copper for immediate use	15 445·90
Stationery, transportation of instruments and supplies, office wagon and horses, fuel, gas, electricity, telegrams, ice, and washing	4 447·00
Miscellaneous expenses, contingencies of all kinds, office furniture, repairs, extra labor, and traveling expenses (office)	4 005·42
Total disbursements	30 856·31
Accounts settled by Auditor as shown under each paragraph	1 375·91
Total expenditures	32 232·22
Total amount appropriated for general expenses, 1898	33 400·00
Received from Marine-Hospital Service	14·79
	33 414·79
Total amount expended for general expenses, 1898	32 232·22
Unexpended balance	1 182·57

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

GENERAL EXPENSES, 1898—Continued.

CLASSIFICATION OF EXPENDITURES FOR GENERAL EXPENSES, 1898.

On what account.	Amount.	On what account.	Amount.
Instruments	$4 123·96	Transportation of instruments and supplies	$338·33
Instrument shop	994·35	Office horse and wagon	345·85
Carpenter shop	923·98	Fuel	1 176·99
Drawing division	894·84	Gas	1 442·70
Books	302·20	Electricity	185·32
Maps	42.24	Telegrams	211·03
Subscriptions	23·34	Ice	193·70
Copper plates	295·20	Washing	173·40
Chart paper	6 473·10	Miscellaneous expenses and contingencies of all kinds	2 151·28
Zinc	189·46	Office furniture	30·50
Engraving, printing, photographing, and electrotyping supplies	3 640·75	Repairs	313·26
Photolithographing and printing from stone and copper for immediate use	4 901·49	Extra labor	1 589·21
Stationery	1 228·99	Traveling expenses (office)	46·75
		Total	32 232·22

STEAMER FOR COAST SURVEY.

To whom paid.	On what account.	Amount.
Edward G. Allen	Traveling expenses	$14·12
Boston Traveler Co	Advertising	28·00
M. G. Copeland & Co	Flags	5·50
Charles C. Fulton & Co	Advertising	24·23
Frank W. Grogan	Services, traveling expenses and incidental.	1 502·46
Marine Record Publishing Co	Advertising	29·00
Lewis Nixon	Construction, equipment and outfit	102 887·25
Oregonian Publishing Co	Advertising	14·25
Post Intelligencer Co	do	13·56
Press Co., Limited	do	44·00
San Francisco Chronicle	do	56·00
Tribune Association	do	75·20
United States Express Co	Transportation	1·25
Expenditures		104 694·82
Appropriation		155 000·00
Expenditures		104 694.82
Unexpended balance		50 305·18

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SALARIES—STANDARD WEIGHTS AND MEASURES, 1898.

To whom paid.	Time employed.	Amount.
ADJUSTER.		
Louis A. Fischer	One year	$1 500·00
VERIFIER.		
Frank A. Wolff, jr	One year	1 500·00
MECHANICIAN.		
Otto Storm	One year	1 250·00
ASSISTANT MESSENGER.		
Dorsey Suber	Eleven months and fifteen days	688·75
WATCHMEN.		
James D. McDowell	Seven months and twenty-four days	470·00
William J. French	Ten days	19·78
Henry D. Hall	One month and twelve days	83·04
Expenditures		5 511·57
Appropriation		5 690·00
Expenditures		5 511·57
Unexpended balance		178·43

CONTINGENT EXPENSES—STANDARD WEIGHTS AND MEASURES, 1898.

MATERIALS AND APPARATUS AND INCIDENTAL EXPENSES.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$4·30
Herman Baumgarten	Contingencies	1·10
J. Baumgarten & Sons	do	·05
James G. Biddle	Apparatus	32·70
William J. Bohn	Contingencies	10·50
W. D. Colt	do	3·00
M. Du Perow	do	·20
H. G. Easterday	do	10·00
Eimer & Amend	do	10·96
George W. Knox Express Co	Transportation	18·62
Z. D. Gilman	Contingencies	6·50
Keiser & Schmidt	Apparatus	134·58
Mackall Bros. & Flemer	Contingencies	13·22
W. H. Mehler	do	·50
John C. Parker	do	3·50
Royce & Marean	do	1·20
Franz Schmidt & Haensch	Apparatus	46·56
Frank A. Wolff, jr	Contingencies and traveling expenses	26·70
Otto Wolffe	Apparatus	104·16
Verwaltung der Isabellen Hutte	do	60·95
Zeigler Electric Co	Contingencies	10·60
Expenditures		499·90
Appropriation		975·00
Expenditures		499·90
Unexpended balance		475·10

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

SURVEY OF YUKON RIVER, 1898 AND 1899.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$24·00
Wm. W. Corey	Outfit for steamer Gedney	9·90
Gas Engine and Power Co., and Chas. L. Seabury & Co., Consolidated.	Construction of steam launches and boats.	15 850·00
Hay & Wright	Outfit for steamer Gedney	1 427·48
J. M. Helm, U. S. N	Hydrography, steamer Gedney	718·00
Marine-Hospital Service	Surgical supplies	11·31
H. K. Mulford Co	Drugs	2·29
Oakland Iron Works	Steamer Gedney	3 062·35
J. F. Pratt	Combined operations	27 126·89
Revenue-Cutter Service	Flags and bunting	65·56
Homer P. Ritter	Reconnoissance, Copper River	8 297·95
Aug. F. Rodgers	Construction and outfit of steamer Taku	11 844·35
F. A. Schmidt	Photographing supplies	22·00
Western Union Telegraph Co	Telegraphic exchange	33·16
Expenditures		68 495·24
Appropriation		100 000·00
Expenditures		68 495·24
Unexpended balance		31 504·76

PUBLISHING CHARTS, 1898 AND 1899.

To whom paid.	On what account.	Amount.
E. F. Campbell	Services	$243·55
Eugene C. Frisby	do	204·84
Andrew B. Graham	Photolithographing	507·50
Raoul F. Le Mat	Services	232·21
A. D. Levi	do	167·74
Sully B. Maize	do	233·62
Mount Holly Paper Co	Lithograph paper	108·30
A. B. Simons, jr	Services	245·16
Expenditures		1 942·92
Appropriation		5 000·00
Expenditures		1 942·92
Unexpended balance		3 057·08

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

NATIONAL DEFENSE.

To whom paid.	On what accouut.	Amount.
Isaac Bassett	Services	$11·67
Jno. E. Buckingham	do	144·22
E. F. Campbell	do	171·15
F. R. Dulin	do	171·15
W. A. Harlow	do	117·30
A. P. Madeira	do	96·15
Kirk McMurtrie	do	144·22
A. O'Neill	do	165·38
Chas. S. Zurhorst	do	132·68
Richard A. Hoyt	do	9·62
A. D. Levi	do	63·21
F. P. Reinhart	do	108·33
A. B. Simons, jr	do	140·00
James R. Long	do	88·34
Raoul F. Le Mat	do	130·97
Expenditures		1 694·39
Allotted from appropriation by deficiency act, Mar. 9, 1898		1 700·00
Expenditures		1 694·39
Unexpended balance		5·61

PARTY EXPENSES, 1896.

TIDES, ETC.

To whom paid.	On what account.	Amount.
B. W. Weeks	Fernandina Tidal	$0·16
Balance on hand, report for 1896		150·95
Expended since, as above		·16
Present unexpended balance		150·79

OBJECTS NOT NAMED.

To whom paid.	On what account.	Amount.
W. R. Hoag	Storage	$15·00
Balance on hand, report for 1897		1 144·39
Expended since, as above		15·00
Present unexpended balance		1 129·39

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1896—Continued.

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Tides, etc	$0.16
Objects not named	15.00
	15.16
Balance on hand, report for 1897	2 787.25
Expended since, as above	15.16
Present unexpended balance	2 772.09

GENERAL EXPENSES, 1896.

COPPERPLATES, CHART PAPER, PRINTING INK, ETC.

To whom paid.	On what account.	Amount.
Ourdan & Kolb Engraving Machine, Engraving and Mercantile Co.	Extra engraving	$998.97
Balance on hand, report for 1897		4 877.01
Expended since, as above		998.97
Present unexpended balance		3 878.04

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Balance on hand, report for 1897	$8 234.57
Expended since, as above	998.97
Present unexpended balance	7 235.60

PARTY EXPENSES, 1897.

PACIFIC COAST.

	Amount.
Railroad accounts referred for settlement	$0.86
Balance on hand, report for 1897	1 056.18
Expended since, as above	.86
Present unexpended balance	1 055.32

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

PARTY EXPENSES, 1897—Continued.

TIDES, ETC.

To whom paid.	On what account.	Amount.
B. W. Weeks	Fernandina Tidal	$0·96
Balance on hand, report for 1897		212·25
Expended since, as above		·96
Present unexpended balance		211·29

TRANSCONTINENTAL WORK.

	Amount.
Railroad accounts referred for settlement	$7·56
Balance on hand, report for 1897	101·47
Expended since, as above	7·56
Present unexpended balance	93·91

OBJECTS NOT NAMED.

To whom paid.	On what account.	Amount.
W. R. Hoag	Storage	$15·00
Frederick Springman	Transportation	3·50
Expenditures		18·50
Balance on hand, report for 1897		1 636·20
Expended since, as above		18·50
Present unexpended balance		1 617·70

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Pacific coast	$0·86
Tides, etc	·96
Transcontinental work	7·56
Objects not named	18·50
Expenditures	27·88
Balance on hand, report for 1897	6 452·53
Expended since, as above	27·88
Present unexpended balance	6 424·65

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1898—Continued.

REPAIRS OF VESSELS, 1897.

To whom paid.	On what account.	Amount.
Campbell & Zell Co	Steamer Blake	$341·00
Oakland Iron Works	Steamer McArthur	2 147·00
Expenditures		2 488·00
Balance on hand, report for 1897		2 691·63
Expended since, as above		2 488·00
Present unexpended balance		203·63

GENERAL EXPENSES, 1897.

INSTRUMENTS, INSTRUMENT SHOP, CARPENTER SHOP, ETC.

To whom paid.	On what account.	Amount.
Annals of mathematics	Books	$2·00
Gustave E. Stechert	do	10·00
Expenditures		12·00
Balance on hand, report for 1897		2 696·42
Expended since, as above		12·00
Present unexpended balance		2 684·42

COPPER PLATES, CHART PAPER, ETC.

To whom paid.	On what account.	Amount.
R. F. Bartle & Co	Extra engraving	$1 767·95
Balance on hand, report for 1897		5 350·59
Expended since, as above		1 767·95
Present unexpended balance		3 582·64

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Instruments, instrument shop, carpenter shop, etc	$12·00
Copper plates, chart paper, etc	1 767·95
Expenditures	1 779·95
Balance on hand, report for 1897	9 095·92
Expended since, as above	1 779·95
Present unexpended balance	7 315·97

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ending June 30, 1898—Continued.

PARTY EXPENSES, 1897 AND 1898.

LEVELING.

To whom paid.	On what account.	Amount.
Isaac Winston	Precise leveling	$1 534·26
Railroad account referred for settlement since last report		42·01
Expenditures		1 576·27
Balance on hand, report for 1897		1 605·09
Expended since, as above		1 576·27
Unexpended balance		28·82

GENERAL RECAPITULATION.

[Showing appropriations, expenditures, and balances for the fiscal year ending June 30, 1898, and also for other accounts included in this Report.]

Name of appropriation.	Appropriated.	Expended.	Balances.
Salaries:			
Pay of field officers, sundry civil act, June 4, 1897	$90 400·00	$90 105·19	$294·81
Pay of office force, sundry civil act, June 4, 1897	136 470·00	134 640·06	1 829·94
Party expenses, sundry civil act, June 4, 1897	122 800·00	113 053·37	9 746·63
Repairs of vessels, sundry civil act, June 4, 1897	35 000·00	33 732·77	1 267·23
Publishing observations, sundry civil act, June 4, 1897	1 000·00	944·22	55·78
General expenses:			
Sundry civil act, June 4, 1897 $33 400·00			
Received from Marine Hospital Service 14·79	33 414·79	32 232·22	1 182·57
Steamer for Coast Survey:			
Sundry civil act, June 4, 1897 $75 000·00			
Sundry civil act, July 1, 1898 80 000·00	155 000·00	104 694·82	50 305·18
Salaries, office of standard weights and measures, legislative act, February 19, 1897	5 690·00	5 511·57	178·43
Contingent expenses, office of standard weights and measures, legislative act, February 19, 1897	975·00	499·90	475·10
Survey of Yukon River, 1898 and 1899, deficiency act, January 28, 1898	100 000·00	68 495·24	31 504·76
Publishing charts, 1898 and 1899, deficiency act, July 7, 1898	5 000·00	1 942·92	3 057·08
National defense, allotted from appropriation by deficiency act, March 9, 1898	1 700·00	1 694·39	5·61
Party expenses, 1896, balance from last report	2 787·25	15·16	2 772·09
General expenses, 1896, balance from last report	8 234·57	998·97	7 235·60
Party expenses, 1897, balance from last report	6 452·53	27·88	6 424·65
Repairs of vessels, 1897, balance from last report	2 691·63	2 488·00	203·63
General expenses, 1897, balance from last report	9 095·92	1 779·95	7 315·97
Party expenses, 1897 and 1898, balance from last report	1 605·09	1 576·27	28·82
Total	718 316·78	594 432·90	123 883·88

Statement of the expenditures of the United States Coast and Geodetic Survey for the fiscal year ending June 30, 1898—Continued.

GENERAL RECAPITULATION—Continued.

Amounts appropriated and available as follows:		
Appropriations for Coast and Geodetic Survey as shown above—sundry civil act, June 4, 1897; deficiency act, January 28, 1898; sundry civil act July 1, 1898; deficiency act, July 7, 1898		$679 070·00
Appropriation for Office of Standard Weights and Measures—legislative act, February 19, 1897		6 665·00
Allotted from appropriation for national defense—deficiency act, March 9, 1898		1 700·00
Received from Marine-Hospital Service		14·79
Balances from last report		30 866·99
		718 316·78
Amounts expended as follows:		
For Coast and Geodetic Survey	$586 727·04	
For Office of Standard Weights and Measures	6 011·47	
For national defense	1 694·39	594 432·90
Total unexpended balance		123 883·88

UNITED STATES COAST AND GEODETIC SURVEY,
OFFICE OF THE DISBURSING AGENT,
Washington, D. C., January 1, 1899.

I certify that the foregoing statement is a correct exhibit of all expenditures made by me for the United States Coast and Geodetic Survey and for the Office of Standard Weights and Measures for the fiscal year ended June 30, 1898, and for preceding years, and also on account of the appropriation for national defense, including all accounts paid to the close of business on December 31, 1898.

SCOTT NESBIT, *Disbursing Agent.*

Approved:
HENRY S. PRITCHETT,
Superintendent, United States Coast and Geodetic Survey.

5. OFFICE OF THE HYDROGRAPHIC INSPECTOR.

PERSONNEL.

Lieut. Commander E. D. TAUSSIG, U. S. N., Assistant, Coast and Geodetic Survey, hydrographic inspector, July 1, 1897, to May 10, 1898.

Mr. GERSHOM BRADFORD, Assistant, Coast and Geodetic Survey, acting hydrographic inspector, May 12, 1898, to June 30, 1898.

Lieut. J. C. GILMORE, U. S. N., Assistant, Coast and Geodetic Survey, chief of hydrographic section and Coast Pilot Party, July 1, 1897, to April 20, 1898.

Mr. J. H. ROETH, clerk, July 1, 1897, to June 30, 1898.

Hydrographic section.—Mr. W. C. Willenbücher (chief), draftsman, July 1, 1897, to June 30, 1898. Mr. F. C. Donn, draftsman, July 1, 1897, to June 30, 1898. Mr. J. T. Watkins, draftsman, July 1, 1897, to June 30, 1898. Mr. E. H. Wyvil, chart corrector, July 1, 1897, to June 30, 1898.

Coast Pilot Party.—Mr. John Ross, nautical expert, July 1, 1897, to May 25, 1898 [resigned to accept commission in U. S. (Volunteer) Navy]. Mr. Talbot Pulizzi, clerk, July 1, 1897, to June 30, 1898.

a. General Statement.

Lieut. Commander E. D. Taussig, U. S. N., Assistant, Coast and Geodetic Survey, was in charge of this division at the beginning of the fiscal year, and continued the direction of its operations as hydrographic inspector until the outbreak of the war with Spain necessitated his withdrawal by the Navy Department. His detachment took effect on May 10, and he was succeeded by Assistant Greshom Bradford on May 12, who remained in charge as acting hydrographic inspector for the remainder of the fiscal year.

The sudden detachment of the naval officers on duty in the hydrographic division and of those who in command of the Coast and Geodetic Survey vessels were conducting the hydrographic operations of the service, became imperative on the declaration of war with Spain. This might have necessitated a serious interruption in the work, but as many of the civilian officers of the Survey were experienced in hydrography, and qualified to supply the place of the naval assistants, operations were continued without any material delay in their progress.

Vessels.—Two of the vessels of the Survey, the *Blake* and the *Bache*, were temporarily assigned to duty under the Navy Department, and were engaged for some time in special surveys at Key West and Dry Tortugas, and were occasionally employed as transports and dispatch boats. They were returned to the Treasury Department in June, the naval officers on board were detached, and the vessels were prepared for duty under the command of civilian assistants. The steamers *Patterson* and *Gedney*, at San Francisco, were transferred to the Navy Department by order of the President, but no occasion for their use by that Department arising, they were, after a short time, returned to the Treasury Department.

During the year two light-draft steamers, the *Taku* and the *Yukon*, were constructed for work in the vicinity of the mouth of the Yukon River. The *Taku*, designed by Lieut. J. M. Helm, U. S. N., Assistant, Coast and Geodetic Survey, was built in San Francisco, and the terms of the contract provided that she should be delivered by the builders at St. Michaels, Alaska. She reached that port in good condition on July 15, 1898. The *Yukon*, designed by Mr. J. F. Pratt, Assistant, Coast and Geodetic Survey, was constructed in New York and was taken to St. Michaels in sections; the vessel having the dismantled steamer on board arrived at St. Michaels on July 4, 1898. Neither vessel was in use by the Survey in this fiscal year.

A contract has been made for the construction of a steamer, subsequently named *Pathfinder*, for service in Alaskan waters, to be built at Elizabeth, N. J.; this vessel will be in size, quarters, coal endurance, and capacity, well fitted for the work. The contract calls for completion by March 1, 1899.

The steamer *Hassler* and schooner *Earnest*, which formed part of the equipment of the Survey for many years, have been disposed of during the present fiscal year. The *Hassler* having been condemned as unseaworthy and unfit for further use in the hydrographic work, was sold in October, 1897; her purchasers fitted her up for the Alaskan trade, and she was lost on her first trip to Lynn Canal. The *Earnest* was also considered to be no longer available for Coast Survey work, and was transferred absolutely to the commandant of the Puget Sound Naval Station, in March, 1898.

Accidents which happened to the steam launch *Cosmos* and the steamer *Patterson* necessitated extensive repairs to both. The *Cosmos*, while at anchor in Bear Bay,

Alaska, caught on a submerged rock during a rapidly falling tide, and, a gale prevailing at the time, she careened and sank. She was raised by the *Patterson* and towed to Sitka, but extensive repairs had to be made to hull and machinery to make good the damages suffered. While lying at anchor in San Francisco Bay, on March 10, during the prevalence of a strong gale, the *Patterson* collided with the bark *Martha Davis*, considerable damage being done to the hulls and spars of both vessels.

Of the vessels of the Survey not employed in surveying operations at the end of the fiscal year: The steamer *Blake* is being fitted out at Baltimore, Md., for the work of the coming season on the Hudson River; the *Bache* is also at Baltimore, where extensive repairs will be made to prepare her for the season's operations in the vicinity of Portsmouth, N. H.; the schooner *Quick* is laid up at Madisonville, La.; the schooners *Transit* and *Spy* have been placed at the disposal of Maj. F. A. Mahan, Corps of Engineers, U. S. A., for use in the vicinity of Pensacola Bay; the steamer *McArthur* is laid up at Oakland Cal.; the *Gedney* is being outfitted at Oakland for work on the coast of Washington; the *Patterson* is laid up at Oakland; the *Yukon* and *Taku*, en route to St. Michaels, Alaska. The steamers *Patterson*, *Gedney*, and *McArthur* were not employed in field work during the last quarter of the fiscal year owing to the exigencies of the war with Spain, as they were held in readiness for naval duty.

Other reference to vessels of the Survey will be found under the head of "Coast work."

TABLE I.—*List of vessels in the service of the United States Coast and Geodetic Survey during the fiscal year 1897–98.*

Name.	Where built.	When built.	Register tonnage.	Length.	Beam.	Draft.	Remarks.
STEAM VESSELS—SCREW.				*Ft. in.*	*Ft. in.*	*Ft. in.*	
Pathfinder	Elizabethport, N. J.	1899	469·00	193 0	33 0	11 0	Building.
A. D. Bache	Wilmington, Del	1871	182·00	147 8	23 5	10 0	Atlantic coast.
G. S. Blake	Baltimore, Md	1874	234·54	148 8	26 6	11 7	Do.
Cosmos	Mare Island, Cal.	1887	25·00	52 5	12 0	4 0	Pacific coast.
Endeavor	Norfolk, Va	1862	86·37	111 0	18 5	7 5	Atlantic coast.
Gedney	New York, N. Y	1875	174·37	140 0	23 8	6 9	Pacific coast.
Hassler	Camden, N. J	1872	319·49	154 0	24 7	12 0	Sold.
McArthur	Mare Island, Cal.	1876	130·47	115 0	20 0	12 0	Pacific coast.
C. P. Patterson	Brooklyn, N. Y	1883	453·00	175 0	27 3	14 2	Do.
Yukon	New York, N. Y	1898	30·00	75 0	15 9	4 0	Alaska coast.
Taku	San Francisco, Cal.	1898	25·00	75 0	16 0	4 0	Do.
SAILING VESSELS—SCHOONERS.							
Drift	Baltimore, Md	1876	87·00	76 0	19 6	10 8	Transferred to Light-House Board.
Earnest	do	1875	80·00	89 0	23 0	7 3	Transferred to Navy.
Eagre[1]	Williamsburg, N. Y.	1875	191·71	121 0	30 4	9 0	Atlantic coast.
Matchless	Key West, Fla	1859	94·50	99 6	24 3	7 0	Do.
Quick	Baltimore, Md	1873	38·00	60 0	21 6	4 6	Gulf coast.
Spy	Tottenville, N. Y	1888	17·00	51 6	14 0	1 6	Do.
Transit	do	1888	21·00	60 0	15 0	1 8	Do.

[1] Formerly *Mohawk*.

TABLE II.—*List of naval officers attached to the United States Coast and Geodetic Survey in the fiscal year 1897–98.*

Name and rank.	Attached.	Detached.
COMMANDER.		
A. Dunlap	May 21, 1896	Apr. 23, 1898
LIEUTENANT-COMMANDERS.		
E. D. Taussig	Dec. 23, 1896	May 10, 1898
W. J. Barnette	Apr. 2, 1897	Apr. 12, 1898
C. T. Forse	June 18, 1897	Apr. 13, 1898
E. K. Moore	Jan. 12, 1895	Mar. 31, 1898
A. P. Osborn	July 22, 1895	Apr. 4, 1898
LIEUTENANTS.		
Robert G. Peck	June 1, 1893	July 1, 1897
M. E. Hall	Dec. 13, 1897	Apr. 4, 1898
G. C. Hanus	Feb. 7, 1895	Nov. 1, 1897
J. M. Helm	Mar. 22, 1897	Apr. 2, 1898
J. C. Gillmore	June 19, 1897	Apr. 20, 1898
J. J. Knapp	July 1, 1896	Dec. 18, 1897
E. H. Tillman	July 19, 1894	Sept. 1, 1897
E. Simpson	Feb. 1, 1898	Apr. 2, 1898
Guy W. Brown[1]	Oct. 20, 1897	July 6, 1898
LIEUTENANTS (JUNIOR GRADE).		
W. B. Hoggatt	Jan. 17, 1894	Oct. 20, 1897
A. M. Beecher	Aug 19, 1897	Feb. 1, 1898
Roger Wells, jr	Feb. 1, 1898	Mar. 31, 1898
G. R. Slocum	Dec. 3, 1896	May 5, 1898
W. W. Gilmer	Dec. 19, 1895	Nov. 8, 1897
R. E. Coontz	Oct. 20, 1897	May 5, 1898
W. A. Edgar	Oct. 11, 1894	Oct. 18, 1897
W. H. Faust	Apr. 7, 1896	Aug. 26, 1897
H. H. Hines	Oct. 27, 1894	Nov. 2, 1897
N. A. McCully	Nov. 26, 1894	Apr. 4, 1898
C. M. Stone	Feb. 20, 1895	Feb. 20, 1898
Thos. Washington	Mar. 30, 1897	Nov. 8, 1897
A. H. Davis	Jan. 7, 1895	June 12, 1898
F. M. Russell	.....do.....	Apr. 15, 1898
ENSIGNS.		
M. L. Miller	May 19, 1896	Feb. 19, 1898
Jas. H. Reid	Dec. 9, 1895	June 30, 1898
H. A. Wiley	Jan. 1, 1896	Apr. 2, 1898
A. Bainbridge Hoff	Aug. 3, 1897	Nov. 13, 1897
G. B. Bradshaw	Feb. 17, 1898	May 21, 1898
C. A. Brand	Aug. 17, 1896	Apr. 22, 1898
P. Williams	Nov. 18, 1896	.....do.....
F. H. Schofield	Mar. 1, 1898	Apr. 3, 1898
F. B. Sullivan	Dec. 18, 1896	July 23, 1897
	Dec. 5, 1897	Apr. 16, 1898
J. H. Sypher	Feb. 1, 1898	Mar. 26, 1898
Chas. F. Preston	Feb. 16, 1898	Apr. 6, 1898
P. Symington	May 7, 1897	Apr. 4, 1898
PAYMASTERS.		
Wm. J. Thomson	Mar. 1, 1898	Apr. 30, 1898
C. M. Ray[2]	May 2, 1898	.....
PASSED ASSISTANT PAYMASTER.		
Jno. Q. Lovell	Mar. 2, 1895	Mar. 1, 1898

[1] Orders detaching him issued by Navy Department June 29, 1898.

[2] Still in service.

TABLE III.—*Repairs to United States Coast and Geodetic Survey vessels during fiscal year 1897–98.*

Name.	Character of repairs.
Blake	Extensive repairs to the machinery, etc., including new boilers and repairs to hull; minor repairs on steam launches.
Bache	New furnace doors; new blower engine; repairs to engine-room skylight, and to the boiler, etc., of steam launch.[1]
Endeavor	New bilge pump; new call-bell system; considerable repairs to machinery and boilers.
Eagre	New water-closets, ice chest, whaleboat, and hose; minor repairs to vessel, equipment of vessel, and to boats.
Matchless	New cables and cabin lamps, and repairs of galley range.
Quick	Small repairs to naphtha launch.
Spy	General repairs, not expensive, but considerable in cost considering value of vessel.
Transit	Same as above.
Patterson	Extensive repairs to hull and spars in consequence of the collision with the Martha Davis, noted above.
Cosmos	Considerable repairs to the hull and machinery, the materials for which were sent from San Francisco to the collector of customs at Sitka.
Gedney	New water-closets and distiller; considerable repairs on engine and hull.
McArthur	New steam windlass and three water tanks; large repairs on hull, and considerable repairs on machinery and boilers.

[1] Total cost of all not great.

b. HYDROGRAPHIC SECTION.

Lieut. J. C. Gillmore, U. S. N., Assistant, Coast and Geodetic Survey, was in charge of this section from July 1, 1897, until his detachment, on April 20, 1898, for naval duty in connection with the war.

The following statement gives the statistics of the routine operations of the section during the year:

Drawings and proofs of charts verified	368
Volumes platted	384
Angles platted	124 203
Soundings platted	599 086
Miles platted	12 378
Sheets platted	44
Miscellaneous drawings and tracings	158
Charts corrected	4 662

The publication of the monthly notice to mariners has been kept up, and the twelve editions have been promptly issued.

Special publication No. 1, "Magnetic ranges in the Bay of San Francisco," was compiled and arranged by Lieutenant Gillmore, and he also compiled a list of "Magnetic ranges for determining the deviation of the compass" at various points along the Atlantic coast between Matinicus light, Maine, and Key West, Fla., which was printed for the use of the vessels of the United States Navy.

Besides the above, a large amount of miscellaneous work has been done, including revision and verification of proofs, tidal data reduced and platted, comparisons of hydrography and topography, and other work.

c. Coast Pilot Party.

This section was also in the charge of Lieutenant Gillmore until his detachment by the Navy Department.

Mr. John Ross, nautical expert, was on duty in this section until May 25, when he resigned to accept a commission in the Navy. Application has been made to the Civil Service Commission for a nautical expert, whose services are very much needed since Mr. Ross's resignation. There is also a pressing need for a nautical expert to complete the preparation of a new edition of the Pacific Coast Pilot, for which much material is now on hand.

During the fiscal year this section was engaged in a revision of the Atlantic Coast Pilot, Part V, New York to Chesapeake Bay entrance, for a second edition, which was published in April; in a revision of the Alaska Coast Pilot, which is still in progress; and in preparing supplements and correcting issues, as required, of the various Coast Pilot parts. Specifications for the new steamer for service in Alaskan waters were prepared by Mr. Ross.

The following table gives the issue of Coast Pilot volumes, under the editorial direction of this section, for the fiscal year 1897-98:

Parts.		Volumes.	Remarks.
	ATLANTIC COAST PILOT.		
I-II	From the St. Croix River to Cape Ann	186	
III	From Cape Ann to Point Judith	213	
IV	From Point Judith to New York	251	
V	From New York to Chesapeake Bay entrance	130	First edition.
		185	Second edition.
VI	Chesapeake Bay and tributaries	187	
VII	From Chesapeake Bay entrance to Key West	190	
VIII	Gulf of Mexico from Key West to the Rio Grande	190	
	PACIFIC COAST PILOT.		
I	California, Oregon, Washington	60	
	Alaska	302	

6. OFFICE OF STANDARD WEIGHTS AND MEASURES.

Dr. Henry S. Pritchett.
Mr. Andrew Braid, Assistant, Coast and Geodetic Survey, in charge of office.
Mr. Louis A. Fischer, adjuster.
Dr. Frank A. Wolff, verifier.
Mr. Otto Storm, mechanician.
Mr. Jas. A. McDowell, watchman.
Dorsey Suber, assistant messenger.

The direction of the operations of this office have remained in charge of Assistant Andrew Braid throughout the fiscal year. Much of Mr. Braid's time was devoted to

the consideration of questions referred to the commission appointed by the Secretary of the Treasury for the purpose of drawing up regulations for the guidance of the sugar chemists at the various custom-houses. As a member of this commission he was required to make investigations of the methods in vogue in Philadelphia, New York, and Boston for polarizing samples of sugar, and also to act in an advisory capacity to the Treasury Department in its controversies with outside sugar chemists.

The constantly increasing importance, from a revenue-producing standpoint, of the importation of sugar has led to many questions by importers as to the methods and apparatus used by the customs service in determining the percentage of pure sugar in the selected samples. As a result, all polariscopic apparatus used in the Government service is being reexamined by this office, and in consequence of the urgency of this work many other important branches are made to suffer.

During the past year the 70-inch standard bars of the Ordnance Department were completed and turned over to the proper official. The production and investigation of these bars required all the time of one expert for three months, on account of the great accuracy demanded, viz: That no space from 1 inch up to 70 inches should have an error greater than 4–10 000 of an inch.

These bars are now kept at the various arsenals, and upon their accuracy will depend to a great extent the interchangeability of the parts of the great rifles which are to defend the coast, for by having standards exactly alike it is possible for the parts of a gun to be made at the several arsenals and then assembled at one, thus reducing the time and cost of manufacture.

Considerable preparatory work has been done in the electrical department. Such instruments and material as could be purchased were secured to the extent of the appropriation, and, in addition, some special apparatus was constructed by the instrument division. Material progress was made in designing the necessary apparatus for comparing electrical standards, and in the actual comparison of standards of resistance acquired from various sources. Some standard Clark cells were made and intercompared. Taken as a whole, the progress has been satisfactory, and it is hoped that in the next fiscal year it can be reported that the Government has at least provisional standards of the more important electrical units.

An unusual number of inquiries have been received concerning the weights and measures in use in foreign countries. These have come from the departments of the Government and from manufacturers and importers, and while in every case the information desired was furnished, it was often at the expense of time which the office could ill afford to spare. As ever increasing foreign commerce is likely to augment the number of such inquiries, it would seem proper to consider means for keeping up to date such information. This is done by the standard department in London, and most of the information furnished by this office is taken from the printed report of that department.

Experience has shown that reexaminations of the Governmental polariscopic apparatus will be necessary at regular intervals if it is to be kept in order. Under present circumstances there appears to be little prospect of ever getting the other work of this office up to date unless additional assistance is given. Much of the time of this office has been devoted to the comparison of weights and measures for manufacturers, surveyors, engineers, and others, who require great precision in their work. Requests for

such services become more frequent as the functions of this office and its facilities for accurate work become more widely known. The following tabulated statements show the service supplied by the office during the year:

TABLE I.—*For the Executive Departments of the Government.*

Date.	Department or Bureau.	Service.
1897.		
July	Treasury Department	Information furnished.
August	Internal Revenue Bureau, Treasury Department.	Thermometer compared.
	Treasury Department	Information furnished.
	United States Fish Commission	Salinometers compared.
September	United States Geological Survey	2 precise leveling rods compared.
	Customs Revenue, Treasury Department.	Apparatus for polariscopic analysis of sugars standardized.
October	United States Geological Survey	2 leveling rods compared.
	Customs Revenue, Treasury Department.	Polariscopic apparatus tested.
	United States Coast and Geodetic Survey.	One 50-meter tape tested.
	United States Coast and Geodetic Survey.	Two 5-meter base bars compared.
	United States Fish Commission	35 salinometers verified.
November	Customs Revenue, Treasury Department.	Polariscopic apparatus standardized.
	United States Coast and Geodetic Survey.	6 thermometers compared.
	Department of Agriculture	Set of gram weights compared.
	Department of Agriculture	Capacity of 6-litre flask determined.
	District of Columbia Engineer, Washington, D. C.	10-foot leveling rod examined.
	Treasury Department	Information furnished.
December	Customs Revenue, Treasury Department.	Polariscopic apparatus tested.
	Customs Revenue, Treasury Department.	300 flasks graduated.
	United States Coast and Geodetic Survey.	Three 50-meter tapes compared.
	United States Coast and Geodetic Survey.	3 metric tapes compared.
1898.		
January	Department of Agriculture	Information furnished.
	United States Coast and Geodetic Survey.	100-foot and 30-meter tape verified.
	United States Coast and Geodetic Survey.	10 thermometers compared.
	United States Coast and Geodetic Survey.	2 thermometers compared.
	United States Coast and Geodetic Survey.	One 300-foot tape compared.
	Treasury Department	Information furnished.
February	Customs Revenue, Treasury Department.	Sugar-testing apparatus tested.
	United States Artillery School, Fort Monroe, Va.	Set of weights verified.
	United States Coast and Geodetic Survey.	2 thermometers verified.
March	United States Coast and Geodetic Survey.	50-meter tape compared.
	Customs Revenue, Treasury Department.	12 thermometers compared.
	Chief of Ordnance, War Department	Three 70-inch bars graduated and compared.
	Customs Revenue, Treasury Department.	Twenty-five 200-millimeter tubes repaired and verified.
	Customs Revenue, Treasury Department.	Sixty 200-millimeter tubes verified.
	Internal Revenue Bureau, Treasury Department.	2 thermometers compared.
	Customs Revenue, Treasury Department.	One set of gram weights, 100-gram to 1-gram, verified.
	Sealer of weights and measures, Washington, D. C.	One set of dry-capacity measures adjusted and verified.
	Department of Agriculture	Capacity of 31 sugar flasks and 4 polariscope tubes determined.
	Commandant United States Navy-Yard, Washington, D. C.	Two 100-foot tapes verified.
	International Boundary Commission	One 20-meter tape verified.

TABLE I.—*For the Executive Departments of the Government*—Continued.

Date.	Department or Bureau.	Service.
1898.		
April.....	United States Coast and Geodetic Survey.	4 metric tapes verified.
May	Customs Revenue, Treasury Department.	6 dozen flasks graduated.
	Customs Revenue, Treasury Department.	Sixty 200-millimeter tubes verified.
June	United States Mint, San Francisco, Cal..	A set of Troy ounces verified.
	Customs Revenue, Treasury Department.	Forty 200-millimeter tubes verified.
	Customs Revenue, Treasury Department.	Seventy-six 100-cubic-centimeter flasks graduated.
	United States Coast and Geodetic Survey.	30-meter and 100-foot tape compared.
	United States Coast and Geodetic Survey.	Two 10-foot rods compared.
	United States appraiser of merchandise, New Orleans, La.	Information furnished.

TABLE II.—*For scientific institutions, the arts, industries, etc.*

Date.	Name.	Service.
1897.		
July.....	Sam. C. Scott, New Waterford, Ohio....	Information furnished.
	C. P. Hicks, Maple Grove, Mo.....	Information furnished.
	Eimer & Amend, New York, N. Y.....	Set of assay weights verified.
	Henry S. Haines, Burlington, N. J.....	Tape compared.
	W. McCulloh Brown, Bayard, Grant County, W. Va.	Tape compared.
	Henry Heil Chemical Co., St. Louis, Mo.	Set of assay weights verified.
August.....	W. E. Allen, secretary American Railway Association, New York.	Information furnished.
	H. R. Munkelt, Salem, Ind.....	Information furnished.
	Prof. W. A. Rodgers, Waterville, Me....	Results furnished.
	Robert W. Curtis, Hartford, Conn.....	Information furnished.
	W. G. Miller, Steelton, Pa.....	Information furnished.
	Thomas F. Livingston, Brooklyn, N. Y..	Information furnished.
	Sam. C. Scott, New Waterford, Ohio....	Quart measure adjusted and verified.
October	Burnham, Williams & Co., Philadelphia, Pa.	Information furnished.
	Lufkin Rule Co., Saginaw, Mich.....	Information furnished.
	J. A. Leonard, Youngstown, Ohio.....	Information furnished.
	E. A. Bright, Washington, D. C.	Information furnished.
	Geo. R. Sherman, Providence, R. I.....	Information furnished.
	E. G. Soltman, New York, N. Y.....	Two 100-foot tapes tested.
	Keuffel & Esser, New York, N. Y.....	One 100-foot tape tested.
	G. A. Gilfillan, Pittsburg, Pa	One 100-foot tape tested.
	Samuel J. Taylor, Indianapolis, Ind.....	Information furnished.
	John C. Callahan, Holyoke, Mass.....	Information furnished.
	Samuel C. Hooker, Philadelphia, Pa	Information furnished.
	Voland & Van Zelm, New Rochelle, N. Y.	Set of weights compared.
	G. E. Barton, Millville, N. Y.....	Information furnished.
	Keuffel & Esser, New York, N. Y.....	Three 100-foot tapes compared.
November	Samuel C. Hooker, Philadelphia, Pa	Polariscopic apparatus standardized.
	Wm. Palmer, Carlisle, Pa	Information furnished.
	Wm. R. Storey, Rochester, N. Y.....	100-foot tape compared.
	S. H. King, Grand Rapids, Ohio.....	Information furnished.
	Nelden-Judson Drug Co., Salt Lake City, Utah.	Information furnished.
	Whitall, Tatum & Co., Philadelphia, Pa..	Information furnished.
	Jesse Pawling, Philadelphia, Pa	Information furnished.

TABLE II.—*For scientific institutions, the arts, industries, etc.*—Continued.

Date.	Name	Service.
1897.		
December	Samuel C. Hooker, Philadelphia, Pa.....	Quartz plate compared.
	W. C. Elsemore, Eureka, Cal.....	Information furnished.
	John A. Grier, Chicago, Ill.....	Information furnished.
	Marston & Gorham, Bangor, Me.....	100-foot tape compared.
	Nelden-Judson Drug Co., Salt Lake City, Utah.	Four weights compared.
	Hearn & Harrison, Montreal, Canada....	Information furnished.
	F. G. Dorsey, Baltimore, Md.....	Information furnished.
	Whitall, Tatum & Co., Millville, N. J....	Information furnished.
	Samuel C. Hooker, Philadelphia, Pa	Information furnished.
1898.		
January	J. G. Adkins, Scott, Dekalb County, Ala .	Information furnished.
	E. A. Trescott, Blacksburg, S. C.....	Information furnished.
	Buchtel College, Akron, Ohio.....	Information furnished.
	Compagna Metalurgica Mexicana, New York.	Information furnished.
	Geo. F. Lucas, Castile, N. Y	Two 400-foot tapes verified.
	Nichols Chemical Co., New York, N. Y ..	Four weights verified.
	E. G. Soltman, New York, N. Y.....	One 50-foot tape compared.
	Whitall, Tatum & Co., Millville, N. J	Information furnished.
	Chief Engineer, Chilean Boundary Commission.	Information furnished.
February	Essiner & Armand, New York, N. Y	Set of weights verified.
	Lufkin Rule Co., Saginaw, Mich	30-meter tape graduated.
	A. J. Galvin, Cleveland, Ohio	100-foot tape verified.
	H. I. Higgins, Denver, Colo	Information furnished.
	Henry M. Teller, United States Senator..	Information furnished.
	North Carolina Agricultural College Experiment Station, Raleigh, N. C.	Polariscope examined.
March.....	Prof. W. A. Withers, North Carolina Agricultural College Experiment Station, Raleigh, N. C.	Polariscopic apparatus examined.
	Massachusetts State sealer of weights and measures.	Set of avoirdupois weights adjusted and verified.
	Dr. James A. Close, St. Louis, Mo	Information furnished.
	John F. Campion, Leadville, Colo.....	Information furnished.
	American Sugar Refining Co., Boston, Mass.	Two 100-cubic-centimeter flasks verified.
	R. S. Paul, Akron, Ohio	Two steel tapes compared.
	Ulmer & Hoff, Cleveland, Ohio.....	Two 100-foot tapes compared.
	The A. S. Aloe Co., St. Louis, Mo	Information furnished.
	Prof. H. C. Sherman, New York, N. Y	Information furnished.
	Charles B. Beckwith, New York, N. Y....	Information furnished.
	J. P. K. Miller, Scottdale, Pa.....	300-foot tape compared.
	Daniel C. V. Palmer, Boston, Mass	Two 100-foot tapes compared.
	George R. Sherman, Providence, R. I	Information furnished.
	H. H. Stock, Scranton, Pa	Information furnished.
	Herman Kohlbusch, New York, N. Y	Five weights verified.
	O. P. Sells, New York, N. Y	Information furnished.
	E. G. Soltman, New York, N. Y.....	100-foot tape compared.
	Clifford Richardson, Long Island City, N. Y.	Information furnished.
	Whitall, Tatum & Co., New York, N. Y ..	Information furnished.
	Christian Becker, New York, N. Y.....	Two weights verified.
	Willis L. Barnes, Charlestown, Ind.....	One 50-foot tape verified.
	E. Machlett & Sons, New York, N. Y....	Information furnished.
April.....	A. Buffat, Knoxville, Tenn	Information furnished.
	Milton Updegraph, Columbia, Mo	200-foot tape verified.
	Ervin E. Ewell, Washington, D. C	Information furnished.
	Leonard Smith, Madison, Wis.....	Information furnished.
	Keuffel & Esser, New York City	400-foot tape verified.

TABLE II.—*For scientific institutions, the arts, industries, etc.*—Continued.

Date.	Name.	Service.
1898.		
May	E. E. Ewell, Department of Agriculture	Information furnished.
	Herman Kohlbusch, New York, N. Y	Three gram weights verified.
	Machlett & Sons, New York, N. Y	Information furnished.
	W. W. Allen, Pueblo, Colo	Information furnished.
	Charles Zimmer, Marietta, Ohio	Information furnished.
	A. Buffat, Knoxville, Tenn	Information furnished.
	Prof. S. P. Langley, Washington, D. C	Information furnished.
	W. W. Allen, Pueblo, Colo	Two sets of weights verified.
	Willis L. Barnes, Charlestown, Ind	Information furnished.
June	F. Bloch, Philadelphia, Pa	100-foot tape compared.
	A. N. Clark, Athens, Mich	100-foot tape compared.
	C. J. Tagliabue, New York, N. Y	Three thermometers verified.
	A. Buffat, Knoxville, Tenn	Information furnished.
	A. Brauns, Green Bay, Wis	100-foot tape compared.
	Courier Blank Book Co., Ottumwa, Iowa	Two 100-foot tapes compared.
	J. A. Sherer, New York, N. Y	Quartz plate compared.
	F. G. Wiechmann, Brooklyn, N. Y	Quartz plate compared.

The permanent force of the Survey remains essentially the same as in the previous year, although it has been found advantageous to make a readjustment in the salaries of some of the office employees and to increase the number employed in the entering grade of the field force, so as to provide a class of qualified young men from which the more responsible positions in the force of field officers may be recruited when necessary. Vacancies occurring in the permanent force have been filled by requisition on the Civil Service Commission, and the employees thus obtained have proved generally efficient and satisfactory.

The work of the Coast and Geodetic Survey is closely correlated with that of the Bureaus in different Departments, and the exchange of service and information is intimate between it and them. Copies of surveys and data are furnished to the United States Engineers, who in return supply information relating to river and harbor improvements for use in the correction of charts. Exchange of maps, charts, and other data is maintained with the Hydrographic Office of the Navy Department, the Light-House Board, the Fish Commission, the Geological Survey, and the topographic office of the Post-Office Department. The Geological Survey makes use of the triangulation and topographic work of the Coast and Geodetic Survey in the preparation of its topographical and geological maps, and is furnished with the copies of surveys, geographic positions, and other information, upon application.

The Survey is indebted to the Hydrographic Office and the Light-House Board for data for chart corrections, to the Fish Commission for copies of surveys and explorations made by its vessels in Alaska and elsewhere, and to the Smithsonian Institution for facilitating the exchange of scientific publications with foreign countries.

The acquisition by the United States of Porto Rico and the Hawaiian Islands will render necessary the extension of surveying operations to include the new territory, and information is being gathered with a view to the commencement of such surveys as soon as means are available.

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OBITUARY.

Assistant Charles T. Iardella, the oldest officer of the Survey both in years and length of service, died at his residence in Washington on October 27, 1897, in the seventy-eighth year of his age.

Assistant Iardella was born in Washington, D. C., October 3, 1820, and entered the Survey as aid in May, 1846, serving in this capacity until July, 1855, when he was promoted to the grade of subassistant. He was made an assistant in January, 1869, and from 1855 to the date of his death was in charge of topographic parties in various parts of the United States, also assisting during the war in various hydrographic and other surveys in connection with the military operations.

During this long career he faithfully devoted his energies to his profession, and the results are shown in the archives of the Survey by the numerous topographical sheets bearing his name.

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SECTION IV.

THE APPENDICES.

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SECTION IV.

THE APPENDICES.

APPENDIX No. 1.—Resulting heights from spirit leveling between Salina and Ellis, Kans.

APPENDIX No. 2.—Resulting heights from spirit leveling between Ellis, Kans., and Hugo, Colo.

APPENDIX No. 3.—Resulting heights from spirit leveling between Hugo and Colorado Springs, Colo.

APPENDIX No. 4.—Inquiry into the value of the Peruvian arc of 1736–1743.

APPENDIX No. 5.—Physical observations made in connection with the Pribilof Islands Expedition of 1897.

APPENDIX No. 6.—Proceedings of the International Geodetic Association conference and geodetic operations in the United States.

APPENDIX No. 7.—Determination of time, longitude, latitude, and azimuth.

APPENDIX No. 8.—A plane-table manual.

APPENDIX No. 9—Problems in physiography. Salinity and temperature of the Pacific Ocean.

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APPENDIX No. 1. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN SALINA AND ELLIS, KANSAS.

Report by C. A. SCHOTT, Assistant.

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APPENDIX No. 1. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN SALINA AND ELLIS, KANS., FROM OBSERVATIONS MADE BY I. WINSTON, ASSISTANT, BETWEEN JULY 2 AND SEPTEMBER 9, 1896.

Report by C. A. SCHOTT, *Assistant.*

This appendix is in continuation of Appendix No. 4 of the annual report for 1897, which carried the line of levels as far as Salina, Kans. The present paper contains the resulting heights along the Union Pacific Railroad from Salina westward to Ellis, Kans., a distance of 208 kilometers, or 129 statute miles. The starting, or zero, level is the same as that given in last year's appendix, viz, the St. Louis city bench mark as transferred to Coast and Geodetic Survey bench mark K_3 at the St. Louis bridge. If absolute heights are desired, the St. Louis mark may provisionally be taken as 125·8 meters, or 412·7 feet, above the mean Gulf level.

Instrument.—Geodetic spirit level No. 5, the same as used last year,* the rods P and Q also are the same.†

Instrumental constants adopted in the present reduction.—Value of 1 division (2 mm.) of level 2″·08; collar inequality + when object end the larger, from observations of January 14, 1896, − 1″·362, and from observations of October 28, 1896, − 0″·720; mean value used, − 1″·04. One turn of micrometer = 100 divisions = 312″·0. Angular value of telemeter threads 18′ 54″·5. Index correction to metric rods of paraffined wood:

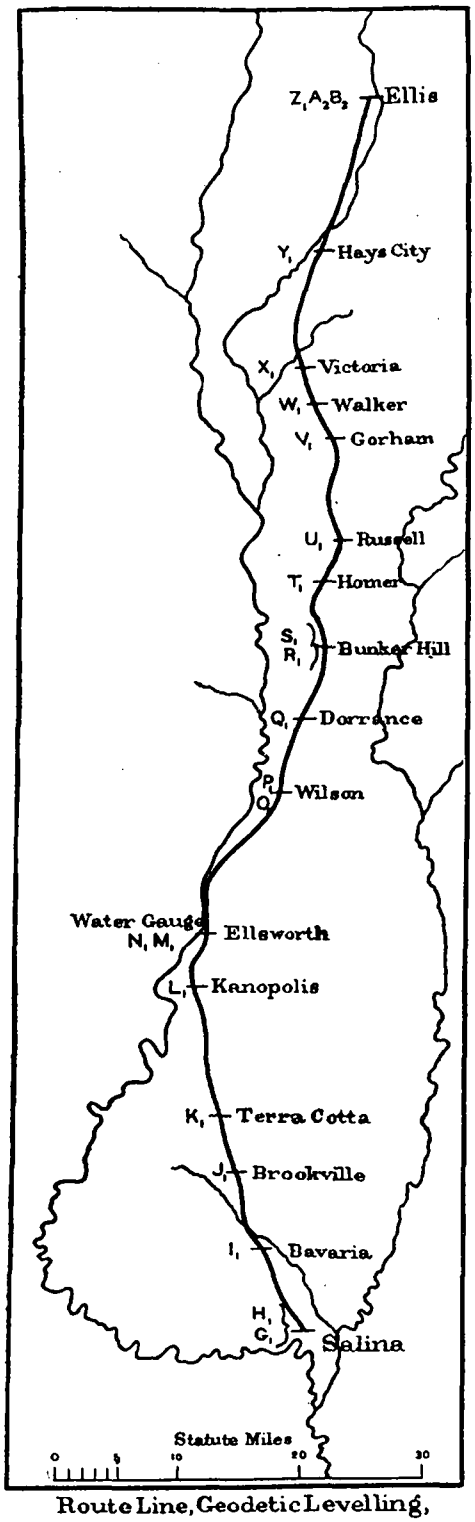
	m.		m.
November 21, 1895	0·1	on rod =	0·0999
October 23, 1896	0·1	" " =	0·1000

same for both rods. Length of rods:

	m.	m.		
Rod P, June 27, 1896,	from 0·1	to 3·0	on rod =	2·901 611 at 24·0 C.
October 27 and 28, 1896,	" "	" "	" " =	2·901 488 " 21·3 C.
Rod Q, June 27, 1896,	" "	" "	" " =	2·901 384 " 24·0 C.
October 27 and 28, 1896,	" "	" "	" " =	2·901 294 " 21·3 C.

* For particulars respecting this instrument see Appendix No. 3, Report for 1896, and Appendix No. 5 of same report.

† For description of leveling rods see Appendix No. 8, Report for 1895.



Route Line, Geodetic Leveling, Salina to Ellis, Kansas.

The values $2^{m}\cdot901\ 521$ and $2^{m}\cdot901\ 327$ at 24° C. were used for P and Q, respectively. The subdivisions tested were—

	m.	m.	m.
Rod P,	0·1 to	1·0	0·900 49
at 21°·3 C.,		2·0	1·900 99
		3·0	2·901 49

	m.	m.	m.
Rod Q,	0·1 to	1·0	0·900 46
at 21°·3 C.,		2·0	1·900 89
		3·0	2·901 29

Method of observing.—The method followed this year was the same as that of last year, viz: The old method of running two parallel and simultaneous lines, one with rod P, the other with rod Q; average distance between instrument and rod about 80 meters.

Computations.—They are made by the observer, assisted by J. B. Baylor and F. A. Young; final revision by I. Winston.

Results.—The resulting differential heights above the St. Louis city level are tabulated and corrected for the effect of difference of temperature of rods from their standard temperature. There are 23 permanent bench marks; their distance apart on the average is very nearly 0·9 kilometer. Squaring the numbers in column headed P—Q and adding we find the mean error m_1 of a single leveling of 1 kilometer

$$m_1 = \sqrt{\frac{[dd]}{2[s]}} = \pm 1\cdot86 \text{ mm.}$$

also the probable r_{11} of a double measure of 1 kilometre

$$r_{11} = 0\cdot675\sqrt{\frac{[dd]}{4[s]}} = \pm 0\cdot89 \text{ mm.}$$

and the probable error of the whole line between bench marks H_1 and A_2,

$$r = 0\cdot675\sqrt{\frac{[dd]}{4}} = \pm 11\cdot8 \text{ mm.}$$

This value supposes the two measures or the results of the P and Q lines to be independent of each other. This not being the case with simultaneous lines for which the instrumental and atmospheric conditions are the same for the two lines, we have to increase the

above value of r by a certain fractional part. Hence, adding one-fourth of r as an approximate (empirical) correction we get $r = \pm 14{\cdot}7$ mm.

The probable error of the height assigned to Salina, distant from St. Louis, Mo., 757·3 kilometers, or 470·3 statute miles, was 33·9 mm.* Hence, we have for the probable error of the height assigned to Ellis mark A. the value $\sqrt{(28{\cdot}9)^2+(17{\cdot}75)^2+(14{\cdot}7)^2} = \pm 36{\cdot}97$ mm., as developed between St. Louis and Ellis, Kans., a total distance of 945·5 kilometers, or 587·5 statute miles, westward along the line of levels.

Results of geodetic spirit leveling from Salina to Ellis, Kans.

Bench mark. From	Bench mark. To	Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks. Line, rod P.	Line, rod Q.	Mean.	Discrepancy. Partial P—Q.	Total accumulated.	Height above K_3 at St. Louis.†
		km.	*km.*‡	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*‡
	G_1		757·322						247·6943
G_1	H_1 (1895)	·180		+ 0·0454	+ 0·0459	+ 0·0457	−0·5	0·0	
G_1	H_1 (1896)	·172		+ 0·0457	+ 0·0472	+ 0·0464	−1·5		
G_1	H_1 (Mean)	·176	757·498	+ 0·0456	+ 0·0466	+ 0·0461	−1·0	− 1·0	247·7404
H_1	1	·827	758·325	− 0·2545	− 0·2517	− 0·2531	−2·8	− 3·8	247·4873
1	2	1·012	759·337	− 0·0977	− 0·0994	− 0·0986	+1·7	− 2·1	247·3887
2	3	1·074	760·411	+ 0·9162	+ 0·9179	+ 0·9170	−1·7	− 3·8	248·3057
3	4	·973	761·384	− 0·0205	− 0·0211	− 0·0208	+0·6	− 3·2	248·2849
4	5	·874	762·258	+ 0·3183	+ 0·3240	+ 0·3212	−5·7	− 8·9	248·6061
5	6	1·038	763·296	+ 1·6579	+ 1·6567	+ 1·6573	+1·2	− 7·7	250·2634
6	7	1·200	764·496	+ 1·5818	+ 1·5856	+ 1·5837	−3·8	−11·5	251·8471
7	8	1·141	765·637	+ 1·1288	+ 1·1304	+ 1·1296	−1·6	−13·1	252·9767
8	9	1·109	766·746	+ 2·5068	+ 2·5105	+ 2·5086	−3·7	−16·8	255·4853
9	10	1·199	767·945	+ 0·0616	+ 0·0649	+ 0·0633	−3·3	−20·1	255·5486
10	11	1·161	769·106	+ 1·8642	+ 1·8681	+ 1·8662	−3·9	−24·0	257·4148
11	12	1·049	770·155	+ 1·8719	+ 1·8772	+ 1·8746	−5·3	−29·3	259·2894
12	13	·838	770·993	+ 0·5496	+ 0·5471	+ 0·5484	+2·5	−26·8	259·8378
13	14	·585	771·578	+ 1·3005	+ 1·2969	+ 1·2987	+3·6	−23·2	261·1365
14	I_1	·063	771·641	+ 1·4482	+ 1·4484	+ 1·4483	−0·2	−23·4	262·5848
14	R. R. Sta. (1)	·067	771·645	+ 0·4601		+ 0·4601			261·5966
14	15	·983	772·561	+ 1·9764	+ 1·9768	+ 1·9766	−0·4	−23·6	263·1131
15	16	1·181	773·742	+ 3·0206	+ 3·0217	+ 3·0212	−1·1	−24·7	266·1343
16	17	1·159	774·901	+ 2·9632	+ 2·9679	+ 2·9656	−4·7	−29·4	269·0999
17	18	1·313	776·214	+ 5·9851	+ 5·9916	+ 5·9884	−6·5	−35·9	275·0883
18	19	·982	777·196	+ 3·4176	+ 3·4190	+ 3·4183	−1·4	−37·3	278·5066
19	20	1·062	778·258	+ 2·4297	+ 2·4304	+ 2·4300	−0·7	−38·0	280·9366
20	21	1·165	779·423	− 0·0751	− 0·0722	− 0·0736	−2·9	−40·9	280·8630
21	22	1·169	780·592	+ 3·3668	+ 3·3648	+ 3·3658	+2·0	−38·9	284·2288
22	23	·965	781·557	+ 2·0436	+ 2·0443	+ 2·0440	−0·7	−39·6	286·2728
23	24	·598	782·155	− 0·0918	− 0·0932	− 0·0925	+1·4	−38·2	286·1803
24	R. R. Sta. (2)	·085	782·240	+ 0·3699		+ 0·3699			286·5502
24	25	·457	782·612	+ 0·2854	+ 0·2849	+ 0·2852	+0·5	−37·7	286·4655
25	J_1	·044	782·656	+ 1·8890	+ 1·8894	+ 1·8892	−0·4	−38·1	288·3547
25	26	1·064	783·676	+ 3·2112	+ 3·2117	+ 3·2114	−0·5	−38·2	289·6769
26	27	1·142	784·818	+ 3·4197	+ 3·4241	+ 3·4219	−4·4	−42·6	293·0988
27	28	1·032	785·850	+ 3·4800	+ 3·4828	+ 3·4814	−2·8	−45·4	296·5802

*Equal to $\sqrt{(28{\cdot}9)^2 + (17{\cdot}75)^2}$.

† For resulting elevations corrected for effect of temperature or length of rods see last page of table.

‡ See Appendix No. 4, Report of 1897.

Results of geodetic spirit leveling from Salina to Ellis, Kans.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.*
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*†	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*†
28	29	1·175	787·025	+ 5·0051	+ 5·0038	+ 5·0044	+1·3	—44·1	301·5846
29	30	1·178	788·203	+ 5·5771	+ 5·5795	+ 5·5783	—2·4	—46·5	307·1629
30	31	·960	789·163	+ 4·5753	+ 4·5722	+ 4·5738	+3·1	—43·4	311·7367
31	32	·987	790·150	+ 2·1604	+ 2·1629	+ 2·1616	—2·5	—45·9	313·8983
32	K_1	·041	790·191	+ 1·0558	+ 1·0559	+ 1·0558	—0·1	—46·0	314·9541
32	33	1·088	791·238	+ 7·1190	+ 7·1189	+ 7·1190	+0·1	—45·8	321·0173
33	34	1·124	792·362	+ 5·3753	+ 5·3742	+ 5·3748	+1·1	—44·7	326·3921
34	35	1·005	793·367	+ 5·1126	+ 5·1144	+ 5·1135	—1·8	—46·5	331·5056
35	36	·932	774·299	+ 5·9152	+ 5·9168	+ 5·9160	—1·6	—48·1	337·4216
36	37	1·046	795·345	+ 8·2666	+ 8·2659	+ 8·2662	+0·7	—47·4	345·6878
37	38	1·193	796·538	+14·1975	+14·2016	+14·1996	—4·1	—51·5	359·8874
38	39	1·016	797·554	— 2·1055	— 2·1062	— 2·1058	+0·7	—50·8	357·7816
39	40	1·151	798·705	—10·1000	—10·1019	—10·1010	+1·9	—48·9	347·6806
40	R. R. Sta. (3)	·114	798·819	— 1·0060		— 1·0060			346·6746
40	41	1·061	799·766	+ 1·1593	+ 1·1610	+ 1·1602	—1·7	—50·6	348·8408
41	42	·872	800·638	+12·3416	+12·3406	+12·3411	+1·0	—49·6	361·1819
42	43	1·231	801·869	+ 8·4631	+ 8·4643	+ 8·4637	—1·2	—50·8	369·6456
43	44	·998	802·867	—12·8831	—12·8809	—12·8820	—2·2	—53·0	356·7636
44	45	·932	803·799	— 5·6993	— 5·7009	— 5·7001	+1·6	—51·4	351·0635
45	46	1·074	804·873	+ 1·5161	+ 1·5148	+ 1·5154	+1·3	—50·1	352·5789
46	47	1·045	805·918	+14·9668	+14·9727	+14·9698	—5·9	—56·0	367·5487
47	48	·961	806·879	+11·8531	+11·8537	+11·8534	—0·6	—56·6	379·4021
48	49	·831	807·710	—10·6648	—10·6608	—10·6628	—4·0	—60·6	368·7393
49	50	·925	808·635	‡ —7·2392	‡ —7·2346	— 7·2369	—4·6	—65·2	361·5024
50	51	1·033	809·668	— 5·2631	— 5·2620	— 5·2626	—1·1	—66·3	356·2398
51	52	1·193	810·861	— 0·1658	— 0·1671	— 0·1664	+1·3	—65·0	356·0734
52	L_1	·869	811·730	+ 1·2061	+ 1·2086	+ 1·2073	—2·5	—67·5	357·2807
52	53	1·028	811·889	— 7·9671	— 7·9635	— 7·9653	—3·6	—68·6	348·1081
53	54	1·151	813·040	— 4·7697	— 4·7684	— 4·7690	—1·3	—69·9	343·3391
54	55	1·196	814·236	— 0·6665	— 0·6672	— 0·6668	+0·7	—69·2	342·6723
55	56	·879	815·115	— 2·2894	— 2·2843	— 2·2868	—5·1	—74·3	340·3855
56	57	·971	816·086	— 1·1955	— 1·1918	— 1·1936	—3·7	—78·0	339·1919
57	58	1·359	817·445	+ 0·5785	+ 0·5783	+ 0·5784	+0·2	—77·8	339·7703
58	R. R. Sta. (4)	·761	818·206	+ 2·9279		+ 2·9279			342·6982
58	59	·793	818·238	+ 2·6391	+ 2·6333	+ 2·6362	+5·8	—72·0	342·4065
59	W. G B. M	·665	818·903	— 3·8138	— 3·8121	— 3·8130	—1·7	—73·7	338·5935
59	R. R. Cros. (5)	1·171	819·409	+ 1·2046		+ 1·2046			343·6121
59	M_1	·247	818·485	+ 1·1375	+ 1·1387	+ 1·1381	—1·2	—73·2	343·5446
M_1	N_1	·247	818·732	— 0·1002	— 0·1008	— 0·1005	+0·6	—72·6	343·4441
59	60	1·145	819·383	+ 1·3735	+ 1·3761	+ 1·3748	—2·6	—74·6	343·7813
60	61	1·014	820·397	— 0·1878	— 0·1831	— 0·1854	—4·7	—79·3	343·5959
61	62	1·088	821·485	+ 1·2187	+ 1·2147	+ 1·2167	+4·0	—75·3	344·8126
62	63	1·038	822·523	+ 1·3961	+ 1·3999	+ 1·3980	—3·8	—79·1	346·2106
63	64	1·041	823·564	+ 1·7896	+ 1·7878	+ 1·7887	+1·8	—77·3	347·9993

* For resulting elevations corrected for effect of temperature or length of rods see last page of table.
† See Appendix No. 4, Report of 1897.
‡ Mean of two measures.

Results of geodetic spirit leveling from Salina to Ellis, Kans.—Continued.

Bench mark. From	Bench mark. To	Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks. Line, rod P.	Line, rod Q.	Mean.	Discrepancy. Partial P—Q.	Total accumulated.	Height above K_3 at St. Louis.*
		km.	*km.*†	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*†
64	65	1·190	824·754	— 0·0286	— 0·0282	— 0·0284	—0·4	— 77·7	347·9709
65	66	1·185	825·939	+ 1·8224	+ 1·8228	+ 1·8226	—0·4	— 78·1	349·7935
66	67	1·140	827·079	— 2·5645	— 2·5629	— 2·5637	—1·6	— 79·7	347·2298
67	68	1·033	828·112	+ 0·3308	+ 0·3316	+ 0·3312	—0·8	— 80·5	347·5610
68	69	1·124	829·236	+ 1·2995	+ 1·3016	+ 1·3006	—2·1	— 82·6	348·8616
69	70	1·175	830·411	+ 2·7575	+ 2·7599	+ 2·7587	—2·4	— 85·0	351·6203
70	R. R. Sta. (6)	·144	830·555	+ 0·3345		+ 0·3345			351·9548
70	71	1·108	831·519	‡+0·0283	‡+0·0337	+ 0·0310	—5·4	— 90·4	351·6513
71	72	1·071	832·590	+ 2·5763	+ 2·5790	+ 2·5776	—2·7	— 93·1	354·2289
72	73	1·133	833·723	+ 9·7780	+ 9·7808	+ 9·7794	—2·8	— 95·9	364·0083
73	74	1·182	834·905	+ 4·3970	+ 4·3980	+ 4·3975	—1·0	— 96·9	368·4058
74	75	1·155	836·060	+ 3·9998	+ 4·0005	+ 4·0002	—0·7	— 97·6	372·4060
75	76	1·043	837·103	+10·2223	+10·2278	+10·2250	—5·5	—103·1	382·6310
76	77	1·034	838·137	+ 6·5353	+ 6·5338	+ 6·5346	+1·5	—101·6	389·1656
77	78	1·162	839·299	— 2·5101	— 2·5055	— 2·5078	—4·6	—106·2	386·6578
78	79	1·174	840·473	— 3·3029	— 3·3009	— 3·3019	—2·0	—108·2	383·3559
79	80	1·023	841·496	+ 0·4442	+ 0·4467	+ 0·4454	—2·5	—110·7	383·8013
80	81	1·111	842·607	+ 0·4739	+ 0·4797	+ 0·4768	—5·8	—116·5	384·2781
81	82	·967	843·574	+ 3·3401	+ 3·3424	+ 3·3412	—2·3	—118·8	387·6193
82	R. R. Sta. (7)	·434	844·008	+ 0·8727		+ 0·8727			388·4920
82	83	·446	844·020	+ 0·7367	+ 0·7367	+ 0·7367	0·0	—118·8	388·3560
83	O_1	·070	844·090	+ 0·7741	+ 0·7740	+ 0·7740	+0·1	—118·7	389·1300
83	P_1	·069	844·089	+ 1·1365	+ 1·1362	+ 1·1364	+0·3	—118·4	389·4924
83	84	1·007	845·027	— 1·5957	— 1·5960	— 1·5958	+0·3	—118·5	386·7602
84	85	1·199	846·226	‡+3·2675	‡+3·2704	+ 3·2690	—2·9	—121·4	390·0292
85	86	1·179	847·405	+ 2·6855	+ 2·6904	+ 2·6880	—4·9	—126·3	392·7172
86	87	·979	848·384	+ 0·5083	+ 0·5099	+ 0·5091	—1·6	—127·9	393·2263
87	88	·906	849·290	+ 0·8254	+ 0·8294	+ 0·8274	—4·0	—131·9	394·0537
88	89	1·072	850·362	‡+4·5065	‡+4·5100	+ 4·5082	—3·5	—135·4	398·5619
89	90	1·128	851·490	+ 1·0827	+ 1·0802	+ 1·0814	+2·5	—132·9	399·6433
90	91	1·184	852·674	— 4·0774	— 4·0763	— 4·0768	—1·1	—134·0	395·5665
91	92	1·117	853·791	+ 5·4127	+ 5·4180	+ 5·4154	—5·3	—139·3	400·9819
92	93	·546	854·337	+ 0·0256	+ 0·0262	+ 0·0259	—0·6	—139·9	401·0078
93	R. R. Sta. (8)	·147	854·484	+ 0·3337		+ 0·3337			401·3415
93	Q_1	·049	854·386	+ 0·8735	+ 0·8730	+ 0·8732	+0·5	—139·4	401·8810
93	94	1·388	855·725	+ 3·7043	+ 3·7074	+ 3·7058	—3·1	—143·0	404·7136
94	95	1·162	856·887	+ 9·3931	+ 9·3955	+ 9·3943	—2·4	—145·4	414·1079
95	96	1·125	858·012	+ 6·1517	+ 6·1500	+ 6·1508	+1·7	—143·7	420·2587
96	97	·981	858·993	+ 7·4707	+ 7·4727	+ 7·4717	—2·0	—145·7	427·7304
97	98	1·188	860·181	+ 5·9405	+ 5·9398	+ 5·9402	+0·7	—145·0	433·6706
98	99	1·072	861·253	+ 3·5673	+ 3·5679	+ 3·5676	—0·6	—145·6	437·2382
99	100	·920	862·173	+ 3·0362	+ 3·0377	+ 3·0370	—1·5	—147·1	440·2752
100	101	·969	863·142	— 5·7319	— 5·7300	— 5·7310	—1·9	—149·0	434·5442
101	102	1·094	864·236	+ 1·3929	+ 1·3930	+ 1·3930	—0·1	—149·1	435·9372
102	103	·923	865·159	+ 2·5955	+ 2·5908	+ 2·5932	+4·7	—144·4	438·5304
103	R. R. Sta. (9)	·553	865·712	+ 2·8653		+ 2·8653			441·3957

* For resulting elevations corrected for effect of temperature or length of rods see last page of table.
† See Appendix No 4, Report of 1897.
‡ Mean of two measures.

Results of geodetic spirit leveling from Salina to Ellis, Kans.—Continued.

Bench mark. From	Bench mark. To	Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks. Line, rod P.	Line, rod Q.	Mean.	Discrepancy. Partial P—Q.	Total accumulated	Height above K_3 at St. Louis.*
		km.	*km.*†	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*†
103	104	·595	865·754	+ 2·8349	+ 2·8350	+ 2·8350	−0·1	−144·5	441·3654
104	R_1	·090	865·844	+ 1·4898	+ 1·4900	+ 1·4899	−0·2	−144·7	442·3553
104	S_1	·537	866·291	+ 2·7053	+ 2·7071	+ 2·7062	−1·8	−146·3	444·0716
104	105	1·144	866·898	− 4·7361	− 4·7378	− 4·7370	+1·7	−142·8	436·6284
105	106	1·087	867·985	− 1·1321	− 1·1348	− 1·1334	+2·7	−140·1	435·4950
106	107	·913	868·898	− 0·2942	− 0·2917	− 0·2930	−2·5	−142·6	435·2020
107	108	1·094	869·992	+ 3·6328	+ 3·6343	+ 3·6336	−1·5	−144·1	438·8356
108	109	1·164	871·156	− 2·1989	− 2·1984	− 2·1986	−0·5	−144·6	436·6370
109	110	1·016	872·172	− 0·8258	− 0·8286	− 0·8272	+2·8	−141·8	435·8098
110	111	1·119	873·291	+ 9·5196	+ 9·5234	+ 9·5215	−3·8	−145·6	445·3313
111	T_1	·369	873·660	+ 1·7987	+ 1·8008	+ 1·7998	−2·1	−147·7	447·1311
111	112	1·180	874·471	− 0·8702	− 0·8677	− 0·8690	−2·5	−148·1	444·4623
112	113	1·197	875·668	− 1·1735	− 1·1723	− 1·1729	−1·2	−149·3	443·2894
113	114	·995	876·663	− 1·7829	− 1·7802	− 1·7816	−2·7	−152·0	441·5078
114	115	·901	877·564	− 2·5458	− 2·5421	− 2·5440	−3·7	−155·7	438·9638
115	116	·983	878·547	− 4·4429	− 4·4409	− 4·4419	−2·0	−157·7	434·5219
116	NW. beas.	·206	878·753	+ 0·2721	+ 0·2719	+ 0·2720	+0·2	−157·5	434·7939
116	117	1·209	879·756	− 3·2231	− 3·2186	− 3·2208	−4·5	−162·2	431·3011
117	118	1·200	880·956	+ 1·0531	+ 1·0522	+ 1·0526	+0·9	−161·3	432·3537
118	R. R. St a. (10)	·496	881·452	− 0·9125		− 0·9125			431·4412
118	119	·592	881·548	− 0·7249	− 0·7249	− 0·7249	0·0	−161·3	431·6288
119	U_1	·094	881·642	+ 1·1423	+ 1·1426	+ 1·1424	−0·3	−161·6	432·7712
119	120	1·204	882·752	+ 6·8353	+ 6·8346	+ 6·8349	+0·7	−160·6	438·4637
120	121	1·202	883·954	+ 3·2561	+ 3·2599	+ 3·2580	−3·8	−164·4	441·7217
121	122	1·200	885·154	+ 1·8479	+ 1·8485	+ 1·8482	−0·6	−165·0	443·5699
122	123	1·202	886·356	+ 1·4656	+ 1·4666	+ 1·4661	−1·0	−166·0	445·0360
123	124	1·196	887·552	+ 0·4327	+ 0·4326	+ 0·4326	+0·1	−165·9	445·4686
124	125	1·178	888·730	+ 1·3237	+ 1·3227	+ 1·3232	+1·0	−164·9	446·7918
125	126	1·182	889·912	+ 3·2418	+ 3·2446	+ 3·2432	−2·8	−167·7	450·0350
126	127	1·033	890·945	+ 4·7927	+ 4·7943	+ 4·7935	−1·6	−169·3	454·8285
127	128	·905	891·850	+ 4·5925	+ 4·5936	+ 4·5930	−1·1	−170·4	459·4215
128	129	1·075	892·925	− 1·5909	− 1·5888	− 1·5898	−2·1	−172·5	457·8317
129	130	1·198	894·123	− 3·3155	− 3·3113	− 3·3134	−4·2	−176·7	454·5183
130	131	1·198	895·321	+ 0·8118	+ 0·8136	+ 0·8127	−1·8	−178·5	455·3310
131	132	0·602	895·923	+ 1·4348	+ 1·4345	+ 1·4346	+0·3	−178·2	456·7656
132	V_1	·080	896·003	+ 1·5390	+ 1·5396	+ 1·5393	−0·6	−178·8	458·3049
132	R. R. Sta. (11)	·140	896·063	+ 0·2285		+ 0·2285			456·9941
132	133	1·124	897·047	− 1·7452	− 1·7432	− 1·7442	−2·0	−180·2	455·0214
133	134	1·198	898·245	− 3·2251	− 3·2245	− 3·2248	−0·6	−180·8	451·7966
134	135	1·184	899·429	+ 7·1346	+ 7·1361	+ 7·1353	−1·5	−182·3	458·9319
135	136	1·166	900·595	+ 6·2494	+ 6·2542	+ 6·2518	−4·8	−187·1	465·1837
136	137	·389	900·984	+ 1·0196	+ 1·0175	+ 1·0186	+2·1	−185·0	466·2023
137	W_1	·083	901·067	+ 1·3280	+ 1·3275	+ 1·3278	+0·5	−184·5	467·5301
137	R. R. Sta. (12)	·112	901·096	+ 0·5074		+ 0·5074			466·7097

* For resulting elevations corrected for effect of temperature or length of rods see last page of table.
† See Appendix No. 4, Report of 1897.

Results of geodetic spirit leveling from Salina to Ellis, Kans.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.*
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*†	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*†
137	138	·990	901·974	+ 1.0326	+ 1·0317	+ 1·0322	+0·9	—184·1	467·2345
138	139	·889	902·863	— 3·1938	— 3·1953	— 3·1946	+1·5	—182·6	464·0399
139	140	·924	903·787	— 6·6413	— 6·6389	— 6·6401	—2·4	—185·0	457·3998
140	141	1·331	905·118	+ 6·2548	+ 6·2521	+ 6·2534	+2·7	—182·3	463·6532
141	142	1·196	906·314	+ 1·0750	+ 1·0771	+ 1·0760	—2·1	—184·4	464·7293
142	R. R. Sta. (13)	·948	907·262	— 5·7358		— 5·7358			458·9934
142	143	·953	907·267	— 6·0295	— 6·0257	— 6·0276	—3·8	—188·2	458·7016
143	X_1	·021	907·288	+ 2·8816	+ 2·8817	+ 2·8816	— 0·1	— 188·3	461·5832
143	144	1·182	908·449	+ 1·6622	+ 1·6647	+ 1·6635	—2·5	—190·7	460·3651
144	145	1·142	909·591	+11·6134	+11·6140	+11·6137	—0·6	—191·3	471·9788
145	146	1·124	910·715	+ 8·8488	+ 8·8485	+ 8·8487	+0·3	—191·0	480·8275
146	147	1·048	911·763	+ 4·5843	+ 4·5845	+ 4·5844	—0·2	—191·2	485·4119
147	148	1·189	912·952	+ 3·5260	+ 3·5264	+ 3·5262	—0·4	—191·6	488·9381
148	149	1·181	914·133	+ 1·7281	+ 1·7297	+ 1·7289	—1·6	—193·2	490·6670
149	150	1·180	915·313	— 7·4053	— 7·4030	— 7·4041	—2·3	—195·5	483·2629
150	151	1·203	916·516	— 0·9341	— 0·9330	— 0·9330	—2·1	—197·6	482·3299
151	152	1·071	917·587	+ 1·8676	+ 1·8682	+ 1·8679	—0·6	—198·2	484·1978
152	153	1·070	918·657	— 0·1209	— 0·1203	— 0·1206	—0·6	—198·8	484·0772
153	154	1·335	919·992	— 3·3844	— 3·3867	— 3·3856	+2·3	—196·5	480·6916
154	155	1·198	921·190	— 1·1573	— 1·1593	— 1·1583	+2·0	—194·5	479·5333
155	156	1·178	922·368	+ 0·3010	+ 0·2987	+ 0·2998	+2·3	—192·2	479·8331
156	157	1·192	923·560	+ 1·4618	+ 1·4656	+ 1·4637	—3·8	—196·0	481·2968
157	Y_1	·348	923·908	+ 1·7974	+ 1·7983	+ 1·7978	—0·9	—196·9	483·0946
157	R. R. Sta. (14)	·555	924·115	+ 2·0330		+ 2·0330			483·3298
157	158	1·132	924·692	+ 1·6690	+ 1·6708	+ 1·6699	—1·8	—197·8	482·9667
158	159	1·024	925·716	+ 1·2016	+ 1·1989	+ 1·2002	+2·7	—195·1	484·1669
159	160	1·036	926·752	+ 1·1828	+ 1·1799	+ 1·1814	+2·9	—192·2	485·3483
160	161	1·198	927·950	+ 5·0820	+ 5·0766	+ 5·0793	+5·4	—186·8	490·4276
161	162	1·202	929·152	— 0·7645	— 0·7625	— 0·7635	—2·0	—188·8	489·6641
162	163	1·119	930·271	+ 4·2853	+ 4·2843	+ 4·2848	+1·0	—187·8	493·9489
163	164	0·876	931·147	+ 1·5054	+ 1·5059	+ 1·5056	—0·5	—188·3	495·4545
164	165	·942	932·089	+ 2·2659	+ 2·2707	+ 2·2683	—4·8	—193·1	497·7228
165	166	1·320	933·409	+ 1·4337	+ 1·4367	+ 1·4352	—3·0	—196·1	499·1580
166	167	1·137	934·546	+ 7·1004	+ 7·1009	+ 7·1006	—0·5	—196·6	506·2586
167	168	1·000	935·546	— 2·7350	— 2·7375	— 2·7362	+2·5	—194·1	503·5224
168	169	1·087	936·633	+ 3·2385	+ 3·2367	+ 3·2376	+1·8	—192·3	506·7600
169	170	1·169	937·802	— 0·9466	— 0·9509	— 0·9488	+4·3	—188·0	505·8112
170	171	1·018	938·820	+ 1·8230	+ 1·8226	+ 1·8228	+0·4	—187·6	507·6340
171	172	·945	939·765	+ 0·8751	+ 0·8762	+ 0·8756	—1·1	—188·7	508·5096
172	173	1·150	940·915	+ 2·4232	+ 2·4202	+ 2·4217	+3·0	—185·7	510·9313
173	174	1·181	942·096	+ 2·8481	+ 2·8494	+ 2·8488	—1·3	—187·0	513·7801
174	175	1·098	943·194	+ 2·6042	+ 2·6041	+ 2·6042	+0·1	—186·9	516·3843
175	176	1·213	944·407	+ 3·3074	+ 3·3081	+ 3·3078	—0·7	—187·6	519·6921
176	177	·966	945·373	— 0·7864	— 0·7876	— 0·7870	+1·2	—186·4	518·9051
177	Z_1	·126	945·499	+ 2·4108	+ 2·4111	+ 2·4110	—0·3	—186·7	521·3161
177	A_2	·152	945·525	+ 1·5176	+ 1·5188	+ 1·5182	—1·2	—187·6	520·4233
177	B_2	·214	945·587	+ 1·4020	+ 1·4040	+ 1·4030	—2·0	—188·4	520·3081

* For resulting elevations corrected for effect of temperature or length of rods see last page of table.
† See Appendix No. 4, Report of 1897.

Resulting elevations of bench marks, Salina to Ellis, Kansas.

Bench mark.	Distance from initial mark.	Height above K_3.	Correction for difference of temperature.	Corrected elevation above K_3.
	km.	*m.*	*m.*	*m.*
G_1	757·322	247·6943	+0·0027	247·6970
H_1	757·498	247·7404	+0·0027	247·7431
I_1	771·642	262·5848	+0·0031	262·5879
J_1	782·656	288·3547	+0·0038	288·3585
K_1	790·191	314·9541	+0·0058	314·9599
L_1	811·730	357·2807	+0·0072	357·2879
M_1	818·485	343·5446	+0·0068	343·5514
N_1	818·732	343·4441	+0·0068	343·4509
Water gauge	818·903	338·5935	+0·0067	338·6002
O_1	844·090	389·1300	+0·0095	389·1395
P_1	844·089	389·4924	+0·0095	389·5019
Q_1	854·386	401·8810	+0·0101	401·8911
R_1	865·844	442·8553	+0·0122	442·8675
S_1	866·291	444·0716	+0·0123	444·0839
T_1	873·660	447·1311	+0·0127	447·1438
Northwest base	878·753	434·7939	+0·0121	434·8060
U_1	881·642	432·7712	+0·0122	432·7834
V_1	896·003	458·3049	+0·0121	458·3170
W_1	901·067	467·5301	+0·0121	467·5422
X_1	907·288	461·5832	+0·0116	461·5948
Y_1	923·908	483·0946	+0·0129	483·1075
Z_1	945·499	521·3161	+0·0138	521·3299
A_1	945·525	520·4233	+0·0138	520·4371
B_1	945·587	520·3081	+0·0138	520·3219

DESCRIPTION OF BENCH MARKS ON THE LINE OF LEVELS BETWEEN SALINA AND ELLIS, KANS.; ESTABLISHED BY I. WINSTON IN 1896.

B. M. G_1.—Mark at Salina, Kans. See Description of Bench Marks, Kansas, 1895. I. Winston, chief of party. When visited in 1896 it was found in good condition and undisturbed.

B. M. H_1.—Mark at Salina, Kans. See Description of Bench Marks for 1895. When visited in July, 1896, it was found in good conditition and undisturbed.

B. M. I_1.—This bench mark is a cross cut on the limestone window sill to the window in the east end of the stone building at Bavaria, Saline County, Kans., used as a railroad station. The cross is cut in the outer face of the window sill, and is formed by two V-shaped lines. The intersection of these lines is the bench mark. The following letters were cut: U. S. + B. M.

B. M. J_1.—This bench mark is a cross cut in the limestone coping to the foundation of the stone public school building at Brookville, Salina County, Kans. It is on the east (front) side of the building about $1^m.4$ from the northeast corner. The cross is formed by two V-shaped lines cut in the outer face of the coping, and the intersection of these two lines is the bench mark. The following letters were cut: U. S. + B. M.

B. M. K_1.—This bench mark is the bottom of a square hole cut in the upper surface of the stone foundation to one of the iron supports to the railroad water tank 1 mile east

of "Terra Cotta" switch. The bench mark is on the west one of the two supports, under the north side of the tank. The following letters were cut: U. S. ■ B. M.

B. M. L_1.—This bench mark is the intersection of two lines cut in the end of a copper bolt that is leaded in the front (north) wall of the three-story brick hotel building at Kanopolis, Ellsworth County, Kans. The bolt is in the fifth course above the limestone foundation and in the second brick from the northeast corner of the building. The building stands on the southwest corner of Ohio and Kansas avenues.

B. M. M_1.—This bench mark is the intersection of two lines cut in the end of a copper bolt that is leaded in the stone foundation to the court-house at Ellsworth, Kans. The bolt is in the front (east) wall in the second course above the ground and in the third stone from the southeast corner of the building. The bench mark is about 25 cm. above the top of the basement window sill (stone).

B. M. N_1.—This bench mark is the bottom of a square hole cut in the top of the marble slab set in the top of the concrete pier marking the telegraphic longitude station at Ellsworth, Kans. The edge of the square hole is about $0^m.01$ north of the small round hole marking the station and the square hole is not cut deep. The pier is in the yard of the public school building and two sandstone posts project from its top some distance above the ground. These posts are marked "U. S. Coast and Geodetic Survey."

Water gauge B. M.—This bench mark was established by the United States Geological Survey in connection with a water gauge near it in the Smoky Hill River. It is a small knob cut on the root of a box elder tree at the south end of the iron road bridge over the river at Ellsworth, Kans. The tree is east of the bridge, between the stone abutment and the river bank. Two iron nails are driven in the top of this knob and the rods were held on top of the north rail. The bench mark is about $0^m.4$ above the ground.

B. M. O_1.—This bench mark is the bottom of a square hole cut in the top of the stone window sill in front of the two-story stone building (with iron front to first story) at Wilson, Ellsworth County, Kans., owned by J. T. Tampier, and used as a general store. The bench mark is under the window east of the door. The building fronts north, faces the track, and is opposite the railroad station. The following letters were cut: U. S. ■ B. M.

B. M. P_1.—This bench mark is the intersection of two lines forming a cross cut in the iron front to the two-story stone building at Wilson, Ellsworth County, Kans, owned by J. F. Tampier. The cross is on the iron column west of the west window in the front of the building between two square projections near the bottom of the column.

B. M. Q_1.—This bench mark is the bottom of a square hole cut in the top of the stone foundation under one of the iron supports to the railroad water tank at Dorrance, Russell County, Kans. The bench mark is on the foundation under the west one of the two supports under the north side of the tank and is north of the iron support. The following letters were cut: U. S. ■ B. M.

B. M. R_1.—This bench mark is the intersection of two lines (forming a cross) cut in the front (east) face of the two-story stone Masonic Hall building at Bunker Hill,

Russell County, Kans. The cross is cut in the third course above the stone sidewalk and in the second stone from the northeast corner of the building, which is owned by the Masonic fraternity. The following letters were cut: U. S. + B. M.

B. M. S_1.—This bench mark is the top of the marble post marking Bunker Hill triangulation station, one of the points in the transcontinental scheme of triangulation. It is situated in the south portion of the town bearing the same name, in Russell County, Kans. The top of the post is divided into four sections by two lines cut in the top, intersecting at the center. The bench mark is the surface of the stone at the southwest corner of the northeast section.

B. M. T_1.—This bench mark is the top of the sandstone post marking southeast base, one end of the Russell base line in the transcontinental scheme of triangulation. It is situated in Russell County, Kans., near Homer railroad station. The top of the post is divided into four sections by two lines cut in the top, intersecting at the center. The bench mark is the surface of the stone at the southwest corner of the northeast quarter.

B. M. U_1.—This bench mark is a cross cut in the west end of the stone railroad station building at Russell, Russell County, Kans. The cross is cut in the stone at the southwest corner of the building and in the fourth course above the platform. The instersection of the V-shaped lines forming the cross is the bench mark. The following letters were cut: U. S. + B. M

B. M. V_1.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the front (north) face of the Union Hotel at Gorham, Russell County, Kans. The hotel is a two-story stone building owned by J. W. Ginther. The bolt is in the sixth course above the ground and in the stone forming the northwest corner about the middle of its north face.

B. M. W_1.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the north wall of the two-story stone building at Walker, Ellis County, Kans. The building is owned by the Catholic Church and stands south of the railroad track and east of the station. The bolt is in the sixth course above the ground and in the stone forming the northwest corner.

B. M. X_1.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the front (north) wall of the two-story stone railroad station at Victoria, Ellis County, Kans. The bolt is in the second course above the platform and in the second stone from the northeast corner of the building.

B. M. Y_1.—This bench mark is the bottom of a square hole cut in the upper surface of the stone forming the lower step to the First National Bank building at Hays, Ellis County, Kans. The entrance to the bank is at the southeast corner of the building, and the bench mark is at the left-hand end of the lower step as you enter the building. The following letters were cut: U. S. ■ B. M.

B. M. Z_1.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the east side of the stone building at Ellis, Kans., used as a railroad station and hotel. The bolt is in the third course above the sidewalk and in the second stone to the left (south) of the door, as you enter the building.

B. M. A_2.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the front face of the stone wall to the one-story business building owned and occupied by Thomas Daly, at Ellis, Kans. The bolt is in the west side wall, in the second course above the foundation, and about the center of the stone forming the course.

B. M. B_2.—This bench mark is the intersection of two lines forming a cross cut in the end of a copper bolt that is leaded in the front face of the east side wall to the two-story stone business building owned and occupied by R. McCloud, at Ellis, Kans. The bolt is in the second course above the foundation and about the middle of the stone forming the course.

The elevation of the following railroad stations and crossing were determined by using the top of the rail in front of the stations:

1. Bavaria, Saline County, Kans.
2. Brookville, Saline County, Kans.
3. Carneiro, Ellsworth County, Kans.
4. Ellsworth, Ellsworth County, Kans.
5. Crossing of Union Pacific and St. Louis and San Francisco railroads at Ellsworth, Ellsworth County, Kans.
6. Black Wolf, Ellsworth County, Kans.
7. Wilson, Ellsworth County, Kans.
8. Dorrance, Russell County, Kans.
9. Bunker Hill, Russell County, Kans.
10. Russell, Russell County, Kans.
11. Gorham, Russell County, Kans.
12. Walker, Ellis County, Kans.
13. Victoria, Ellis County, Kans.
14. Hays, Ellis County, Kans.

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APPENDIX No. 2. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN ELLIS, KANSAS, AND HUGO, COLORADO.

Report by C. A. SCHOTT, Assistant.

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APPENDIX No. 2. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN ELLIS, KANS., AND HUGO, COLO., FROM OBSERVATIONS BY I. WINSTON, ASSISTANT, BETWEEN JUNE 11 AND NOVEMBER 17, 1897.

Report by C. A. SCHOTT, *Assistant.*

In this appendix are given the results of the line of levels as carried forward to Hugo, Colo., the numbers connecting directly with those of the preceding Appendix No. 1, 1897–1898. The line follows the Union Pacific Railroad over a distance of 372 kilometers, or 231 statute miles.

As stated in Appendix No. 1, the reference level is that passing through the St. Louis bench mark K_3 at the bridge pier; for this mark we have provisionally the height 125·8 meters, or 412·7 feet, above the mean Gulf level.

Instrument and method of observing are the same as in last year's work, described in preceding appendix, to which reference should be made for particulars.

A new determination of the level value (on October 31, 1896) gave 1 division = 1″·97 and two new determinations of the collar inequality gave the results: April 8, 1897, −0″·73, and January 24, 1898, +1″·69; mean value used in the computation, +0″·48, the + sign indicating the collar near object end to be the larger of the two. The length of the rods P and Q was redetermined on March 24, 1897, viz:

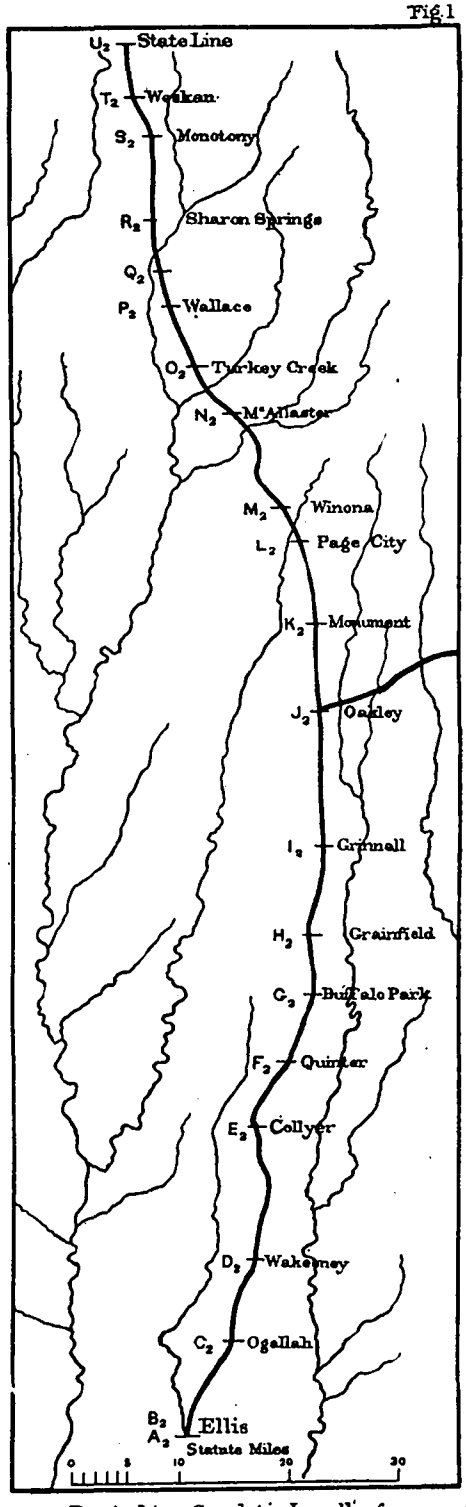
	m.	m.			m.	m.	
Rod P at 24° C.	0·1	to 1·0	0·900 51	Rod Q at 24° C.	0·1	to 1·0	0·900 51
	1·0	to 2·0	1·000 54		1·0	to 2·0	1·000 50
	2·0	to 3·0	1·000 54		2·0	to 3·0	1·000 47
hence	0·1	to 3·0	2·901 59	hence	0·1	to 3·0	2·901 48

The index correction on February 19, 1897, was found to be 0, and on January 22, 1898, −0·0003; mean −0·0001, which may be neglected. Coefficient of expansion 0·000 004 per degree Centigrade.

The field computation is by the observer, the office computation and revision by I. Winston and D. L. Hazard.

Results.—The resulting differential heights above the St. Louis city datum level (bench mark K_3 on bridge) are given in tabular form and are corrected for effect of

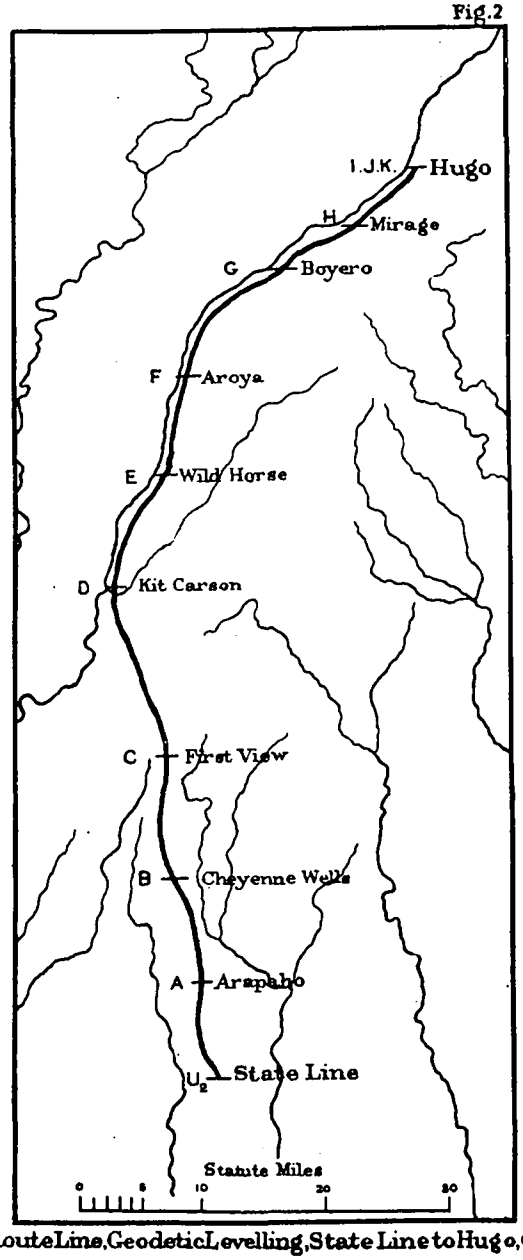
Fig.1



Route Line, Geodetic Levelling, Ellis, Kan. to Colorado State Line.

N. B.—In the remaining half year of 1898 the line of levels was extended from Hugo to Colorado Springs, thence to Denver and back to Limon near Hugo.

Fig.2



Route Line, Geodetic Levelling, State Line to Hugo, Col.

difference of temperature of the rods from their temperature of standardization. Squaring the numbers in the column headed P — Q and adding, we find the mean error m_1 of a single leveling of 1 kilometer

$$m_1 = \sqrt{\frac{[dd]}{2[s]}} = \pm 1.7 \text{ mm},$$

also the probable error of a double measure of 1 kilometer

$$r_{11} = 0.675\sqrt{\frac{[dd]}{4[s]}} = \pm 0.81 \text{ mm},$$

and the probable error of the whole line between bench marks A_2 and K

$$r = 0.675\sqrt{\frac{[dd]}{4}} = \pm 15.7 \text{ mm}.$$

This value supposes the results of the P and Q lines to be independent, a supposition which does not hold in the case of simultaneous lines when the instrumental and atmospheric conditions are the same for both lines; to get a more appropriate value we add one-fourth of r to the above value and adopt $r = \pm 19.6$ mm.

The probable error of the height assumed to the mark at Ellis, distant from St. Louis, Mo., 945.5 kilometers, or 587.5 statute miles, was 37.0 mm, as developed between these two places; hence we get for the probable error of the height assigned to bench mark K at Hugo, Colo.,

$$\sqrt{(37.0)^2 + (19.6)^2} = \pm 41.9 \text{ mm},$$

which value has yet to be combined with the probable error of the St. Louis bench mark.

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
	B_2								520.3219
B_2	A_2 1896					+ 0.1152			
B_2	A_2 1897		945.525	+ 0.1175	+ 0.1174	+ 0.1174	+0.1	+ 0.1	
						Mean + 0.1163			520.4382
A_2	R.R.Sta. (1)	0.185	945.710	— 0.3475		— 0.3475			520.0907
A_2	1	.752	946.277	+ 0.6521	+ 0.6531	+ 0.6526	—1.0	— 0.9	521.0908
1	2	1.042	947.319	+ 2.4774	+ 2.4780	+ 2.4777	—0.6	— 1.5	523.5685
2	3	.922	948.241	+ 2.7317	+ 2.7332	+ 2.7325	—1.5	— 3.0	526.3010
3	4	.597	948.838	+ 1.2752	+ 1.2735	+ 1.2744	+1.7	— 1.3	527.5754
4	5	1.431	950.269	+ 1.9697	+ 1.9670	+ 1.9684	+2.7	+ 1.4	529.5438
5	6	1.186	951.455	+ 6.4746	+ 6.4730	+ 6.4738	+1.6	+ 3.0	536.0176
6	7	1.089	952.544	+10.2527	+10.2548	+10.2538	—2.1	+ 0.9	546.2714
7	8	1.252	953.796	+ 5.2020	+ 5.1985	+ 5.2003	+3.5	+ 4.4	551.4717
8	9	.742	954.538	+ 0.2204	+ 0.2203	+ 0.2204	+0.1	+ 4.5	551.6921
9	10	1.118	955.656	+10.1804	+10.1813	+10.1808	—0.9	+ 3.6	561.8729
10	11	.856	956.512	+ 7.8570	+ 7.8566	+ 7.8568	+0.4	+ 4.0	569.7297
11	12	1.325	957.837	+ 8.8606	+ 8.8597	+ 8.8602	+0.9	+ 4.9	578.5899
12	13	.982	958.819	+ 3.9163	+ 3.9133	+ 3.9148	+3.0	+ 7.9	582.5047

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
13	14	1·114	959·933	+10·2723	+10·2698	+10·2710	+2·5	+10·4	592·7757
14	15	·868	960·801	+ 2·4088	+ 2·4122	+ 2·4105	−3·4	+ 7·0	595·1862
15	16	1·290	962·091	+ 2·7854	+ 2·7822	+ 2·7838	+3·2	+10·2	597·9700
16	C_2	·118	962·209	+ 0·6150	+ 0·6142	+ 0·6146	+0.8	+11·0	598·5846
16	R.R.Sta.(2)	·087	962·178	+ 0·3983		+ 0·3983			598·3683
16	17	·968	963·059	+ 1·4910	+ 1·4881	+ 1·4896	+2·9	+13·1	599·4596
17	18	·884	963·943	+ 3·3175	+ 3·3200	+ 3·3188	−2·5	+10·6	602·7784
18	19	·990	964·933	+ 3·4485	+ 3·4493	+ 3·4489	−0·8	+ 9·8	606·2273
19	20	·925	965·858	+ 2·2566	+ 2·2541	+ 2·2553	+2·5	+12·3	608·4826
20	21	·944	966·802	+ 1·4791	+ 1·4776	+ 1·4784	+1·5	+13·8	609·9610
21	22	·962	967·764	+ 1·6660	+ 1·6644	+ 1·6652	+1·6	+15·4	611·6262
22	23	1·170	968·934	+ 0·7476	+ 0·7472	+ 0·7474	+0·4	+15·8	612·3736
23	24	1·213	970·147	+ 2·1627	+ 2·1593	+ 2·1610	+3·4	+19·2	614·5346
24	25	1·196	971·343	+ 4·9349	+ 4·9331	+ 4·9340	+1·8	+21·0	619·4686
25	26	1·197	972·540	+ 0·9580	+ 0·9572	+ 0·9576	+0·8	+21·8	620·4262
26	27	1·198	973·738	− 0·4372	− 0·4397	− 0·4384	+2·5	+24·3	619·9878
27	28	1·198	974·936	+ 1·6561	+ 1·6569	+ 1·6565	−0·8	+23·5	621·6443
28	29	·980	975·916	+ 0·6682	+ 0·6680	+ 0·6681	+0·2	+23·7	622·3124
29	D_2	·253	976·169	+ 2·9550	+ 2·9552	+ 2·9551	−0·2	+23·5	625·2675
29	R.R.Sta.(3)	·168	976·084	+ 0·4336		+ 0·4336			622·7460
29	30	1·267	977·183	+ 1·4874	+ 1·4912	+ 1·4893	−3·8	+19·9	623·8017
30	31	1·198	978·381	− 1·8903	− 1·8869	− 1·8886	−3·4	+16·5	621·9131
31	32	1·168	979·549	+10·2486	+10·2514	+10·2500	−2·8	+13·7	632·1631
32	33	1·171	980·720	− 3·8786	− 3·8786	− 3·8786	0·0	+13·7	628·2845
33	34	·950	981·670	+ 8·5134	+ 8·5080	+ 8·5107	+5·4	+19·1	636·7952
34	35	1·049	982·719	+ 0·8127	+ 0·8112	+ 0·8120	+1·5	+20·6	637·6072
35	36	1·185	983·904	+ 3·6709	+ 3·6722	+ 3·6715	−1·3	+19·3	641·2787
36	37	1·378	985·282	− 0·0485	− 0·0525	− 0·0505	+4·0	+23·3	641·2282
37	38	1·182	986·464	+ 4·1733	+ 4·1758	+ 4·1746	−2·5	+20·8	645·4028
38	39	1·198	987·662	+ 3·2047	+ 3·2050	+ 3·2049	−0·3	+20·5	648·6077
39	R. Cros. (4)	·811	988·473	+ 2·5958		+ 2·5958			651·2035
39	40	1·158	988·820	+ 2·1979	+ 2·2005	+ 2·1992	−2·6	+17·9	650·8069
40	41	1·104	989·924	− 3·1300	− 3·1340	− 3·1320	+4·0	+21·9	647·6749
41	42	·923	990·847	+ 2·3322	+ 2·3326	+ 2·3324	−0·4	+21·5	650·0073
42	43	1·015	991·862	− 0·3589	− 0·3609	− 0·3599	+2·0	+23·5	649·6474
43	44	1·138	993·000	+ 5·6514	+ 5·6500	+ 5·6507	+1·4	+24·9	655·2981
44	45	1·080	994·080	+ 1·9643	+ 1·9616	+ 1·9630	+2·7	+27·6	657·2611
45	46	1·332	995·412	+ 0·1269	+ 0·1284	+ 0·1276	−1·5	+26·1	657·3887
46	47	1·143	996·555	+ 2·1528	+ 2·1539	+ 2·1534	−1·1	+25·0	659·5421
47	48	·916	997·471	+ 0·1750	+ 0·1757	+ 0·1754	−0·7	+24·3	659·7175
48	E_2	·076	997·547	+ 1·4295	+ 1·4300	+ 1·4298	−0·5	+23·8	661·1473
48	R.R.Sta.(5)	·135	997·606	+ 0·2741		+ 0·2741			659·9916
48	49	1·152	998·623	+ 2·9798	+ 2·9794	+ 2·9796	+0·4	+24·7	662·6971
49	50	·942	999·565	+ 2·1721	+ 2·1755	+ 2·1738	−3·4	+21·3	664·8709
50	51	·922	1 000·487	+ 4·1628	+ 4·1626	+ 4·1627	+0·2	+21·5	669·0336
51	52	1·068	1 001·555	+ 2·6523	+ 2·6528	+ 2·6526	−0·5	+21·0	671·6862
52	53	1·151	1 002·706	+ 0·3934	+ 0·3988	+ 0·3961	−5·4	+15·6	672·0823
53	54	1·106	1 003·812	+ 1·2971	+ 1·2979	+ 1·2975	−0·8	+14·8	673·3798
54	55	1·106	1 004·918	+ 0·6102	+ 0·6131	+ 0·6116	−2·9	+11·9	673·9914
55	56	1·087	1 006·005	+ 3·5468	+ 3·5461	+ 3·5464	+0·7	+12·6	677·5378

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
56	57	1·142	1 007·147	+1·5354	+1·5386	+1·5370	−3·2	+ 9·4	679·0748
57	58	1·106	1 008·253	+4·5840	+4·5902	+4·5871	−6·2	+ 3·2	683·6619
58	59	·962	1 009·215	+2·7414	+2·7440	+2·7427	−2·6	+ 0·6	686·4046
59	60	·381	1 009·596	+0·2215	+0·2235	+0·2225	−2·0	− 1·4	686·6271
60	F_2	·548	1 010·144	+4·1564	+4·1577	+4·1571	−1·3	− 2·7	690·7842
60	R.R.Sta.(6)	·148	1 009·744	−0·4927		−0·4927			686·1344
60	61	1·142	1 010·738	−1·9044	−1·9051	−1·9048	+0·7	− 0·7	684·7223
61	62	1·124	1 011·862	*+4·4642	+4·4625	+4·4634	+1·7	+ 1·0	689·1857
62	63	1·050	1 012·912	+5·0376	+5·0419	+5·0398	−4·3	− 3·3	694·2255
63	64	·832	1 013·744	*+0·9967	*+0·9923	+0·9945	+4·4	+ 1·1	695·2200
64	65	·887	1 014·631	−1·5070	−1·5046	−1·5058	−2·4	− 1·3	693·7142
65	66	·922	1 015·553	+1·6518	+1·6512	+1·6515	+0·6	− 0·7	695·3657
66	67	·960	1 016·513	+3·8148	+3·8146	+3·8147	+0·2	− 0·5	699·1804
67	68	1·142	1 017·655	+0·4672	+0·4648	+0·4660	+2·4	+ 1·9	699·6464
68	69	1·104	1 018·759	+2·3368	+2·3395	+2·3382	−2·7	− 0·8	701·9846
69	70	·962	1 019·721	+1·0105	+1·0096	+1·0100	+0·9	+ 0·1	702·9946
70	71	1·014	1 020·735	+3·5989	+3·6003	+3·5996	−1·4	− 1·3	706·5942
71	72	1·077	1 021·812	+4·4641	+4·4662	+4·4652	−2·1	− 3·4	711·0594
72	G_2	·101	1 021·913	+1·4107	+1·4119	+1·4113	−1·2	− 4·6	712·4707
72	R.R.Sta.(7)	·115	1 021·927	+0·6301		+0·6301			711·6895
72	73	1·062	1 022·874	+3·6626	+3·6646	+3·6636	−2·0	− 5·4	714·7230
73	74	1·152	1 024·026	+2·5378	+2·5395	+2·5386	−1·7	− 7·1	717·2616
74	75	1·089	1 025·115	+3·0754	+3·0729	+3·0742	+2·5	− 4·6	720·3358
75	76	1·140	1 026·255	+1·5421	+1·5430	+1·5426	−0·9	− 5·5	721·8784
76	77	1·342	1 027·597	+4·6357	+4·6340	+4·6348	+1·7	− 3·8	726·5132
77	78	1·141	1 028·738	+0·8201	+0·8219	+0·8210	−1·8	− 5·6	727·3342
78	79	1·134	1 029·872	+1·1336	+1·1336	+1·1336	0·0	− 5·6	728·4678
79	80	·562	1 030·434	+2·3600	+2·3591	+2·3596	+0·9	− 4·7	730·8274
80	H_2	·361	1 030·795	+0·9964	+0·9975	+0·9970	−1·1	− 5·8	731·8244
80	R.R.Sta.(8)	·116	1 030·550	+0·7149		+0·7149			731·5423
80	81	1·298	1 031·732	+3·1640	+3·1621	+3·1630	+1·9	− 2·8	733·9904
81	82	1·102	1 032·834	−1·5547	−1·5528	−1·5538	−1·9	− 4·7	732·4366
82	83	1·078	1 033·912	+1·4320	+1·4274	+1·4297	+4·6	− 0.1	733·8663
83	84	1·056	1 034·968	+2·8197	+2·8190	+2·8194	+0·7	+ 0·6	736·6857
84	85	1·140	1 036·108	+1·9217	+1·9232	+1·9224	−1·5	− 0·9	738·6081
85	86	1·030	1 037·138	+7·1997	+7·2027	+7·2012	−3·0	− 3·9	745·8093
86	87	·893	1 038·031	+3·6428	+3·6416	+3·6422	+1·2	− 2·7	749·4515
87	88	1·123	1 039·154	−0·5080	−0·5056	−0·5068	−2·4	− 5·1	748·9447
88	89	1·137	1 040·291	+0·2847	+0·2845	+0·2846	+0·2	− 4·9	749·2293
89	90	1·068	1 041·359	+1·2794	+1·2804	+1·2799	−1·0	− 5·9	750·5092
90	91	1·139	1 042·498	+3·4089	+3·4115	+3·4102	−2·6	− 8·5	753·9194
91	92	1·332	1 043·830	+3·6353	+3·6337	+3·6345	+1·6	− 6·9	757·5539
92	93	·842	1 044·672	+2·7074	+2·7067	+2·7070	+0·7	− 6·2	760·2609
93	I_2	.081	1 044·753	+1·0997	+1·0995	+1·0996	+0·2	− 6·0	761·3605
93	R.R.Sta.(9)	.116	1 044·788	+0·3673		+0·3673			760·6282
93	94	1·085	1 045·757	+3·0060	+3·0069	+3·0064	−0·9	− 7·1	763·2673
94	95	1·144	1 046·901	+1·9981	+2·0038	+2·0010	−5·7	−12·8	765·2683
95	96	1·142	1 048·043	+0·0725	+0·0741	+0·0733	−1·6	−14·4	765·3416

* Mean of two measures.

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
96	97	1·126	1 049·169	+ 4·3703	+ 4·3694	+ 4·3698	+0·9	−13·5	769·7114
97	98	1·332	1 050·501	+ 3·4466	+ 3·4454	+ 3·4460	+1·2	−12·3	773·1574
98	99	1·108	1 051·609	+ 5·3568	+ 5·3602	+ 5·3585	−3·4	−15·7	778·5159
99	100	·959	1 052·568	+ 0·9631	+ 0·9635	+ 0·9633	−0·4	−16·1	779·4792
100	101	1·094	1 053·662	+ 4·1763	+ 4·1747	+ 4·1755	+1·6	−14·5	783·6547
101	102	1·150	1 054·812	+ 2·6846	+ 2·6859	+ 2·6852	−1·3	−15·8	786·3399
102	103	1·104	1 055·916	+ 1·7068	+ 1·7092	+ 1·7080	−2·4	−18·2	788·0479
103	104	·902	1 056·818	+ 0·4151	+ 0·4155	+ 0·4153	−0·4	−18·6	788·4632
104	105	1·303	1 058·121	+ 2·8051	+ 2·8057	+ 2·8054	−0·6	−19·2	791·2686
105	106	1·052	1 059·173	+ 2·7180	+ 2·7188	+ 2·7184	−0·8	−20·0	793·9870
106	107	·925	1 060·098	+ 2·1026	+ 2·1050	+ 2·1038	−2·4	−22·4	796·0908
107	108	·992	1 061·090	+ 2·2233	+ 2·2207	+ 2·2220	+2·6	−19·8	798·3128
108	109	1·114	1 062·204	+ 5·2893	+ 5·2921	+ 5·2907	−2·8	−22·6	803·6035
109	110	1·132	1 063·336	+ 1·0623	+ 1·0644	+ 1·0633	−2·1	−24·7	804·6668
110	111	·707	1 064·043	− 1·5633	− 1·5623	− 1·5628	−1·0	−25·7	803·1040
111	J_2	·124	1 064·167	+ 1·2572	+ 1·2581	+ 1·2576	−0·9	−26·6	804·3616
111	R.R.Sta.(10)	·077	1 064·120	+ 0·3835		+ 0·3835			803·4875
111	112	·904	1 064·947	+ 0·0496	+ 0·0524	+ 0·0510	−2·8	−28·5	803·1550
112	113	1·122	1 066·069	+ 3·1392	+ 3·1371	+ 3·1382	+2·1	−26·4	806·2932
113	114	1·128	1 067·197	+ 6·9176	+ 6·9167	+ 6·9172	+0·9	−25·5	813·2104
114	115	1·112	1 068·309	+ 2·7893	+ 2·7886	+ 2·7890	+0·7	−24·8	815·9994
115	116	1·062	1 069·371	+ 3·4430	+ 3·4451	+ 3·4440	−2·1	−26·9	819·4434
116	117	1·028	1 070·399	− 2·2278	− 2·2258	− 2·2268	−2·0	−28·9	817·2166
117	118	1·143	1 071·542	+ 2·8269	+ 2·8302	+ 2·8286	−3·3	−32·2	820·0452
118	119	1·124	1 072·666	− 0·7516	− 0·7501	− 0·7508	−1·5	−33·7	819·2944
119	120	1·068	1 073·734	+ 2·6301	+ 2·6309	+ 2·6305	−0·8	−34·5	821·9249
120	121	1·144	1 074·878	+ 2·9974	+ 2·9992	+ 2.9983	−1·8	−36·3	824·9232
121	122	1·140	1 076·018	+ 8·1991	+ 8·1990	+ 8·1990	+0·1	−36·2	833·1222
122	123	·959	1 076·977	+ 6·2152	+ 6·2167	+ 6·2160	−1·5	−37·7	839·3382
123	K_2	·496	1 077·473	+ 1·7669	+ 1·7693	+ 1·7681	−2·4	−40·1	841·1063
123	124	·490	1 077·467	+ 1·5111	+ 1·5120	+ 1·5116	−0·9	−38·6	840·8498
124	R.R.Sta.(11)	·548	1 078·015	+ 2·7155		+ 2·7155			843·5653
124	125	1·532	1 078·999	+ 3·9623	+ 3·9638	+ 3·9630	−1·5	−40·1	844·8128
125	126	1·032	1 080·031	+ 1·0862	+ 1·0843	+ 1·0852	+1·9	−38·2	845·8980
126	127	1·061	1 081·092	− 4·7123	− 4·7105	− 4·7114	−1·8	−40·0	841·1866
127	128	1·098	1 082·190	− 6·5154	− 6·5147	− 6·5151	−0·7	−40·7	834·6715
128	129	1·100	1 083·290	+10·9748	+10·9766	+10·9757	−1·8	−42·5	845·6472
129	130	1·132	1 084·422	+ 3·3376	+ 3·3389	+ 3·3382	−1·3	−43·8	848·9854
130	131	1·122	1 085·544	+ 3·4823	+ 3·4804	+ 3·4814	+1·9	−41·9	852·4668
131	132	1·088	1 086·632	+ 2·3595	+ 2·3652	+ 2·3623	−5·7	−47·6	854·8291
132	133	1·142	1 087·774	+ 1·0459	+ 1·0448	+ 1·0453	+1·1	−46·5	855·8744
133	134	1·142	1 088·916	+ 4·0872	+ 4·0881	+ 4·0877	−0·9	−47·4	859·9621
134	R.R.Sta.(12)	1·058	1 089·974	+ 1·0412		+ 1·0412			861·0033
134	135	1·122	1 090·038	+ 0·8206	+ 0·8206	+ 0·8206	0·0	−47·4	860·7827
135	136	1·134	1 091·172	− 5·4242	− 5·4239	− 5·4240	−0·3	−47·7	855·3587
136	L_2	1·125	1 092·297	+ 2·2737	+ 2·2772	+ 2·2754	−3·5	−51·2	857·6341
L_2	137	1·332	1 093·629	− 0·4358	− 0·4316	− 0·4337	−4·2	−55·4	857·2004
137	138	1·125	1 094·754	+10·7894	+10·7916	+10·7905	−2·2	−57·6	867·9909
138	139	1·143	1 095·897	+ 9·7646	+ 9·7659	+ 9·7652	−1·3	−58·9	877·7561
139	140	1·112	1 097·009	+ 6·2841	+ 6·2865	+ 6·2853	−2·4	−61·3	884·0414

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
140	141	1·128	1 098·137	+ 1·8819	+ 1·8811	+ 1·8815	+0·8	— 60·5	885·9229
141	142	·647	1 098·784	+ 1·1328	+ 1·1289	+ 1·1308	+3·9	— 56·6	887·0537
142	M_2	·125	1 098·909	+ 0·4396	+ 0·4395	+ 0·4396	+0·1	— 56·5	887·4933
142	R.R.Sta.(13)	·163	1 098·947	— 0·1822		— 0·1822			886·8715
142	143	1·106	1 099·890	+ 3·5299	+ 3·5348	+ 3·5324	−4·9	— 61·5	890·5861
143	144	1·130	1 101·020	— 5·4277	— 5·4257	— 5·4267	−2·0	— 63·5	885·1594
144	145	1·025	1 102·045	+ 0·6180	+ 0·6159	+ 0·6169	+2·1	— 61·4	885·7763
145	146	·960	1 103·005	— 8·8071	— 8·8023	— 8·8047	−4·8	— 66·2	876·9716
146	147	1·012	1 104·017	— 2·7694	— 2·7665	— 2·7680	−2·9	— 69·1	874·2036
147	148	1·108	1 105·125	−13·7350	−13·7342	−13·7346	−0·8	— 69·9	860·4690
148	149	·962	1 106·087	— 7·5378	— 7·5337	— 7·5358	−4·1	— 74·0	852·9332
149	150	1·116	1 107·203	— 6·6243	— 6·6220	— 6·6232	−2·3	— 76·3	846·3100
150	151	1·121	1 108·324	— 8·8984	— 8·8953	— 8·8969	−3·1	— 79·4	837·4131
151	152	1·126	1 109·450	−11·3371	−11·3371	−11·3371	−0·0	— 79·4	826·0760
152	R.R.Sta.(14)	·501	1 109·951	— 1·6791		— 1·6791			824·3969
152	153	1·102	1 110·552	— 5·6626	— 5·6571	— 5·6599	−5·5	— 84·9	820·4161
153	R.R.b.(15)	·631	1 111·183	+ 1·4364		+ 1·4364			821·8525
153	154	1·018	1 111·570	+ 8·0558	+ 8·0590	+ 8·0574	−3·2	— 88·1	828·4735
154	155	1·106	1 112·676	+ 7·1193	+ 7·1225	+ 7·1209	−3·2	— 91·3	835·5944
155	156	·807	1 113·483	+ 0·2140	+ 0·2181	+ 0·2161	−4·1	— 95·4	835·8105
156	N_2	·086	1 113·569	+ 0·0515	+ 0·0511	+ 0·0513	+0·4	— 95·0	835·8618
156	R.R.Sta.(16)	·096	1 113·579	+ 0·3618		+ 0·3618			836·1723
156	157	1·036	1 114·519	+ 4·9608	+ 4·9625	+ 4·9617	−1·7	— 97·1	840·7722
157	158	1·142	1 115·661	+ 6·0140	+ 6·0156	+ 6·0148	−1·6	— 98·7	846·7870
158	159	1·144	1 116·805	+ 8·0740	+ 8·0728	+ 8·0734	+1·2	— 97·5	854·8604
159	160	1·014	1 117·819	— 1·6451	— 1·6443	— 1·6447	−0·8	— 98·3	853·2157
160	161	1·105	1 118·924	— 2·1512	— 2·1509	— 2·1511	−0·3	— 98·6	851·0646
161	162	1·036	1 119·960	−13·7117	−13·7097	−13·7107	−2·0	−100·6	837·3539
162	163	·986	1 120·946	+ 6·3460	+ 6·3450	+ 6·3455	+1·0	— 99·6	843·6994
163	164	·997	1 121·943	+ 9·6037	+ 9·6079	+ 9·6058	−4·2	−103·8	853·3052
164	165	·923	1 122·866	+ 8·1662	+ 8·1661	+ 8·1661	+0·1	−103·7	861·4713
165	R.R.Sta.(17)	·369	1 123·235	— 1·3312		— 1·3312			860·1401
165	O_2	·582	1 123·448	— 2·4529	— 2·4523	— 2·4526	−0·6	−104·3	859·0187
O_2	168	·981	1 124·429	+10·6614	+10·6622	+10·6618	−0·8	−105·1	869·6805
168	169	1·106	1 125·535	−10·4905	−10·4893	−10·4899	−1·2	−106·3	859·1906
169	170	1·070	1 126·605	+ 2·8842	+ 2·8852	+ 2·8847	−1·0	−107·3	862·0753
170	171	·998	1 127·603	+ 1·4857	+ 1·4846	+ 1·4852	+1·1	−106·2	863·5605
171	172	1·089	1 128·692	+ 3·7673	+ 3·7660	+ 3·7666	+1·3	−104·9	867·3271
172	173	1·013	1 129·705	+ 5·1379	+ 5·1436	+ 5·1408	−5·7	−110·6	872·4679
173	174	1·178	1 130·883	— 3·5644	— 3·5680	— 3·5662	+3·6	−107·0	868·9017
174	175	1·106	1 131·989	+ 9·7434	+ 9·7479	+ 9·7456	−4.5	−111·5	878·6473
175	176	·968	1 132·957	*+ 7·2499	*+ 7·2550	+ 7·2524	−5·1	−116·6	885·8997
176	R.R.Sta.(18)	·867	1 133·824	— 2·7141		— 2·7141			883·1856
176	177	1·014	1 133·971	— 3·3473	— 3·3484	— 3·3479	+1·1	−115·5	882·5518
177	P_2	·146	1 134·117	+ 1·6620	+ 1·6630	+ 1·6625	−1·0	−116·5	884·2143

* Mean of two measures.

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
177	178	1·120	1 135·091	+ 0·3417	+ 0·3408	+ 0·3413	+0·9	−114·6	882·8931
178	179	·980	1 136·071	— 3·7340	— 3·7364	— 3·7352	+2·4	−112·2	879·1579
179	180	1·110	1 137·181	— 5·4745	— 5·4754	— 5·4750	+0·9	−111·3	873·6829
180	181	1·137	1 138·318	+ 8·0287	+ 8·0308	+ 8·0298	−2·1	−113·4	881·7127
181	Q_2	1·312	1 139·630	+10·2805	+10·2812	+10·2808	−0·7	−114·1	891·9935
Q_2	166	1·020	1 140·650	— 5·6034	— 5·6057	— 5·6045	+2·3	−111·8	886·3890
166	167	1·126	1 141·776	+ 6·3984	+ 6·3974	+ 6·3979	+1·0	−110·8	892·7869
167	182	·962	1 142·738	+ 3·1188	+ 3·1199	+ 3·1194	−1·1	−111·9	895·9063
182	183	1·136	1 143·874	+ 5·2760	+ 5·2818	+ 5·2789	−5·8	−117·7	901·1852
183	184	1·105	1 144·979	+ 8·4114	+ 8·4133	+ 8·4124	−1·9	−119·6	909·5976
184	185	1·028	1 146·007	+ 6·3237	+ 6·3233	+ 6·3235	+0·4	−119·2	915·9211
185	186	·906	1 146·913	+ 3·4970	+ 3·4919	+ 3·4945	+5·1	−114·1	919·4156
186	R.R.Sta.(19)	·844	1 147·757	+ 3·3991		+ 3·3991			922·8147
186	187	·935	1 147·848	+ 3·1208	+ 3.1195	+ 3·1202	+1·3	−112·8	922·5358
187	R_2	·209	1 148·057	+ 4·3941	+ 4·3929	+ 4·3935	+1·2	−111·6	926·9393
187	188	1·134	1 148·982	+ 6·9776	+ 6·9826	+ 6·9801	−5·0	−117·8	929·5159
188	189	1·122	1 150·104	+10·9504	+10·9540	+10·9522	−3·6	−121·4	940·4681
189	190	1·106	1 151·210	— 2·5472	— 2·5498	— 2·5485	+2·6	−118·8	937·9196
190	191	1·143	1 152·353	+11·1564	+11·1548	+11·1556	+1·6	−117.2	949·0752
191	192	1·140	1 153·493	+11·6348	+11·6375	+11·6362	−2·7	−119·9	960·7114
192	193	1·146	1 154·639	+ 6·4460	+ 6·4457	+ 6·4458	+0·3	−119·6	967·1572
193	194	1·135	1 155·774	+11·7705	+11·7751	+11·7728	−4·6	−124·2	978·9300
194	195	1·145	1 156·919	+11·9241	+11·9247	+11·9244	−0·6	−124·8	990·8544
195	196	1·082	1 158·001	+10·9756	+10·9764	+10·9760	−0·8	−125·6	1 001·8304
196	197	1·251	1 159·252	+12·3884	+12·3946	+12·3915	−6·2	−131·8	1 014·2219
197	198	1·118	1 160·370	+ 7·2835	+ 7·2840	+ 7·2838	−0·5	−132·3	1 021·5057
198	S_2	·842	1 161·212	+ 4·6499	+ 4.6490	+ 4·6494	+0·9	−131·4	1 026·1551
S_2	R.R.Sta.(20)	·165	1 161·377	— 0·0331		— 0·0331			1 026·1220
S_2	199	1·086	1 162·298	+ 1·0050	+ 1·0062	+ 1·0056	−1·2	−132·6	1 027·1607
199	200	1·303	1 163·601	+ 9·0212	+ 9·0244	+ 9·0228	−3·2	−135·8	1 036·1835
200	201	1·051	1 164·652	+ 6·0211	+ 6·0195	+ 6·0203	+1·6	−134·2	1 042·2038
201	202	1·034	1 165·686	+ 1·7177	+ 1·7202	+ 1·7189	−2·5	−136·7	1 043·9227
202	203	·345	1 166·031	— 3·3652	— 3·3667	— 3·3659	+1·5	−135·2	1 040·5568
203	T_2	·096	1 166·127	+ 0·6859	+ 0·6859	+ 0·6859	0·0	−135·2	1 041·2427
203	R.R.Sta.(21)	·810	1 166·841	+ 4·3477		+ 4·3477			1 044·9045
203	204	·995	1 167·026	+ 4·4506	+ 4·4540	+ 4·4523	−3·4	−138·6	1 045·0091
204	205	1·102	1 168·128	+ 4·3968	+ 4·3998	+ 4·3983	−3·0	−141·6	1 049·4074
205	206	1·143	1 169·271	+ 1·0689	+ 1·0684	+ 1·0687	+0·5	−141·1	1 050·4761
206	207	1·142	1 170·413	+ 1·3776	+ 1·3776	+ 1·3776	0·0	−141·1	1 051·8537
207	208	1·050	1 171·463	+ 0·4443	+ 0·4451	+ 0·4447	−0·8	−141·9	1 052·2984
208	209	1·016	1 172·479	— 0·9476	— 0·9523	— 0·9500	+4·7	−137·2	1 051·3484
209	U_2	1·240	1 173·719	+ 4·0695	+ 4·0682	+ 4·0689	+1·3	−135·9	1 055·4173
U_2	210	1·142	1 174·861	+ 4·5862	+ 4·5889	+ 4·5876	−2·7	−138·6	1 060·0049
210	211	1·140	1 176·001	+ 3·6763	+ 3·6736	+ 3·6750	+2·7	−135·9	1 063·6799
211	R.R.Sta.(22)	·871	1 176·872	+ 7·8748		+ 7·8748			1 071·5547
211	212	1·314	1 177·315	+ 9·2820	+ 9·2788	+ 9·2804	+3·2	−132·7	1 072·9603
212	213	1·070	1 178·385	— 0·9412	— 0·9374	— 0·9393	−3·8	−136·5	1 072·0210
213	214	·922	1 179·307	+ 9·2445	+ 9·2443	+ 9·2444	+0·2	−136·3	1 081·2654
214	215	1·048	1 180·355	+ 7·7247	+ 7·7260	+ 7·7254	−1·3	−137·6	1 088·9908

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
215	216	1·108	1 181·463	+ 5·0021	+ 5·0037	+ 5·0029	—1·6	—139·2	1 093·9937
216	217	1·032	1 182·495	— 0·0689	— 0·0714	— 0·0702	+2·5	—136·7	1 093·9235
217	218	·924	1 183·419	— 7·1080	— 7·1104	— 7·1092	+2·4	—134·3	1 086·8143
218	219	1·105	1 184·524	+ 4·9269	+ 4·9237	+ 4·9253	+3·2	—131·1	1 091·7396
219	A	·826	1 185·350	+ 5·5848	+ 5·5832	+ 5·5840	+1·6	—129·5	1 097·3236
219	R.R.Sta.(23)	·829	1 185·353	+ 5·2136		+ 5·2136			1 096·9532
219	220	·998	1 185·522	+ 4·8287	+ 4·8271	+ 4·8279	+1·6	—129·5	1 096·5675
220	221	1·051	1 186·573	*+ 7·8536	*+7·8574	+ 7·8555	—3·8	—133·3	1 104·4230
221	222	1·069	1 187·642	+ 7·0371	+ 7·0373	+ 7·0372	—0·2	—133·5	1 111·4602
222	223	1·108	1 188·750	+ 8·8136	+ 8·8119	+ 8·8128	+1·7	—131·8	1 120·2730
223	224	1·140	1 189·890	+10·3160	+10·3165	+10·3162	—0·5	—132·3	1 130·5892
224	225	1·126	1 191·016	+ 3·3902	+ 3·3866	+ 3·3884	+3·6	—128·7	1 133·9776
225	226	1·138	1 192·154	— 3·3102	— 3·3103	— 3·3102	+0·1	—128·6	1 130·6674
226	227	1·104	1 193·258	+ 5·6510	+ 5·6506	+ 5·6508	+0·4	—128·2	1 136·3182
227	R.R.Sta.(24)	·157	1 193·415	+ 0·5648		+ 0·5648			1 136·8830
227	228	1·096	1 194·354	*+ 4·9546	*+4·9594	+ 4·9570	—4·8	—133·0	1 141·2752
228	229	1·036	1 195·390	+ 4·4093	+ 4·4066	+ 4·4080	+2·7	—130·3	1 145·6832
229	230	1·124	1 196·514	+ 0·3501	+ 0·3476	+ 0·3488	+2·5	—127·8	1 146·0320
230	231	1·141	1 197·655	+ 4·9437	+ 4·9424	+ 4·9430	+1·3	—126·5	1 150·9750
231	232	1·146	1 198·801	+10·9975	+11·0000	+10·9988	—2·5	—129·0	1 161·9738
232	233	1·091	1 199·892	+11·2465	+11·2499	+11·2482	—3·4	—132·4	1 173·2220
233	B	·804	1 200·696	+ 5·8547	+ 5·8529	+ 5·8538	+1·8	—130·6	1 179·0758
233	R.R.Sta.(25)	·831	1 200·723	+ 5·0677		+ 5·0677			1 178·2897
233	234	1·002	1 200·894	+ 4·8097	+ 4·8075	+ 4·8086	+2·2	—130·2	1 178·0306
234	235	1·130	1 202·024	+ 4·7540	+ 4·7544	+ 4·7542	—0·4	—130·6	1 182·7848
235	236	1·129	1 203·153	+ 0·8711	+ 0·8716	+ 0·8714	—0·5	—131·1	1 183·6562
236	237	1·073	1 204·226	+ 7·6778	+ 7·6765	+ 7·6772	+1·3	—129·8	1 191·3334
237	238	1·052	1 205·278	+ 2·0326	+ 2·0348	+ 2·0337	—2·2	—132·0	1 193·3671
238	239	1·306	1 206·584	+10·8449	+10·8459	+10·8454	—1·0	—133·0	1 204·2125
239	240	1·056	1 207·640	+10·5986	+10·6041	+10·6014	—5·5	—138·5	1 214·8139
240	241	·945	1 208·585	+ 6·3941	+ 6·3904	+ 6·3922	+3·7	—134·8	1 221·2061
241	R.R.Sta.(26)	·157	1 208·742	+ 0·3327		+ 0·3327			1 221·5388
241	242	1·069	1 209·654	+ 3·7768	+ 3·7776	+ 3·7772	—0·8	—135·6	1 224·9833
242	243	1·118	1 210·772	+ 7·5557	+ 7·5536	+ 7·5546	+2·1	—133·5	1 232·5379
243	244	1·118	1 211·890	+ 7·5929	+ 7·5930	+ 7·5930	—0·1	—133·6	1 240·1309
244	245	1·024	1 212·914	+ 2·8406	+ 2·8391	+ 2·8398	+1·5	—132·1	1 242·9707
245	246	1·103	1 214·017	+ 5·8239	+ 5·8200	+ 5·8220	+3·9	—128·2	1 248·7927
246	247	1·154	1 215·171	+ 7·2358	+ 7·2338	+ 7·2348	+2·0	—126·2	1 256·0275
247	248	1·076	1 216·247	+ 0·7851	+ 0·7858	+ 0·7854	—0·7	—126·9	1 256·8129
248	249	1·144	1 217·391	+11·6030	+11·6056	+11·6043	—2·6	—129·5	1 268·4172
249	C	·436	1 217·827	+ 1·3952	+ 1·3970	+ 1·3961	—1·8	—131·3	1 269·8133
249	R.R.Sta.(27)	·433	1 217·824	+ 1·6340		+ 1·6340			1 270·0512
249	250	1·038	1 218·429	— 5·2021	— 5·1996	— 5·2008	—2·5	—132·0	1 263·2164
250	251	1·125	1 219·554	—11·3639	—11·3677	—11·3658	+3·8	—128·2	1 251·8506
251	252	1·052	1 220·606	—10·6450	—10·6406	—10·6428	—4·4	—132·6	1 241·2078
252	253	·962	1 221·568	— 8·0696	— 8·0706	— 8·0701	+1·0	—131·6	1 233·1377
253	254	·514	1 222·082	— 5·1396	— 5·1396	— 5·1396	0·0	—131·6	1 227·9981
254	257	1·123	1 223·205	—11·0615	—11·0609	—11·0612	—0·6	—132·2	1 216·9369

* Mean of two measures.

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark. From	Bench mark. To	Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks. Line, rod P.	Line, rod Q.	Mean.	Discrepancy. Partial P—Q.	Total accumulated.	Height above K_3 at St. Louis.
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
257	258	1·096	1 224·301	−10·4596	−10·4652	−10·4624	+5·6	−126·6	1 206·4745
258	259	1·146	1 225·447	− 9·0726	− 9·0722	− 9·0724	−0·4	−127·0	1 197·4021
259	260	1·148	1 226·595	− 9·8706	− 9·8724	− 9·8715	+1·8	−125·2	1 187·5306
260	261	1·080	1 227·675	− 7·4001	− 7·4046	− 7·4024	+4·5	−120·7	1 180·1282
261	262	1·114	1 228·789	− 6·6953	− 6·6944	− 6·6948	−0·9	−121·6	1 173·4334
262	263	1·162	1 229·951	− 7·4720	− 7·4715	− 7·4718	−0·5	−122·1	1 165·9616
263	264	1·016	1 230·967	− 1·9182	− 1·9213	− 1·9198	+3·1	−119·0	1 164·0418
264	R.R.Sta.(28)	·634	1 231·601	− 2·0354		− 2·0354			1 162·0064
264	265	1·055	1 232·022	− 4·2089	− 4·2076	− 4·2082	−1·3	−120·3	1 159·8336
265	266	1·126	1 233·148	+ 0·9619	+ 0·9623	+ 0·9621	−0·4	−120·7	1 160·7957
266	267	1·144	1 234·292	+ 2·5358	+ 2·5311	+ 2·5334	+4·7	−116·0	1 163·3291
267	268	1·128	1 235·420	+ 6·2802	+ 6·2826	+ 6·2814	−2·4	−118·4	1 169·6105
268	269	1·142	1 236·562	− 0·2956	− 0·2956	− 0·2956	0·0	−118·4	1 169·3149
269	270	1·133	1 237·695	+ 0·1169	+ 0·1139	+ 0·1154	+3·0	−115·4	1 169·4303
270	271	1·325	1 239·020	+ 5·7896	+ 5·7898	+ 5·7897	−0·2	−115·6	1 175·2200
271	255	1·180	1 240·200	+ 4·6835	+ 4·6876	+ 4·6856	−4·1	−119·7	1 179·9056
255	D	·080	1 240·280	+ 0·9794	+ 0·9799	+ 0·9796	−0·5	−120·2	1 180·8852
255	R.R.Sta (29)	·080	1 240·280	+ 0·1889		+ 0·1889			1 180·0945
255	256	1·018	1 241·218	+ 1·6930	+ 1·6916	+ 1·6923	+1·4	−118·3	1 181·5979
256	272	·727	1 241·945	+ 1·7971	+ 1·7969	+ 1·7970	+0·2	−118·1	1 183·3949
272	273	1·148	1 243·093	+ 4·2990	+ 4·2986	+ 4·2988	+0·4	−117·7	1 187·6937
273	274	1·106	1 244·199	+ 1·3808	+ 1·3838	+ 1·3823	−3·0	−120·7	1 189·0760
274	275	1·068	1 245·267	+ 4·3238	+ 4·3222	+ 4·3230	+1·6	−119·1	1 193·3990
275	276	1·314	1 246·581	+ 1·4999	+ 1·4986	+ 1·4992	+1·3	−117·8	1 194·8982
276	277	1·144	1 247·725	+ 6·1389	+ 6·1393	+ 6·1391	−0·4	−118·2	1 201·0373
277	278	1·070	1 248·795	+ 2·5104	+ 2·5092	+ 2·5098	+1·2	−117·0	1 203·5471
278	279	1·135	1 249·930	+ 5·1873	+ 5·1813	+ 5·1843	+6·0	−111·0	1 208·7314
279	R.R.Sta (30)	·130	1 250·060	+ 1·0666		+ 1·0666			1 209·7980
279	280	1·096	1 251·026	+ 4·1374	+ 4·1391	+ 4·1382	−1·7	−112·7	1 212·8696
280	281	1·126	1 252·152	+ 3·6110	+ 3·6100	+ 3·6105	+1·0	−111·7	1 216·4801
281	282	1·031	1 253·183	+ 1·8929	+ 1·8923	+ 1·8926	+0·6	−111·1	1 218·3727
282	283	1·068	1 254·251	+ 1·5058	+ 1·5016	+ 1·5037	+4·2	−106·9	1 219·8764
283	284	·952	1 255·203	+ 1·4884	+ 1·4868	+ 1·4876	+1·6	−105·3	1 221·3640
284	285	1·016	1 256·219	+ 3·2935	+ 3·2931	+ 3·2933	+0·4	−104·9	1 224·6573
285	286	1·104	1 257·323	+ 0·9839	+ 0·9829	+ 0·9834	+1·0	−103·9	1 225·6407
286	287	1·143	1 258·466	+ 0·4785	+ 0·4780	+ 0·4782	+0·5	−103.4	1 226·1189
287	E	·054	1 258·520	− 0·3238	− 0·3233	− 0·3236	−0·5	−103·9	1 225·7953
287	288	1·142	1 259·608	+ 4·3518	+ 4·3558	+ 4·3538	−4·0	−107·4	1 230·4727
288	R.R.Sta.(31)	·451	1 260·059	+ 0·9444		+ 0·9444			1 231·4171
288	289	1·044	1 260·652	+ 2·8168	+ 2·8183	+ 2·8176	−1·5	−108·9	1 233·2903
289	290	1·142	1 261·794	+ 5·1748	+ 5·1767	+ 5·1758	−1·9	−110·8	1 238·4661
290	291	1·143	1 262·937	+ 3·0303	+ 3·0322	+ 3·0312	−1·9	−112·7	1 241·4973
291	292	1·069	1 264·006	+ 4·2355	+ 4·2308	+ 4·2332	+4·7	−108·0	1 245·7305
292	293	1·032	1 265·038	+ 4·5837	+ 4·5799	+ 4·5818	+3·8	−104·2	1 250·3123
293	294	1·126	1 266·164	+ 6·7461	+ 6·7454	+ 6·7458	+0·7	−103·5	1 257·0581
294	295	1·142	1 267·306	+ 4·5449	+ 4·5473	+ 4·5461	−2·4	−105·9	1 261·6042
295	296	1·144	1 268·450	− 5·0285	− 5·0293	− 5·0289	+0·8	−105·1	1 256·5753
296	297	1·086	1 269·536	+ 4·5904	+ 4·5883	+ 4·5894	+2·1	−103·0	1 261·1647
297	298	1·117	1 270·653	+ 0·6351	+ 0·6316	+ 0·6334	+3·5	− 99·5	1 261·7981

Results of geodetic spirit leveling between Ellis, Kans., and Hugo, Colo.—Continued.

Bench mark.		Distance between successive marks.	Distance from initial mark K_3	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
298	F	1·362	1 272·015	+ 3·0398	+ 3·0437	+ 3·0418	−3·9	−103·4	1 264·8399
F	R.R.Sta.(32)	·066	1 272·081	+ 0·0984		+ 0·0984			1 264·9383
F	299	·966	1 272·981	+ 4·7125	+ 4·7120	+ 4·7122	+0·5	−102·9	1 269·5521
299	300	1·092	1 274·073	+ 1·1215	+ 1·1233	+ 1·1224	−1·8	−104·7	1 270·6745
300	301	1·146	1 275·219	+ 4·2168	+ 4·2154	+ 4·2161	+1·4	−103·3	1 274·8906
301	302	1·144	1 276·363	+ 3·1386	+ 3·1415	+ 3·1400	−2·9	−106·2	1 278·0306
302	303	1·142	1 277·505	+ 2·5200	+ 2·5147	+ 2·5174	+5·3	−100·9	1 280·5480
303	304	1·144	1 278·649	+ 8·4689	+ 8·4671	+ 8·4680	+1·8	− 99·1	1 289·0160
304	305	1·142	1 279·791	+ 4·6805	+ 4·6815	+ 4·6810	−1·0	−100·1	1 293·6970
305	306	1·142	1 280·933	+ 3·7699	+ 3·7697	+ 3·7698	+0·2	− 99·9	1 297·4668
306	307	1·144	1 282·077	− 1·1275	− 1·1305	− 1·1290	+3·0	− 96·9	1 296·3378
307	308	1·334	1 283·411	+ 4·3801	+ 4·3802	+ 4·3802	−0·1	− 97·0	1 300·7180
308	309	1·142	1 284·553	+ 5·0573	+ 5·0561	+ 5·0567	+1·2	− 95·8	1 305·7747
309	310	1·144	1 285·697	+ 2·8748	+ 2·8754	+ 2·8751	−0·6	− 96·4	1 308·6498
310	311	1·143	1 286·840	+ 3·3632	+ 2·3641	+ 2·3636	−0·9	− 97·3	1 311·0134
311	312	1·142	1 287·982	+ 4·6937	+ 4·6936	+ 4·6936	+0·1	− 97·2	1 315·7070
312	G	·433	1 288·415	+ 3·1676	+ 3·1691	+ 3·1684	−1·5	− 98·7	1 318·8754
312	R.R.Sta.(33)	·419	1 288·401	+ 2·7917		+ 2·7917			1 318·4987
312	313	·986	1 288·968	+ 3·2107	+ 3·2139	+ 3·2123	−3·2	−100·4	1 318·9193
313	314	1·142	1 290·110	+ 1·6079	+ 1·6113	+ 1·6096	−3·4	−103·8	1 320·5289
314	315	1·108	1 291·218	+ 5·3863	+ 5·3845	+ 5·3854	+1·8	−102·0	1 325·9143
315	316	1·088	1 292·306	+ 3·7886	+ 3·7901	+ 3·7894	−1·5	−103·5	1 329·7037
316	317	1·122	1 293·428	+ 2·8580	+ 2·8558	+ 2·8569	+2·2	−101·3	1 332·5606
317	318	1·316	1 294·744	+ 3·0490	+ 3·0469	+ 3·0480	+2·1	− 99·2	1 335·6086
318	319	1·140	1 295·884	+ 4·2471	+ 4·2447	+ 4·2459	+2·4	− 96·8	1 339·8545
319	320	1·141	1 297·025	+ 5·4518	+ 5·4485	+ 5·4502	+3·3	− 93·5	1 345·3047
320	321	1·143	1 298·168	+ 1·8375	+ 1·8382	+ 1·8378	−0·7	− 94·2	1 347·1425
321	322	1·142	1 299·310	+ 3·3436	+ 3·3458	+ 3·3447	−2·2	− 96·4	1 350·4872
322	323	1·141	1 300·451	+ 4·8073	+ 4·8056	+ 4·8064	+1·7	− 94·7	1 355·2936
323	H	·904	1 301·355	+ 3·0682	+ 3·0711	+ 3·0696	−2·9	− 97·6	1 358·3632
H	R.R.Sta.(34)	·685	1 302·040	+ 2·2776		+ 2·2776			1 360·6408
H	324	1·032	1 302·387	+ 2·9313	+ 2·9292	+ 2·9302	+2·1	− 95·5	1 361·2934
324	325	1·034	1 303·421	+ 3·6229	+ 3·6180	+ 3·6204	+4·9	− 90·6	1 364·9138
325	326	1·142	1 304·563	+ 2·6396	+ 2·6384	+ 2·6390	+1·2	− 89·4	1 367·5528
326	327	1·143	1 305·706	+ 4·6278	+ 4·6299	+ 4·6288	−2·1	− 91·5	1 372·1816
327	328	1·141	1 306·847	+ 9·2492	+ 9·2490	+ 9·2491	+0·2	− 91·3	1 381·4307
328	329	1·098	1 307·945	+ 5·3097	+ 5·3071	+ 5·3084	+2·6	− 88·7	1 386·7391
329	330	1·142	1 309·087	− 1·5241	− 1·5225	− 1·5233	−1·6	− 90·3	1 385·2158
330	331	1·134	1 310·221	+ 6·3387	+ 6·3440	+ 6·3414	−5·3	− 95·6	1 391·5572
331	332	1·132	1 311·353	+ 0·8864	+ 0·8847	+ 0·8856	+1·7	− 93·9	1 392·4428
332	333	1·100	1 312·453	+ 2·5889	+ 2·5850	+ 2·5870	+3·9	− 90·0	1 395·0298
333	334	1·144	1 313·597	+ 7·9235	+ 7·9265	+ 7·9250	−3·0	− 93·0	1 402·9548
334	335	1·141	1 314·738	− 1·2083	− 1·2134	− 1·2108	+5·1	− 87·9	1 401·7440
335	336	1·136	1 315·874	+ 5·1537	+ 5·1517	+ 5·1527	+2·0	− 85·9	1 406·8967
336	337	·783	1 316·657	+ 2·7841	+ 2·7841	+ 2·7841	0·0	− 85·9	1 409·6808
337	R.R.Sta.(35)	·116	1 316·773	+ 0·4184		+ 0·4184			1 410·0992
337	I	·480	1 317·137	+ 2·1376	+ 2·1410	+ 2·1393	−3·4	− 89·3	1 411·8201
I	J	·095	1 317·232	+ 0·3671	+ 0·3665	+ 0·3668	+0·6	− 88·7	1 412·1869
I	K	·094	1 317·231	+ 0·3640	+ 0·3639	+ 0·3640	+0·1	− 89·2	1 412·1841

Side lines to triangulation stations.

From B. M.	to B. M.	Difference of height. Rod P.	Rod Q.	Mean.	Discrepancy.	Height above bench mark K_3.
		m.	*m.*	*m.*	*mm.*	*m.*
	C					1 269·813
C	a	− 4·987	− 4·991	− 4·989	+ 4	1 264·824
a	First View △	+ 9·652	+ 9·651	+ 9·652	+ 1	1 274·476
	272					1 183·395
272	a	− 2·493	− 2·494	− 2·494	+ 1	1 180·901
a	b	+ 6·479	+ 6·477	+ 6·478	+ 2	1 187·379
b	c	+ 8·283	+ 8·294	+ 8·288	−11	1 195·667
c	d	− 0·005	0·000	− 0·002	− 5	1 195·665
d	e	+ 1·140	+ 1·138	+ 1·139	+ 2	1 196·804
e	f	+ 7·860	+ 7·858	+ 7·859	+ 2	1 204·663
f	Kit Carson △	+ 14·990	+14·990	+14·990	0	1 219·653
	337					1 409·681
337	k	+ 2·404	+ 2·411	+ 2·408	− 7	1 412·089
k	j	+16·545	+16·537	+16·541	+ 8	1 428·630
j	i	+ 3·817	+ 3·819	+ 3·818	− 2	1 432·448
i	h	+19·346	+19·346	+19·346	0	1 451·794
h	g	+19·466	+19·451	+19·458	+15	1 471·252
g	f	+ 7·961	+ 7·956	+ 7·958	+ 5	1 479·210
f	Hugo △	+20·360	+20·356	+20·358	+ 4	1 499·568

B. M. A_2.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt that is leaded in the front face of the stone wall to the one-story business building owned and occupied by Thomas Daly, at Ellis, Kans. The bolt is in the west side wall, in the second course above the foundation and about the center of the stone forming the course. Established in 1896.

B. M. B_2.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt that is leaded in the front face of the east side wall to the two-story stone business building owned and occupied by R. McCloud, at Ellis, Kans. The bolt is in the second course above the foundation and about the middle of the stone forming the course.

B. M. C_2.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the east front face of the two-story stone building at Ogallah, Kans., owned by William Baldwin, and used as a store and post-office. The bolt is in the fourth course above the foundation and in the stone forming the northeast corner.

B. M. D_2.—This bench mark is the bottom of a square hole cut in the stone doorsill to the entrance to the court house at Wakeeney, Kans. The building fronts west and the bench mark is at the the north or left side of the door as the building is entered. The following letters were cut: U. S. ■ B. M.

B. M. E_2.—This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the front (west) face of the stone pump house to the railroad water tank at Collyer, Kans. The bolt is on the right of the door

as the building is entered, in the fifth course above the ground and is in the stone forming the southwest corner. The following letters were cut: U. S. ● B. M.

B. M. F_2.—This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the north wall to the two-story brick schoolhouse at Quinter, Kans. The building is about 500 meters south of the railroad. The bolt is in the sixth course of brick above the stone foundation and in the second brick from the northeast corner.

B. M. G_2.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the east wall of the stone pump house at the west end of the railroad station platform at Buffalo Park, Kans. The bolt is in the second course above the platform and in the stone forming the southeast corner. The following letters were cut: U. S. ● B. M.

B. M. H_2.—This bench mark is the intersection of two lines, forming a cross, cut in the iron front to the two-story brick building (called the Opera House) at Grainfield, Kans. The building fronts east and the mark is near the southeast corner. The maker's mark is on the iron in raised letters and the cross is placed as follows: Mesker & Bros., St. + Louis, Mo. The letters U. S. B. M. were cut in the iron immediately below the cross.

B. M. I_2.—This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the east wall of the stone pump house to the railroad water tank at Grinnell, Kans. The bolt is in the ninth course above the foundation and in the stone forming the northeast corner of the building.

B. M. J_2.—This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the east wall to the stone pump house to the railroad water tank at Oakley, Kans. The bolt is in third course above the ground and in the stone forming the southeast corner of the building. The following letters were cut: U. S. ● B. M.

B. M. K_2.—This bench mark is the intersction of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the front south wall of the stone basement to the one-story frame dwelling house at Monument, Kans., owned by Thomas Handley. The house is north of the railroad and about 800 meters east of the railroad station. The bolt is at the west side of the east window, in the second course above the ground and in the stone forming the west side of the window. The following letters were cut: U. S. B. M.

B. M. L_2.—This bench mark is the surface of the iron at the intersection of two lines, forming a cross, cut in the upper surface of the pedestal to the iron monument marking the end of the bonded portion of the Union Pacific Railway. The monument stands north of the track about 2½ kilometers west of Page City, Kans. The cross is at the southeast corner, and the following letters were cut: U. S. + B. M.

B. M. M_2.—This bench mark is the bottom of a square hole cut in the upper surface of the stone foundation supporting one of the iron columns under the railroad water tank at Winona, Kans. The hole is in the southeast stone of the four supporting the central group of columns and on its south sloping face. The following letters were cut: U. S. ■ B. M.

B. M. N$_2$.—This bench mark is the bottom of a square hole cut in the top of a granite post, at its center, buried 3½ feet in the ground at McAllaster, Kans., between the railroad track and switch near the southeast corner of the platform around the railroad station. The post is 4 feet long, rough except at the top, which is dressed to 6 by 6 inches, 6 inches below the top. The following letters were cut in the top of the post: U. S. ■ B. M.

B. M. O$_2$.—This bench mark is the bottom of a square hole cut in the top of a granite post, at its center, buried 3½ feet in the ground at Turkey Creek, Kans., on the railway right of way between the track and the telegraph pole used as the 414-mile post. The post is 4 feet long, rough except at the top, which is dressed to 6 by 6 inches, 6 inches below the top. The following letters were cut in the top of the post: U. S. ■ B. M.

B. M. P$_2$.—This bench mark is the bottom of a square hole cut in the top of the sandstone post forming the west support of the transit at the telegraph longitude station at Wallace, Kans. The station is in the northeast corner of the inclosure east of the stone house formerly used as the office of the division superintendent of the Union Pacific Railway. The following letters were cut: U. S. ■ B. M.

B. M. O$_2$.—This bench mark is the bottom of a square hole cut in the upper surface of the stone foundation under one of the iron columns supporting the railroad water tank, 3½ miles west of Wallace, Kans. The hole is in the southwest stone of the four supporting the central group of columns, and near its south side. The following letters were cut: U. S. ■ B. M.

B. M. R$_2$.— This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the stone foundation under the east front wall of a one-story business building at Sharon Springs, Kans. The building is on the west side of the main street, and is owned by Colonel Woodhouse. The bolt is in the stone forming the southeast corner of the foundation, and projects a little outside the stone.

B. M. S$_2$.—This bench mark is the bottom of a square hole cut in the top of a granite post, at its center, buried 3½ feet in the ground, on the railway right of way about 10 feet south of the station sign at Monotony, Kans. The post is 4 feet long, rough, except at the top, which is dressed to 6 by 6 inches, 6 inches below the top. The following letters were cut: U. S. ■ B. M.

B. M. T$_2$.—This bench mark is the intersection of two lines cut in the end of a copper bolt, forming a cross at its center, leaded in the front (east) wall of the stone pump house to the railway water tank at Weskan, Kans. The bolt is in the second course below the top of the wooden door casing, and in the third stone from the southeast corner of the building.

B. M. U$_2$.—This bench mark is the surface of the iron at the intersection of two lines cut in the upper surface of the pedestal to the iron monument marking the Kansas-Colorado State line. The monument is north of the track, on the railway right of way.

The cross is at the southwest corner between the round hole and the corner. The following letters were cut: U. S. + B. M.

B. M. A.—This bench mark is the bottom of a square hole cut in the top of a granite post in the southeast corner of the yard around the railway section house at Arapahoe, Cheyenne County, Colo. The post is 4 feet long, buried 3½ feet in the ground, and rough, except for the part above ground, which is dressed to 6 by 6 inches. The following letters are cut in the top surface of the post: U. S. ■ B. M.

B. M. B.—This bench mark is the bottom of a square hole cut in the limestone window sill to the brick railway roundhouse at Cheyenne Wells, Cheyenne County, Colo. The bench mark is about the middle of the sill to the window on the left of the door as you enter the roundhouse from the main track. The following letters were cut: U. S. ■ B. M.

B. M. C.—This bench mark is the bottom of a square hole cut in the top of a granite post in the yard to the railway station (and dwelling of the agent) at First View, Cheyenne County, Colo., about the middle of the south side, just inside the fence. The post projects about 6 inches above the ground, and that part of it is dressed to 6 by 6 inches. The following letters were cut in the top surface of the post: U. S. ■ B. M.

B. M. D.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the front (east) wall of the stone pump house to the railway water tank at Kit Carson, Cheyenne County, Colo. The bolt is in the fourth course above the ground, in the stone forming the southeast corner.

B. M. E.—This bench mark is the bottom of a square hole cut in the top of the coping to the stone retaining wall of the culvert 1 mile east of Wildhorse, Cheyenne County, Colo. The hole is north of the track, at the west angle in the wall. The following letters were cut: U. S. ■ B. M.

B. M. F.—This bench mark is the bottom of a square hole cut in the top of a granite post near the east end of the railway section house at Aroya, Cheyenne County, Colo. The post projects 6 inches above the ground, and that part of it is dressed to 6 by 6 inches. The following letters were cut in the top surface: U. S. ■ B. M.

B. M. G.—This bench mark is the bottom of a square hole cut in the top of a granite post in the southeast corner of the yard to the railway section house at Boyero, Lincoln County, Colo. The post projects 6 inches above the surface of the ground, and that part of it is dressed to 6 by 6 inches. The following letters were cut in the top surface of the post: U. S. ■ B. M.

B. M. H.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the brick pump house to the railway water tank at Mirage, Lincoln County, Colo. The bolt is in the eighth course above the stone foundation and in the sixth brick to the right of the door as you enter.

B. M. I.—This bench mark is the bottom of a square hole cut in the top of a granite post in the yard to the county jail at Hugo, Lincoln County, Colo., east of the building. The post projects 6 inches above the surface of the ground, and that part of

it is dressed to 6 by 6 inches. The following letters were cut in the top surface of the post: U. S. ■ B. M.

B. M. J.— This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the stone water table to the brick jail building at Hugo, Lincoln County, Colo. The bolt is in the front wall near the southeast corner of the building, and on the right of the door as you enter the jail.

B. M. K.—This bench mark is the intersection of two lines, forming a cross, cut in the end of a copper bolt leaded in the stone water table to the brick jail building at Hugo, Lincoln County, Colo. The bolt is in the front wall near the southwest corner of the building, and on the left of the door as you enter the jail.

The elevation of the following railroad stations and road crossing were determined by using the top of the rail in front of the stations at the crossing:

1 Ellis, Kans.
2 Ogallah, Kans.
3 Wakeeney, Kans.
4 Colono, Kans. (road crossing).
5 Collyer, Kans.
6 Quinter, Kans.
7 Buffalo Park, Kans.
8 Grainfield, Kans.
9 Grinnell, Kans.
10 Oakley, Kans.
11 Monument, Kans.
12 Page City, Kans.
13 Winona, Kans.
14 Lisbon, Kans.
15 Bridge over North Fork Smoky Hill River, Kansas.
16 McAllaster, Kans.
17 Turkey Creek, Kans.
18 Wallace, Kans.
19 Sharon Springs, Kans.
20 Monotony, Kans.
21 Weskan, Kans.
22 Chemung, Colo.
23 Arapahoe, Colo.
24 Namouna, Colo.
25 Cheyenne Wells, Colo.
26 Ascalon, Colo.
27 First View, Colo.
28 Arena, Colo.
29 Kit Carson, Colo.
30 Sorrento, Colo.
31 Wild Horse, Colo.
32 Aroya, Colo.
33 Boyero, Colo.
34 Mirage, Colo.
35 Hugo, Colo.

APPENDIX No. 3. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN HUGO AND COLORADO SPRINGS, COLORADO.

Report by C. A. SCHOTT, Assistant.

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APPENDIX No. 3. 1897-98.

RESULTING HEIGHTS FROM SPIRIT LEVELING BETWEEN HUGO AND COLORADO SPRINGS, COLO., FROM OBSERVATIONS BY I. WINSTON, ASSISTANT, BETWEEN APRIL 20 AND JULY 8, 1898.

Report by C. A. SCHOTT, *Assistant.*

Between April 20 and July 8, 1898, the transcontinental line of spirit levels was extended from Hugo to Colorado Springs, Colo., and the resulting heights are here presented in the usual tabular form. The reference level is that passing through bench mark K_3 on the bridge pier at St. Louis. For this mark we have provisionally the height 125·8 meters, or 412·7 feet, above the mean Gulf level. The resulting heights of the part of the line leveled in 1897 ending at Hugo, Colo., are given in Appendix No. 2, Report for 1897–1898.

The line follows the Union Pacific Railway to Limon, and then follows the Chicago, Rock Island and Pacific Railway to Colorado Springs, a total distance of 151 kilometers, or 94 statute miles.

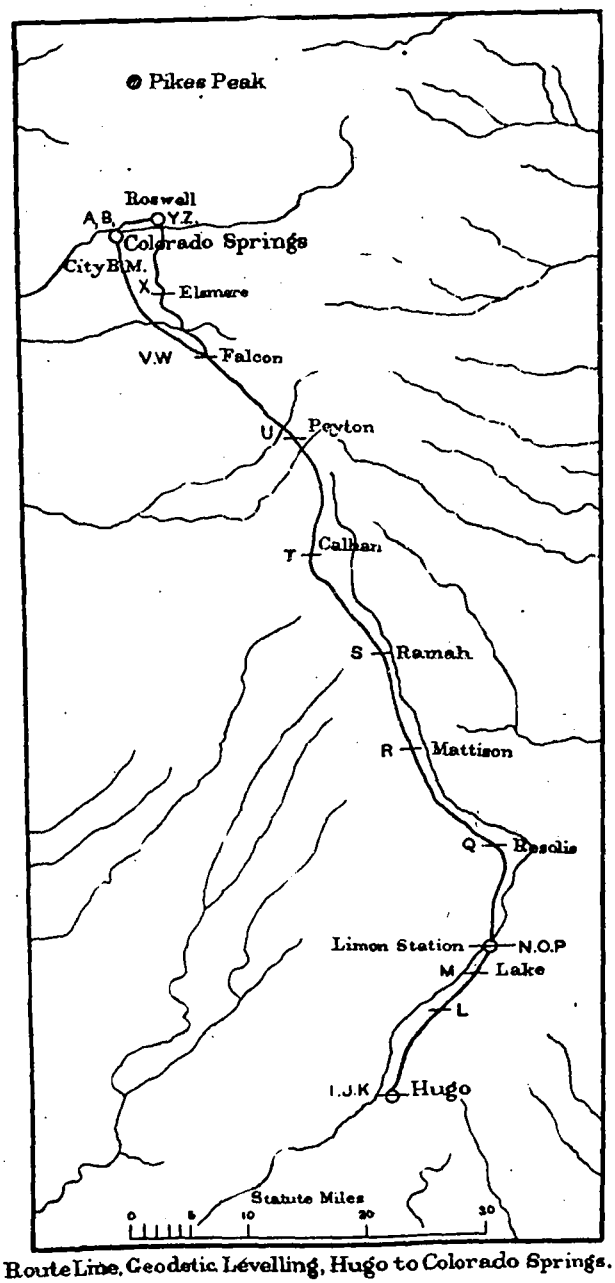
Micrometer spirit levels Nos. 5 and 6 and rods P and Q (described in Appendix No. 8, 1895) were used. A simultaneous double line was run in one direction over the whole distance.

The instrumental constants are as follows:

Instrument.*	No. 5.	No. 6.
Aperture of telescope	2·9 cm.	2·9 cm.
Focal length of telescope	34·8 cm.	34·8 cm.
Magnifying power	28	28
Value of 1 division of striding level as determined	1″·97 October 31, 1896	2″·45 December 9, 1891
Inequality of collars†	−0″·63 April 13, 1898	+0″·72 October 28, 1896
Value of 1 turn of micrometer	312″·0	312″·0
Angular value of telemeter threads	Until May 6 18′ 54″·5 After May 12 19 20·9	18′ 50″·6

*Spirit levels Nos. 5 and 6 were made at the Survey office in 1888. For mention of these instruments see Appendices 3 and 4, Report for 1892, also Appendices Nos. 2, 3, and 5, Report for 1896.

†The collars of No. 5 were reground; the minus sign indicates object end the smaller of the two.



Route Line, Geodetic Levelling, Hugo to Colorado Springs.

The lengths of rods P and Q, at 24° C., as determined March 24, 1897, are—

		P.	Q.
m	m	m	m
0·1 to 1·0		0·90051	0·90051
1·0 to 2·0		1·00054	1·00050
2·0 to 3·0		1·00054	1·00047
Hence 0·1 to 3·0		2·90159	2·90148

Coefficient of expansion 0·000004 per degree centigrade. The index correction is the same for both rods, viz:—0·0003 m., determined January 22, 1898.

The field computation is by the observer, the office computation by D. L. Hazard. We have as usual the mean error of a single leveling of 1 kilometer

$$m_1 = \sqrt{\frac{[dd]}{2[s]}} = \pm 1{\cdot}6 \text{ mm.}$$

the probable error of a double leveling of 1 kilometer

$$r_{11} = 0{\cdot}675\sqrt{\frac{[dd]}{4[s]}} = \pm 0{\cdot}77 \text{ mm.}$$

and the probable error of the whole line between bench marks K and B,

$$r = 0{\cdot}674\sqrt{\frac{[dd]}{4}} = 9{\cdot}4 \text{ mm.}$$

This value supposes the results of the P and Q lines to be independent, a supposition which does not hold in the case of simultaneous lines, since the atmospheric and instrumental conditions are the same for both lines. A closer approximation to the truth will be obtained by increasing r by one-fourth its above value and adopting $r = \pm 11{\cdot}8$ mm.

The probable error of the height assigned to the mark at Hugo, distant 1 317 kilometers or 818 statute miles from St. Louis, was $\pm 41{\cdot}9$ mm. as developed between the two places, hence the probable error of B. M. B., at Colorado Springs $= \sqrt{(41{\cdot}9)^2 + (11{\cdot}8)^2} = \pm 43{\cdot}5$ mm., which value has yet to be combined with the probable error of the St. Louis bench mark.

Results of geodetic spirit leveling between Hugo and Colorado Springs, Colo.

Bench marks.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
	J								I 412·1869
J	K		I 317·231	— 0·0031	— 0·0026	— 0·0028	—0·5		I 412·1841
K	1	0·788	I 318·019	— 0·4795	— 0·4770	— 0·4782	—2·5	— 2·5	I 411·7059
1	2	1·079	I 319·098	+ 7·8709	+ 7·8700	+ 7·8704	+0·9	— 1·6	I 419·5763
2	3	1·056	I 320·154	+ 4·5112	+ 4·5085	+ 4·5098	+2·7	+ 1·1	I 424·0861
3	4	0·947	I 321·101	+ 1·9603	+ 1·9589	+ 1·9596	+1·4	+ 2·5	I 426·0457
4	5	1·039	I 322·140	+ 9·7579	+ 9·7593	+ 9·7586	—1·4	+ 1·1	I 435·8043
5	6	1·039	I 323·179	+ 9·2152	+ 9·2154	+ 9·2153	—0·2	+ 0·9	I 445·0196
6	7	1·128	I 324·307	*+10·1303	*+10·1324	+10·1314	—2·1	— 1·2	I 455·1510
7	8	1·323	I 325·630	— 0·1220	— 0·1190	— 0·1205	—3·0	— 4·2	I 455·0305
8	R.R.Sta.(1)	0·822	I 326·452	— 2·6727		— 2·6727			I 452·3578
8	9	1·015	I 326·645	— 2·4617	— 2·4655	— 2·4636	+3·8	— 0·4	I 452·5669
9	10	1·031	I 327·676	+ 4·4769	+ 4·4751	+ 4·4760	+1·8	+ 1·4	I 457·0429
10	11	1·258	I 328·934	+ 2·7127	+ 2·7159	+ 2·7143	—3·2	— 1·8	I 459·7572
11	12	1·036	I 329·970	+10·3956	+10·3932	+10·3944	+2·4	+ 0·6	I 470·1516
12	13	0·923	I 330·893	+ 2·6643	+ 2·6672	+ 2·6658	—2·9	— 2·3	I 472·8174
13	L	0·995	I 331·888	— 2·3637	— 2·3608	— 2·3622	—2·9	— 5·2	I 470·4552
13	14	0·991	I 331·884	— 2·0864	— 2·0843	— 2·0854	—2·1	— 4·4	I 470·7320
14	15	1·011	I 332·895	+ 1·6337	+ 1·6374	+ 1·6356	—3·7	— 8·1	I 472·3676
15	17	1·033	I 333·928	+ 6·8799	+ 6·8805	+ 6·8802	—0·6	— 8·7	I 479·2478
17	18	0·929	I 334·857	+ 1·6713	+ 1·6710	+ 1·6712	+0·3	— 8·4	I 480·9190
18	19	0·907	I 335·764	+ 0·2046	+ 0·2041	+ 0·2044	+0·5	— 7·9	I 481·1234
19	20	1·271	I 337·035	+ 6·8342	+ 6·8322	+ 6·8332	+2·0	— 5·9	I 487·9566
20	M	0·180	I 337·215	+ 2·0032	+ 2·0055	+ 2·0044	—2·3	— 8·2	I 489·9610
20	R.R.Sta.(2)	0·328	I 337·363	+ 1·4842		+ 1·4842			I 489·4408
20	21	1·093	I 338·128	+ 6·2977	+ 6·2948	+ 6·2962	+2·9	— 3·0	I 494·2528
21	22	1·149	I 339·277	+ 4·5131	+ 4·5129*	+ 4·5130	+0·2	— 2·8	I 498·7658
22	23	1·150	I 340·427	+ 5·1637	+ 5·1624	+ 5·1630	+1·3	— 1·5	I 503·9288
23	24	0·906	I 341·333	+ 3·7635	+ 3·7653	+ 3·7644	—1·8	— 3·3	I 507·6932
24	16	0·279	I 341·612	— 0·8682	— 0·8697	— 0·8690	+1·5	— 1·8	I 506·8242
16	N	0·142	I 341·754	— 0·7868	— 0·7866	— 0·7867	—0·2	— 2·0	I 506·0375
16	R.R.Cros.(3)	0·290	I 341·902	+ 1·1412		+ 1·1412			I 507·9654
16	O	0·189	I 341·801	+ 6·2096	+ 6·2102	+ 6·2099	—0·6	— 2·4	I 513·0341
O	P	0·026	I 341·827	— 0·0123	— 0·0120	— 0·0122	—0·3	— 2·7	I 513·0219
24	25	0·370	I 341·703	— 1·1387	— 1·1408	— 1·1398	+2·1	— 1·2	I 506·5534
25	26	1·146	I 342·849	+ 5·3546	+ 5·3584	+ 5·3565	—3·8	— 5·0	I 511·9099
26	27	1·073	I 343·922	+ 8·6004	+ 8·6054	+ 8·6029	—5·0	—10·0	I 520·5128
27	28	1·043	I 344·965	+ 3·8865	+ 3·8892	+ 3·8878	—2·7	—12·7	I 524·4006
28	29	1·148	I 346·113	+ 1·5589	+ 1·5584	+ 1·5586	+0·5	—12·2	I 525·9592
29	30	1·118	I 347·231	+11·3358	+11·3403	+11·3380	—4·5	—16·7	I 537·2972
30	31	1·047	I 348·278	+ 2·6350	+ 2·6351	+ 2·6350	—0·1	—16·8	I 539·9322
31	32	1·141	I 349·419	+ 4·4048	+ 4·4058	+ 4·4053	—1·0	—17·8	I 544·3375
32	33	1·138	I 350·557	+ 6·3902	+ 6·3934	+ 6·3918	—3·2	—21·0	I 550·7293
33	34	0·890	I 351·447	+ 2·0119	+ 2·0101	+ 2·0110	+1·8	—19·2	I 552·7403
34	35	1·008	I 352·455	+ 8·8384	+ 8·8344	+ 8·8364	+4·0	—15·2	I 561·5767
35	36	1·063	I 353·518	+ 9·9791	+ 9·9786	+ 9·9788	+0·5	—14·7	I 571·5555
36	37	1·542	I 355·060	+ 2·2261	+ 2·2301	+ 2·2281	—4·0	—18·7	I 573·7836

* Mean of two measures.

Results of geodetic spirit leveling between Hugo and Colorado Springs, Colo.—Continued.

Bench marks.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
37	R.R.Sta.(4)	0·329	1 355·389	+ 0·0568		+ 0·0568			1 573·8404
37	38	0·385	1 355·445	− 0·3857	− 0·3886	− 0·3872	+2·9	−15·8	1 573·3964
38	Q	0·038	1 355·483	+ 0·5616	+ 0·5614	+ 0·5615	+0·2	−15·6	1 573·9579
38	39	1·102	1 356·547	+ 2·1313	+ 2·1328	+ 2·1320	−1·5	−17·3	1 575·5284
39	40	1·027	1 357·574	+ 7·7284	+ 7·7256	+ 7·7270	+2·8	−14·5	1 583·2554
40	41	1·139	1 358·713	+ 1·4772	+ 1·4782	+ 1·4777	−1·0	−15·5	1 584·7331
41	42	1·156	1 359·869	+ 4·6817	+ 4·6823	+ 4·6820	−0·6	−16·1	1 589·4151
42	43	1·158	1 361·027	+ 4·8593	+ 4·8601	+ 4·8597	−0·8	−16·9	1 594·2748
43	44	1·140	1 362·167	+ 3·9609	+ 3·9589	+ 3·9599	+2·0	−14·9	1 598·2347
44	45	1·136	1 363·303	+ 2·8283	+ 2·8318	+ 2·8300	−3·5	−18·4	1 601·0647
45	46	1·157	1 364·460	+ 7·2807	+ 7·2811	+ 7·2809	−0·4	−18·8	1 608·3456
46	47	1·100	1 365·560	+ 5·2871	+ 5·2874	+ 5·2872	−0·3	−19·1	1 613·6328
47	48	1·138	1 366·698	+ 4·8901	+ 4·8900	+ 4·8900	+0·1	−19·0	1 618·5228
48	49	1·155	1 367·853	+ 3·8305	+ 3·8324	+ 3·8314	−1·9	−20·9	1 622·3542
49	50	1·167	1 369·020	+ 4·5608	+ 4·5597	+ 4·5602	+1·1	−19·8	1 626·9144
50	51	1·157	1 370·177	+ 5·9177	+ 5·9132	+ 5·9154	+4·5	−15·3	1 632·8298
51	52	1·112	1 371·289	+ 2·7635	+ 2·7597	+ 2·7616	+3·8	−11·5	1 635·5914
52	53	0·577	1 371·866	+ 2·2069	+ 2·2080	+ 2·2074	−1·1	−12·6	1 637·7988
53	R	0·054	1 371·920	+ 0·9906	+ 0·9908	+ 0·9907	−0·2	−12·8	1 638·7895
53	R.R.Sta.(5)	0·186	1 372·052	+ 0·3027		+ 0·3027			1 638·1015
53	54	1·156	1 373·022	+ 7·5392	+ 7·5367	+ 7·5380	+2·5	−10·1	1 645·3368
54	55	1·108	1 374·130	+10·7734	+10·7666	+10·7700	+6·8	− 3·3	1 656·1068
55	56	1·157	1 375·287	+ 7·4048	+ 7·4041	+ 7·4044	+0·7	− 2·6	1 663·5112
56	57	1·154	1 376·441	+ 1·8774	+ 1·8787	+ 1·8780	−1·3	− 3·9	1 665·3892
57	58	1·038	1 377·479	+ 7·8108	+ 7·8099	+ 7·8104	+0·9	− 3·0	1 673·1996
58	59	1·038	1 378·517	− 3·0507	− 3·0513	− 3·0510	+0·6	− 2·4	1 670·1486
59	60	1·150	1 379·667	+ 6·2846	+ 6·2838	+ 6·2842	+0·8	− 1·6	1 676·4328
60	61	1·132	1 380·799	+ 5·6679	+ 5·6713	+ 5·6696	−3·4	− 5·0	1 682·1024
61	62	1·205	1 382·004	+ 9·8830	+ 9·8859	+ 9·8844	−2·9	− 7·9	1 691·9868
62	63	1·152	1 383·156	+ 6·8231	+ 6·8219	+ 6·8225	+1·2	− 6·7	1 698·8093
63	64	1·097	1 384·253	+ 2·5649	+ 2·5594	+ 2·5622	+5·5	− 1·2	1 701·3715
64	65	0·870	1 385·123	+ 3·2909	+ 3·2883	+ 3·2896	+2·6	+ 1·4	1 704·6611
65	66	1·076	1 386·199	+ 6·9823	+ 6·9815	+ 6·9819	+0·8	+ 2·2	1 711·6430
66	67	1·132	1 387·331	+ 3·8405	+ 3·8381	+ 3·8393	+2·4	+ 4·6	1 715·4823
67	68	1·151	1 388·482	+ 7·6341	+ 7·6309	+ 7·6325	+3·2	+ 7·8	1 723·1148
68	S	1·228	1 389·710	+ 7·5789	+ 7·5779	+ 7·5784	+1·0	+ 8·8	1 730·6932
S	R.R.Sta.(6)	0·127	1 389·837	+ 0·5963		+ 0·5963			1 731·2895
S	69	1·150	1 390·860	+ 5·0622	+ 5·0623	+ 5·0622	−0·1	+ 8·7	1 735·7554
69	70	1·148	1 392·008	+ 5·7688	+ 5·7708	+ 5·7698	−2·0	+ 6·7	1 741·5252
70	71	1·076	1 393·084	+ 8·3525	+ 8·3538	+ 8·3532	−1·3	+ 5·4	1 749·8784
71	72	1·149	1 394·233	+ 5·0317	+ 5·0320	+ 5·0318	−0·3	+ 5·1	1 754·9102
72	73	1·076	1 395·309	+10·8637	+10·8650	+10·8644	−1·3	+ 3·8	1 765·7746
73	74	1·058	1 396·367	+ 8·8125	+ 8·8125	+ 8·8125	0·0	+ 3·8	1 774·5871
74	75	1·342	1 397·709	+ 8·1895	+ 8·1880	+ 8·1888	+1·5	+ 5·3	1 782·7759
75	76	1·058	1 398·767	+10·4565	+10·4584	+10·4574	−1·9	+ 3·4	1 793·2333
76	77	1·002	1 399·769	+ 9·6935	+ 9·6920	+ 9·6928	+1·5	+ 4·9	1 802·9261
77	78	1·342	1 401·111	+12·8261	+12·8259	+12·8260	+0·2	+ 5·1	1 815·7521
78	79	1·133	1 402·244	+10·8572	+10·8566	+10·8569	+0·6	+ 5·7	1 826·6090
79	80	1·042	1 403·286	+10·1319	+10·1364	+10·1342	−4·5	+ 1·2	1 836·7432
80	81	1·078	1 404·364	+10·5513	+10·5517	+10·5515	−0·4	+ 0·8	1 847·2947
81	82	0·959	1 405·323	+ 9·0342	+ 9·0358	+ 9·0350	−1·6	− 0·8	1 856·3297

Results of geodetic spirit leveling between Hugo and Colorado Springs, Colo.—Continued.

Bench marks.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
82	T	0·135	1 405·458	+ 1·7713	+ 1·7722	+ 1·7718	— 0·9	— 1·7	1 858·1015
82	R.R.Sta.(7)	0·168	1 405·491	+ 1·6364		+ 1·6364			1 857·9661
82	83	1·122	1 406·445	+ 10·2539	+ 10·2523	+ 10·2531	+ 1·6	+ 0·8	1 866·5828
83	84	1·150	1 407·595	+ 10·8526	+ 10·8492	+ 10·8509	+ 3·4	+ 4·2	1 877·4337
84	85	1·114	1 408·709	+ 10·4214	+ 10·4218	+ 10·4216	— 0·4	+ 3·8	1 887·8553
85	86	1·111	1 409·820	+ 10·1200	+ 10·1206	+ 10·1203	— 0·6	+ 3·2	1 897·9756
86	87	1·150	1 410·970	+ 10·3811	+ 10·3803	+ 10·3807	+ 0·8	+ 4·0	1 908·3563
87	88	1·168	1 412·138	+ 11·2460	+ 11·2433	+ 11·2446	+ 2·7	+ 6·7	1 919·6009
88	89	1·146	1 413·284	+ 10·7050	+ 10·7064	+ 10·7057	— 1·4	+ 5·3	1 930·3066
89	90	1·159	1 414·443	+ 10·8098	+ 10·8107	+ 10·8102	— 0·9	+ 4·4	1 941·1168
90	91	1·149	1 415·592	+ 10·2772	+ 10·2774	+ 10·2773	— 0·2	+ 4·2	1 951·3941
91	92	1·148	1 416·740	+ 11·3069	+ 11·3079	+ 11·3074	— 1·0	+ 3·2	1 962·7015
92	93	1·074	1 417·814	+ 9·7816	+ 9·7820	+ 9·7818	— 0·4	+ 2·8	1 972·4833
93	R.R.Sta.(8)	0·306	1 418·120	+ 0·9973		+ 0·9973			1 973·4806
93	94	0·903	1 418·717	— 4·8493	— 4·8515	— 4·8504	+ 2·2	+ 5·0	1 967·6329
94	95	1·148	1 419·865	— 10·4584	— 10·4644	— 10·4614	+ 6·0	+11·0	1 957·1715
95	96	1·074	1 420·939	— 7·7364	— 7·7349	— 7·7356	— 1·5	+ 9·5	1 949·4359
96	97	1·094	1 422·033	— 6·8774	— 6·8799	— 6·8786	+ 2·5	+12·0	1 942·5573
97	Divide			+190·809	+190·824	+190.8165	—15·0		2 133·374
97	98	1·148	1 423·181	+ 1·3177	+ 1·3164	+ 1.3170	+ 1·3	+13·3	1 943·8743
98	U	0·123	1 423·304	+ 3·9441	+ 3.9448	+ 3·9444	— 0·7	+12·6	1 947·8187
98	R.R.Sta.(9)	0·321	1 423·502	+ 0·4667		+ 0·4667			1 944·3410
98	99	1·150	1 424·331	+ 2·5316	+ 2·5308	+ 2·5312	+ 0·8	+14·1	1 946·4055
99	100	1·149	1 425·480	+ 5·0645	+ 5·0662	+ 5·0654	— 1·7	+12·4	1 951·4709
100	101	1·151	1 426·631	+ 4·1532	+ 4·1515	+ 4·1524	+ 1·7	+14·1	1 955·6233
101	102	0·976	1 427·607	+ 2·8738	+ 2·8734	+ 2·8736	+ 0·4	+14·5	1 958·4969
102	103	1·040	1 428·647	+ 5·1510	+ 5·1512	+ 5·1511	— 0·2	+14·3	1 963·6480
103	104	1·152	1 429·799	+ 1·3872	+ 1·3875	+ 1·3874	— 0·3	+14·0	1 965·0354
104	105	1·112	1 430·911	+ 1·9201	+ 1·9143	+ 1·9172	+ 5·8	+19·8	1 966·9526
105	106	1·168	1 432·079	+ 2·4895	+ 2·4902	+ 2·4898	— 0·7	+19·1	1 969·4424
106	107	1·150	1 433·229	+ 2·9326	+ 2·9299	+ 2·9312	+ 2·7	+21·8	1 972·3736
107	W. Base			+ 68·536	+ 68.534	+ 68·535	+ 2·0	+23·8	2 040.909
107	108	1·122	1 434·351	+ 0·7581	+ 0·7591	+ 0·7586	— 1·0	+20·8	1 973·1322
108	109	1·040	1 435·391	+ 1·2849	+ 1·2868	+ 1·2858	— 1·9	+18·9	1 974·4180
109	110	1·039	1 436·430	— 5·5442	— 5·5449	— 5·5446	+ 0·7	+19·6	1 968·8734
110	111	1·112	1 437·542	— 5·2100	— 5·2100	— 5·2100	0·0	+19·6	1 963·6634
111	V	0·789	1 438·331	— 5·7109	— 5·7110	— 5.7110	+ 0·1	+19·7	1 957·9524
V	R.R.Sta.(10)	0·098	1 438·429	— 1·0116		— 1·0116			1 956·9408
V	W	1·007	1 439·338	— 7·5909*	— 7·5940*	— 7·5924	+ 3.1	+22·8	1 950·3600
V	112	1·007	1 439·338	— 9·4994*	— 9·5033*	— 9·5014	+ 3·9	+23·6	1 948·4510
112	113	1·132	1 440·470	— 6·7667	— 6·7662	— 6·7664	— 0.5	+23·1	1 941·6846
113	114	1·149	1 441·619	— 11·2948	— 11·2977	— 11·2962	+ 2·9	+26·0	1 930·3884
114	115	1·132	1 442·751	— 11·4778*	— 11·4812*	— 11·4795	+ 3·4	+29·4	1 918·9089
115	116	1·148	1 443·899	— 10·6818	— 10·6832	— 10·6825	+ 1·4	+30·8	1 908·2264
116	117	1·130	1 445·029	— 10·4099	— 10·4116	— 10·4108	+ 1·7	+32·5	1 897·8156
117	118	1·134	1 446·163	— 11·2897	— 11·2895	— 11·2896	— 0·2	+32·3	1 886·5260
118	119	1·148	1 447·311	— 10·9066	— 10·9052	— 10·9059	— 1·4	+30·9	1 875·6201

* Mean of two measures.

Results of geodetic spirit leveling between Hugo and Colorado Springs, Colo.—Continued.

Bench marks.		Distance between successive marks.	Distance from initial mark K_3.	Difference in height between marks.			Discrepancy.		Height above K_3 at St. Louis.
From	To			Line, rod P.	Line, rod Q.	Mean.	Partial P—Q.	Total accumulated.	
		km.	*km.*	*m.*	*m.*	*m.*	*mm.*	*mm.*	*m.*
119	120	1·126	1 448·437	−10·1489	−10·1463	−10·1476	−2·6	+28.3	1 865·4725
120	121	1·168	1 449·605	−10·7360	−10·7399	−10·7380	+3·9	+32·2	1 854·7345
121	122	1·150	1 450·755	−10·9798	−10·9814	−10·9806	+1·6	+33·8	1 843·7539
122	123	1·129	1 451·884	−10·1570	−10·1529	−10·1550	−4·1	+29·7	1 833·5989
123	124	0·346	1 452·230	− 3·0526	− 3·0532	− 3·0529	+0·6	+30·3	1 830·5460
124	X	0·041	1 452·271	+ 0·5101	+ 0·5102	+ 0·5102	−0·1	+30·2	1 831·0562
124	125	0·972	1 453·202	− 7·4823	− 7·4805	− 7·4814	−1·8	+28·4	1 823·0646
125	126	1·153	1 454·355	*−10·7027	*−10·7047	−10·7037	+2·0	+30·4	1 812·3609
126	127	1·057	1 455·412	−10·5108	−10·5135	−10·5122	+2·7	+33·1	1 801·8487
127	128	1·021	1 456·433	− 9·0697	− 9·0669	− 9·0683	−2·8	+30·3	1 792·7804
128	129	1·148	1 457·581	− 7·8350	− 7·8338	− 7·8344	−1·2	+29·1	1 784·9460
129	130	1·150	1 458·731	−10·1648	−10·1695	−10·1672	+4·7	+33·8	1 774·7788
130	131	1·038	1 459·769	−10·7058	−10·7069	−10·7064	+1·1	+34·9	1 764·0724
131	132	1·093	1 460·862	−10·1680	−10·1696	−10·1688	+1·6	+36·5	1 753·9036
132	133	1·150	1 462·012	− 9·6210	− 9·6218	− 9·6214	+0·8	+37·3	1 744·2822
133	134	0·920	1 462·932	− 7·8389	− 7·8396	− 7·8392	+0·7	+38·0	1 736·4439
134	Y	0·037	1 462·969	+ 1·5257	+ 1·5255	+ 1·5256	+0·2	+38·2	1 737·9686
134	135	1·003	1 463·935	− 8·5867	− 8·5907	− 8·5887	+4·0	+42·0	1 727·8543
135	Z	0·350	1 464·285	− 0·6937	− 0·6952	− 0·6944	+1·5	+43·5	1 727·1599
Z	R.R.Sta.(11)	0·122	1 464·407	− 1·8909		− 1·8909			1 725·2690
Z	R.R.Sta.(12)	. .		− 2·0507		− 2·0507			1 725·1092
Z	138	1·010	1 465·295	− 8·8079	− 8·8054	− 8·8066	−2·5	+41·0	1 718·3533
138	137	1·031	1 466·326	*−10·1348	*−10·1340	−10·1344	−0·8	+40·2	1 708·2189
137	A_1	1·117	1 467·443	− 9·2376	− 9·2345	− 9·2360	−3·1	+37·1	1 698·9829
A_1	City B. M.	0·484	1 468·483	− 2·4113	− 2·4132	− 2·4122	+1·9	+39·0	1 696·5707
A_1	R.R.Sta.(13)	0·505	1 468·504	− 2·9255		− 2·9255			1 696·0574
A_1	136	0·556	1 467·999	− 3·9138	− 3·9150	− 3·9144	+1·2	+38·3	1 695·0685
136	B_1	0·034	1 468·033	+ 1·8384	+ 1·8386	+ 1·8385	−0·2	+38·1	1 696·9070
136	N. Mast, top of black band.			+ 2·154					1 697·222
136	S. Mast, top of black band.			+ 1·841					1 696·909
136	Nail established by Eimbeck.			+ 1·282					1 696·350
136	Reference B. M. established by Eimbeck.			+ 2·379					1 697·447
136	R. R. Sta. (14) top of rail in front of depot.			+ 1·096					1 696·164
136	V. C. Post, vertical circle post used by Eimbeck.			+ 0·886					1 695·954

* Mean of two measures.

Reference B. M.—This bench mark is center of sill of west window in south face of Denver and Rio Grande Railroad passenger station, Colorado Springs, El Paso County, Colo. The upper part of front of sill has a sloping face and the bench mark is where this sloping face intersects the perpendicular front of the sill.

V. C. Post B. M.—This is the top of a wooden post, 8 by 8 inches in cross section, and about 4 feet above surface of ground. It is 1 meter west of "South Mast" bench

mark, in Colorado Springs, El Paso County, Colo. The post was used as a support for vertical circle in 1895, when vertical angles were measured on Pikes Peak and surrounding points by Assistant Eimbeck.

B. M. I.—This bench mark was established at Hugo, Colo., in 1897, as a reference bench mark. Having served its purpose it was removed in April, 1898, for use elsewhere. No mark left.

B. M. J.—This bench mark was established at Hugo, Colo., in 1897. For description see "Descriptions of bench marks," Colorado, 1897, preceding appendix.

B. M. K.—This bench mark was established at Hugo, Colo., in 1897. For description see "Descriptions of bench marks," Colorado, 1897, preceding appendix.

B. M. L.—This bench mark is the bottom of a square hole cut in the top of the stone wing wall to the railroad culvert nearly opposite milepost 544. The bench mark is south of the track and near the western edge of the wall on the stone forming the corner. The following letters were cut: U. S. ■ B. M.

B. M. M.—This bench mark is the intersection of two lines (forming a cross at its center) cut in end of a copper bolt, leaded in the east (front) wall of the stone pump house to the railroad water tank at Lake, Lincoln County, Colo. The bolt is in the fourth course above the ground and in the third stone from the southeast corner of the building.

B. M. N.—This bench mark is the bottom of a square hole cut in the top of a granite post at Limon Station, Lincoln County, Colo. The post is 4½ feet long, rough, except at the top, which is dressed to 6 by 6 inches, 6 inches below the top, and it is buried 4 feet in the ground. It is situated in the northeast corner (near front fence) of the yard to the public school at Limon. The following letters are cut in the top of the post. U. S. ■ B. M.

B. M. O.—This bench mark is the bottom of a square offset cut in the sloping top to the artificial stone foundation under one of the supports to the Chicago, Rock Island and Pacific Railroad water tank at Limon Station, Lincoln County, Colo. The mark is on the foundation under the north one of the two western supports (nearest the track), is south of the support and near the southeast corner of the stone.

B. M. P.—This bench mark is the bottom of a square offset cut in the sloping top to the artificial stone foundation under one of the supports to the Chicago, Rock Island and Pacific Railroad water tank at Limon, Lincoln County, Colo. The mark is on the foundation under the northwest one of the central group of supports (4) and is near the northwest corner of the stone.

B. M. Q.—This bench mark is a limestone post 4 feet long, rough, except at the top, which is dressed to 6 by 6 inches, 6 inches below the top, buried 46 inches in the ground, in the northeast corner of the yard to the railroad section house at Resolis, Elbert County, Colo. A square hole (1 by 1 inch) is cut in the top of the post and the bottom of this hole is the bench mark. The top of the post is lettered as follows: U. S. ■ B. M.

B. M. R.—A square offset was cut in the sloping surface of the stone under one of the wooden posts supporting the railroad water tank at Mattison, Elbert County, Colo.,

for this bench mark. The stone is under the north one of the two western supports under the tank, and is at the northeast corner of the stone. The following letters were cut around the mark. U. S. and the bottom of the offset is the bench mark. B. M.

B. M. S.—This bench mark is the bottom of a square hole cut in the top of a limestone post buried in the southeast corner of the yard to the railroad section house at Ramah, El Paso County, Colo. The post is 4 feet long, rough, except at the top, which is dressed to 6 by 6 inches, 6 inches below the top, and it is buried 44 inches in the ground. The top of the post is lettered as follows: U. S. B.M.

B. M. T.—This bench mark is the bottom of a square offset cut in the upper surface of the stone foundation supporting one of the wooden uprights under the railroad water tank at Calhan, El Paso County, Colo. The bench mark is on the stone under the east one of the two uprights at the north side of the tank, and it is near the northwest corner of the stone. The following letters were cut around the bench mark: U. S. B.M.

B. M. U.—This bench mark is the intersection of two lines cut in the end of a copper bolt leaded in the stone foundation to the Russel Gates Mercantile Company's store at Peyton, El Paso County, Colo. The bolt is in the upper stone of the foundation, on the south side, at the southeast corner of the building, at the west end of the steps leading to the front porch. The lines intersect, forming a cross, near the center of the end of the bolt.

B. M. V.—This bench mark is the bottom of a square offset cut in the top of the stone under one of the supports to the Chicago, Rock Island and Pacific Railroad water tank at Falcon, El Paso County, Colo. The bench mark is on the stone under the east one of the two supports under the south side of the tank, and it is at the southeast corner of the stone. The following letters were cut around the bench mark: U. S. B.M.

B. M. W.—This bench mark is the bottom of a square hole cut in the top of one of the stones forming the abutment to the Union Pacific, Denver and Gulf Railway bridge over the Chicago, Rock Island and Pacific Railroad at Falcon, El Paso County, Colo. The bench mark is on the west abutment, at the north end, on top of the stone forming the third course above the Chicago, Rock Island and Pacific Railroad track and the first of the series of steps or offsets leading to the top of the abutment. The following letters were cut: U. S. B.M

B. M. X.—This bench mark is the bottom of a square offset cut in the top of one of the artificial stones under the supports to the railroad water tank at Elsmere, El Paso County, Colo. The bench mark is on the stone under the south one of the two supports under the east side of the tank, and it is at the southwest corner of the stone. The following letters were cut around the bench mark: U. S. B.M. The stone crumbles easily and both mark and letters are roughly cut.

B. M. Y.—This bench mark is the bottom of a square hole cut in the upper surface of the stone forming the first step or offset in the stone abutment to the Atchison, Topeka and Sante Fe Railway bridge over the Chicago, Rock Island and Pacific Rail-

way, near Roswell, El Paso County, Colo. The mark is on the abutment north of the Chicago, Rock Island and Pacific Railway track at the east end. The following letters were cut: U. S. ■ B. M.

B. M. Z.—This bench mark is the bottom of a square hole cut in the upper surface of a stone window sill to a window in the roundhouse (stone) of the Chicago, Rock Island and Pacific Railway at Roswell, El Paso County, Colo. There is one window and a door in the south end of the roundhouse, and the bench mark is cut in the sill to this window. The following letters were cut: U. S. ■ B. M.

B. M. A_1.—A square hole was cut in the top of the stone abutment to the Denver and Rio Grande Railroad bridge over Monument Creek, about 800 meters north of the railroad station at Colorado Springs, El Paso County, Colo., for this bench mark. The bench mark is west of the track, on the north abutment, and on the second stone from the end where the offsets begin. The bottom of the square hole is the bench mark. The following letters were cut: U. S. ■ B. M.

B. M. B_1.—This bench mark is the intersection of two lines (forming a cross near the center) cut in the end of a copper bolt leaded in the wall of the Denver and Rio Grande passenger depot at Colorado Springs, El Paso County, Colo. The bolt is in the third course above the platform and in the second stone from the southwest corner of the building, in the east wall.

City B. M.—This bench mark is the surface of the stone door sill of the north door (west side) of the Denver and Rio Grande Railroad passenger station at Colorado Springs, El Paso County, Colo. It is near the front edge and the north end of the sill. There is no mark and its location was pointed out by the city engineer. Its elevation has been determined by the railroad company.

North mast B. M.—This bench mark is on an unusually tall telegraph pole. It is about 20 inches in diameter and is the nearest to the Denver and Rio Grande Railroad station of two such poles which are on the railway right of way. This pole is about 34·8 meters from the middle of the west window in the south face of the passenger station. The bench mark is the top of the black band about the base of the pole.

South mast B. M.—This bench mark is an unusually large (in height and girth) telegraph pole near the passenger station of the Denver and Rio Grande Railway in Colorado Springs, El Paso County, Colo. There are two of these poles along the railway right of way—south mast is the southern one; it is also the most western pole of a long line of similar poles extending from the railroad line to the central telegraph office in Colorado Springs. It is about 46 meters south of "north mast bench mark," and 80.2 meters distant from the middle of the west window in south face of railway station. South mast is about 20 inches in diameter. The bench mark is the top of the black band about the base of the pole.

Nail B. M.—Nail bench mark is the head of a nail which was driven in "south mast" on a level with the center of the vertical circle when mounted near Denver and Rio Grande Railway passenger depot at time observations for vertical angles on Pikes Peak and surrounding points were made, in 1895.

The elevations of the following railroad stations and crossings were determined by using the top of the rail in front of the stations:

1. Bagdad.
2. Lake.
3. Limon, crossing of Union Pacific and Chicago, Rock Island and Pacific railways.
4. Resolis.
5. Mattison.
6. Ramah.
7. Calhan.
8. Tip Top, top of rail at south end of switch.
9. Peyton.
10. Falcon.
11. Roswell (Denver and Rio Grande track).
12. Roswell (Chicago, Rock Island and Pacific track).
13. Colorado Springs, in line with south end of Denver and Rio Grande passenger depot (Eimbeck).
14. Colorado Springs, in front of Denver and Rio Grande passenger depot.

APPENDIX No. 4. 1897-98.

INQUIRY INTO THE VALUE OF THE PERUVIAN ARC OF 1736-1743.

Report by C. A. SCHOTT, Assistant.

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APPENDIX No. 41. 897-98.

INQUIRY INTO THE RELATIVE VALUE AND NEED OF A CHECK OF THE PERUVIAN ARC OF 1736-1743.

Report by C. A. SCHOTT, *Assistant.*

This arc of the meridian has for the last century and a half remained unquestioned as to its value and has formed an integral part of the collection of later and of modern measures, and has been treated on a par value with the latter. With the advances made, theoretically and practically, in geodesy and its instrumental appliances, it is not surprising that the measure should have been scrutinized and compared with similar work in our time.* The Peruvian arc by virtue of its equatorial position still exerts a considerable influence on the resulting figure of the earth, though less now than formerly, in consequence of the increased number of measures available. From the modern standpoint we find it rather short (amplitude but 3° 7′), to be dependent upon but two astronomic latitudes in a region where great local deflections of the vertical must be expected, and lastly we notice a great uncertainty in its reduction to the sea level. The question then may be asked, "Is it desirable to remedy these defects either by remeasures or by an extension of the arc?" Respecting the latter it would appear that the academicians of the past century had utilized the whole length of the valley, but the topographical features of the terminal regions are so imperfectly known that a reconnoissance would be necessary to make sure of it. Difficulties must be expected in recovering the cairns marking the triangulation stations, but if found, half a dozen astronomic latitudes could readily be supplied to relieve to some extent any injurious effect of local deflections. The principal defect of the arc lies in the uncertainty of its reduction to the sea level, the altitude being made dependent on a barometric height and on vertical angles, the latter subject to the unknown local attraction of the Andes in the plane of their measure. The uncertainty in height has been estimated at 100 meters, besides there is the rise of the equipotential surface of the sea level when produced inland below the Andes, which should be taken into account, so as to reduce the triangulation to the geometric level instead of to what may be called the physical level, to which latter the vertical angle measures necessarily conform more or less closely.

*Coast Survey Report for 1877, Appendix No. 6, p. 95. Coast and Geodetic Survey Report for 1889, Appendix No. 18, pp. 494-495.

Ibid, Appendix No. 7, pp. 199-208.

Considering that the triangulation is not without some blemish notwithstanding the accord of its two base lines, that the arc covers a region of great deflections of the vertical, and lastly that the uncertainty in the *reduction to the sea level* seems even now difficult to overcome, the value of this arc, as compared with modern work, appears in a less favorable light and properly raises the question of advisability of strengthening or enlarging it. While not recommending either, an entirely new measure in a better locality would be preferable if one can be found. The tropical forests extending over the whole equatorial region of South America present insuperable difficulties to any site for an arc, yet some inquiry would be desirable respecting feasibility for measure of two localities, viz: One, the region of the western flank of the Andes, following the coast foothills between Esmeraldas ($\varphi = +1°$), Ecuador, and Chiclayo ($\varphi = -7°$) Peru, and the other in British Guiana, namely, the valley of the Essequibo, though wholly north of the equator.

That the Peruvian arc shows but small corrections (less than 1″) to its terminal latitudes can not be taken as a proof of its perfection of measure, in fact, in view of what has been said this may be rather accidental, at least within certain limits.

Pending some further inquiry to be made as to sites I have not attempted to submit an estimate of the cost and time required for a new survey in the vicinity of this historic arc.

APPENDIX No. 5. 1897-98.

PHYSICAL OBSERVATIONS MADE IN CONNECTION WITH THE PRIBILOF ISLANDS EXPEDITION OF 1897.

Report by G. R. PUTNAM, Assistant.

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APPENDIX No. 5. 1897-98.

PHYSICAL OBSERVATIONS MADE IN CONNECTION WITH THE PRIBILOF ISLANDS SURVEY OF 1897.

Report by G. R. PUTNAM, *Assistant.*

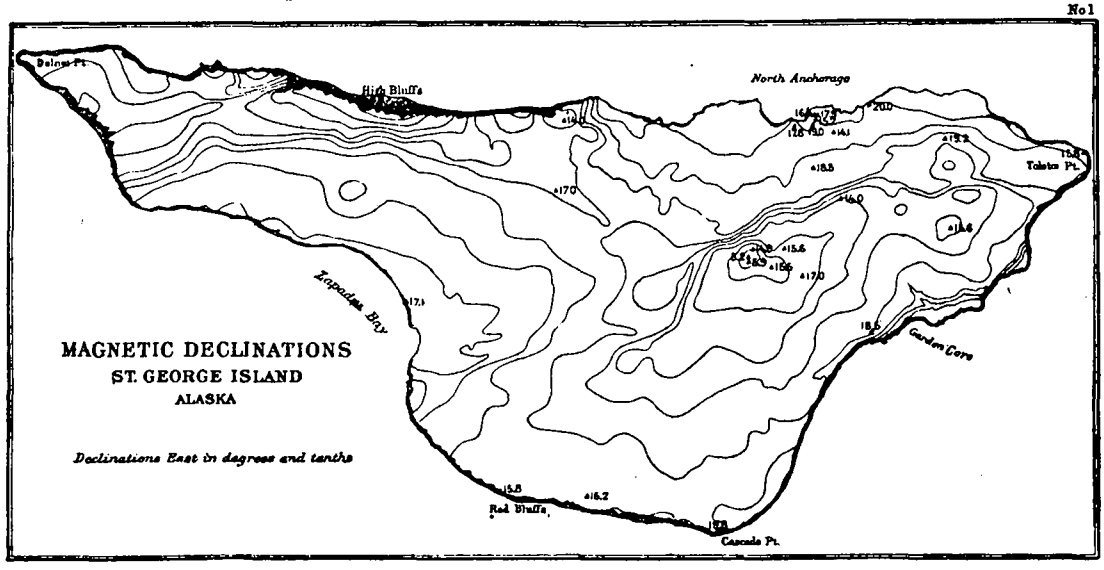
I. MAGNETIC IRREGULARITIES ON ST. GEORGE ISLAND.

During the progress of the topographical work on St. Paul Island it was noticed that there was considerable difference in the magnetic declination in various parts of the island. Some special observations were made on St. George Island when opportunity offered, to ascertain the extent of the irregularities in declination there. Regular observations of all the magnetic elements were made at a base station on each island, and the declination alone was determined at 24 additional points on St. George. About half of these points were triangulation stations, at which the true azimuth of some distant signal used as a mark was known from the triangulation. At the balance of the magnetic stations the true azimuths were derived from additional angles measured to and from triangulation stations. The observations were made with a magnetometer (No. 19) carried from point to point, a single reading being made on the magnet and on the mark. Observations were also made each day at the base station so as to detect any unusual diurnal disturbance. All observations were reduced to the mean of the day.

The Pribilof Islands are of volcanic origin. The surface of St. George is covered with lava rock, scoria, and cinders. Small pieces of these materials held near the magnet disturbed its position by as much as one-fourth of a degree, indicating that they are all more or less magnetic. The table gives a summary of the observed declinations, the positions, and dates. The points of observation were distributed over the eastern two-thirds of the island. The range in declination was nearly 15°, from 5° 14′ east to 20° 03′ east, and it seems to be quite irregularly distributed over the island. The disturbances appear to be rather local in character; on the summit of Ulakiyá, the high central hill of the island, over 940 feet in elevation, the declination at the two stations was 5°·2 east, and 5°·9 east (stations Nos. 6 and No. 25), while at No. 24, 728 feet distant, it was 14°·9 east, and at No. 22, 2 142 feet distant, it was 15°·6 east, and at No. 23, 1 450 feet distant, it was 15°·5 east. Near a scoria bank north of the village church, at three stations within 160 feet of each other, the declinations were 16°·4 east, 17°·9 east, and

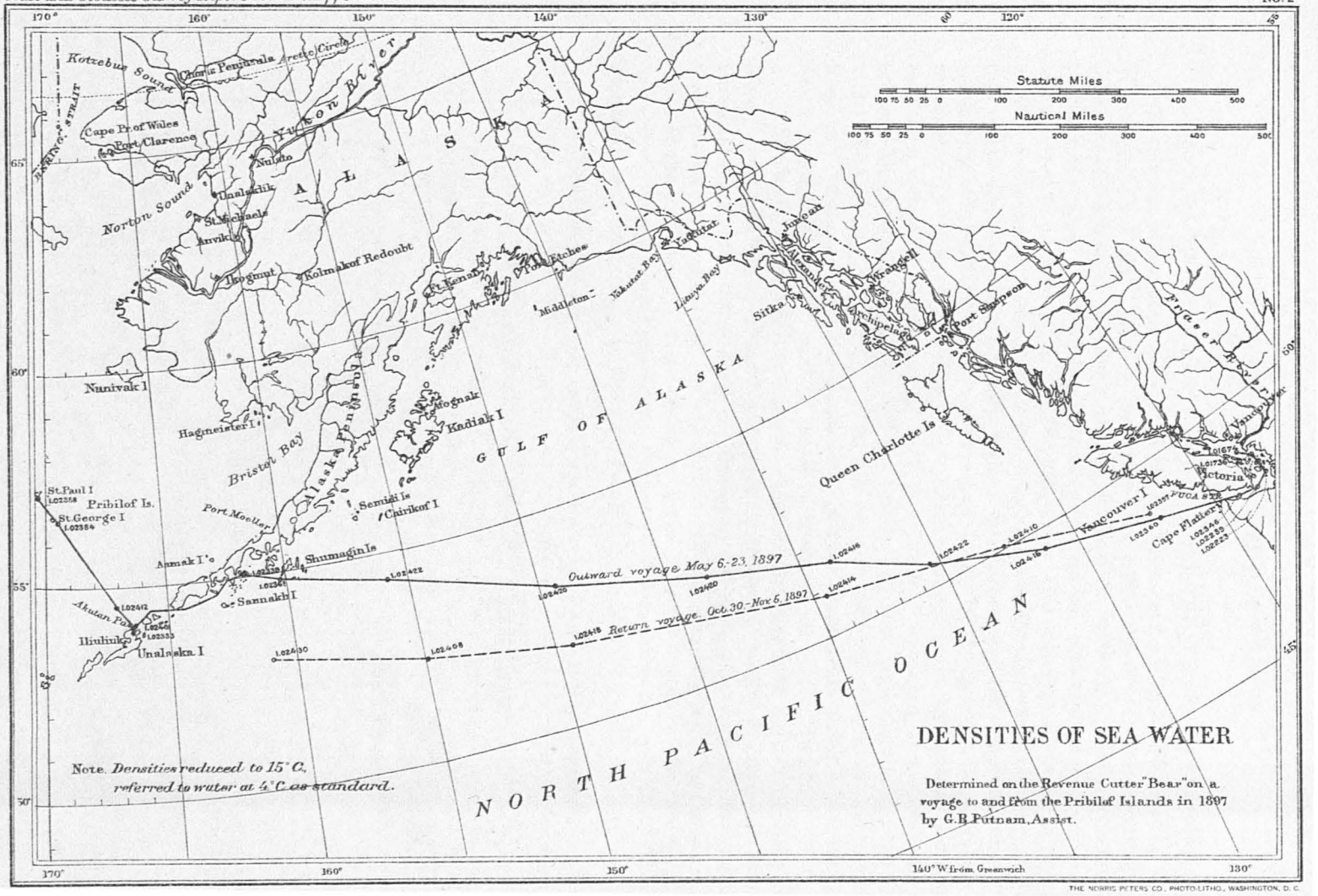
15°·2 east (Nos. 15, 16, and 17). At the base station on St. George (No. 1), the determinations of the magnetic elements gave the following mean results:

Declination, Aug. 29–Sept. 5, 1897, 19° 02′·7 east of north.
Horizontal force, 0·1877 dynes.
Total force, 0·5462 dynes.
Dip, 69° 54′·1 north.



Summary of magnetic declinations observed on St. George Island.

Number.	Station.	Latitude north.	Longitude west.	Date.	Declination E. of N.
		° ′	° ′	1897.	° ′
1	Magnetic station	56 36·2	169 32·5	Aug. and Sept.	19 03
2	East Base	36·2	32·8	Sept. 29	17 50
3	Meridian Mark	35·7	32·5	" 29	18 28
4	Cemetery Hill	36·1	32·1	" 29	14 06
5	Ridge Cairn	35·4	32·0	Oct. 5	14 01
6	Ulakiyá	34·8	33·7	" 5	5 14
7	Little Ulakiyá	34·6	32·7	" 5	16 59
8	Garden	34·1	31·5	" 5	18 30
9	Cascade	32·1	34·2	" 5	19 48
10	West Cairn	32·4	36·6	" 5	16 12
11	Red Bluff	32·5	38·1	" 5	15 51
12	Zapadni House	34·4	39·8	" 5	17 04
13	High Cairn	35·5	37·1	" 5	16 59
14	First Bluff	36·2	37·0	" 5	14 01
15	North of village church	36·3	32·5	" 9	16 24
16	East of No. 15, 50 metres	36·3	32·4	" 9	17 54
17	Southwest of No. 16, 20 metres	36·3	32·4	" 9	15 13
18	Northeast	36·4	31·5	" 9	20 03
19	Gull Hill Cross	36·0	30·2	" 14	19 11
20	Tolstoi	35·9	27·7	" 14	15 51
21	South Sealion	35·1	30·0	" 14	15 39
22	East Flag	34·9	33·0	" 14	15 38
23	Middle Cairn	34·7	33·3	" 14	15 27
24	Red Flag.	34·9	33·6	" 14	14 55
25	South Cairn	34·8	33·7	" 14	5 54



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II. SEA WATER DENSITIES IN THE NORTHEAST PACIFIC AND BERING SEA.

Specimens of sea water were collected on the voyage out and back between Seattle, Wash., and the Pribilof Islands, on the revenue cutter *Bear*, and determinations of the densities of these specimens were made at convenient intervals. The results are given in the table showing the date of observation, position, and density reduced to 15° C., and referred to pure water at 4° C. as standard. The positions are from the log of the *Bear* or from charts. At sea the specimens were usually taken at noon, when the position of the ship was computed either from observation or from dead reckoning. The navigating officers, Lieut. C. S. Cochran and Lieut. B. H. Camden, furnished the data required. The densities were determined with salinometers or hydrometer floats, which had been standardized in the Office of Weights and Measures, and corrections were applied for thermometer errors and graduation errors of salinometers, and the results were reduced to 15° C., correcting for the temperature effect both on the salinometer itself and the water. (The reduction was in accordance with Bulletin No. 18, United States Coast and Geodetic Survey, prepared by Assistant O. H. Tittmán.)

The lowest density observed was in the Gulf of Georgia off the mouth of the Fraser River, and from thence there was a steady increase of density through the Straits of Fuca until well out in the Pacific. Thence the density was uniform until the Aleutian Islands were approached, where it diminished, increasing again in the Bering Sea north of those islands and diminishing near the Pribilof Islands. The observations on the return voyage were made about five months later, and mostly farther south, and specimens were taken only in the open Pacific.

Summary of determinations of sea-water densities (surface specimens).

No.	Date, 1897.	Local mean time.	Latitude north.	Longitude west.	Density at 15° C. referred to water at 4° C.	Locality.
			° ′	° ′		
1	May 6	11 50 A. M.	48 24	122 47	1·02223	Washington Sound.
2	" 6	3 50 P. M.	48 48	122 51	1·01736	Gulf of Georgia.
3	" 6	7 46 P. M.	49 00	123 21	1·01674	" " "
4	" 10	2 00 P. M.	48 15	123 23	1·02289	Straits of Fuca.
5	" 10	7 45 P. M.	48 18	124 04	1·02346	" " "
6	" 11	Noon.	48 49	126 58	1·02360	Pacific Ocean.
7	" 12	"	49 33	131 16	1·02416	" "
8	" 13	"	50 30	135 22	1·02422	" "
9	" 14	"	51 38	138 48	1·02416	" "
10	" 15	"	52 27	143 29	1·02420	" "
11	" 16	"	53 25	149 23	1·02420	" "
12	" 17	"	54 25	155 48	1·02422	" "
13	" 18	8 00 A. M.	54 52	160 12	1·02368	Near Aleutian Ids.
14	" 19	Noon.	55 07	161 50	1·02339	Among " "
15	" 20	8 00 A. M.	54 02	166 25	1·02401	Near Unalaska.
16	" 21	3 00 P. M.	53 53	166 32	1·02333	Dutch Harbor.
17	" 22	8 00 A. M.	54 34	167 08	1·02412	Bering Sea.
18	" 23	9 00 A. M.	56 33	169 27	1·02384	" "
19	" 23	3 00 P. M.	57 05	170 20	1·02358	" "
20	Oct. 30	Noon.	53 03	160 59	1·02430	Pacific Ocean.
21	" 31	"	52 23	154 56	1·02408	" "
22	Nov. 1	"	51 46	149 18	1·02418	" "
23	" 3	"	50 56	138 30	1·02414	" "
24	" 4	"	50 05	132 37	1·02410	" "
25	" 5	"	49 01	127 20	1·02397	" "

III. DETERMINATION OF THE FORCE OF GRAVITY ON ST. PAUL ISLAND, BERING SEA.

Advantage was taken of the fact that time observations must necessarily be made at St. Paul Island in connection with the longitude determination to make also at this point a relative determination of the force of gravity with the half-second pendulums. The station was near the center of the village, immediately north of the company house, and its position as determined was latitude 57° 07′ 17″ N., longitude 170° 16′ 37″ W. of Greenwich; elevation 10 metres above sea level. The pendulum case was mounted on a large rock, bedded in cement; the measured flexure was 7 microns at the knife edge, this large amount being due to the loose character of the surface material, consisting principally of broken scoria. Beneath this was probably more solid volcanic rock. Owing to the pecular climatic conditions, time observations could only be obtained at very infrequent intervals. On this account, and also because the observer could only devote to these observations time that could not be utilized in the general survey work, no attempt was made to make the observations continuously between two time determinations, as has been the practice. Each pendulum was swung on four different days, and the mean chronometer rate applied as derived from two time determinations made by Assistant Morse. The mean-time chronometer, used with the flash apparatus, was compared before and after each set of observations with the other eleven chronometers which were used for the longitude determination. The rates adopted were tne means of the rates derived from the twelve chronometers. Otherwise the methods of observation used in recent work were followed.

The periods of these pendulums were determined at Washington in October, 1896, and again in January, 1898. The table gives the details of the latter observations and those on St. Paul Island. Those for October, 1896, are given in Appendix No. 6, report for 1897.

The following is a summary of the corrected periods:

	Pendulum A4.	Pendulum A5.	Pendulum A6.	Mean of three pendulums.
	s.	s.	s.	s.
Washington, D. C., Oct. 15-17, 1896	·5008392	·5006665	·5006303	·5007120
" " Jan. 23-25, 1898	8396	6685	6290	7124
St. Paul Island, Alaska, May 29, June 20, 1897	4280	2550	2184	3005

The remarkable constancy of these pendulums is again shown by this last determination at Washington, the mean period of this station differing but ^{s}·0000004 from that of a year and a half previous, and but ^{s}·0000002 from the determination in April, 1894, nearly four years before, since which time they have been transported great distances and used under a variety of conditions. These differences are as likely due to uncertainities of observation as to any real change in the periods. Probably no other pendulums have shown a greater constancy of period.

Using the previously adopted value for the base station at Washington, $g = 980{\cdot}098$ dynes or centimetres, and the mean of the periods at Washington, the value of g at St. Paul Island is found to be 981·712 dynes, from the relation

$$g = \left(\frac{\text{period at Washington}}{\text{period at St. Paul}}\right)^2 g \text{ at Washington.}$$

The reduction to sea level is +·002 by Bouguer's formula or +·003 using the reduction for elevation only, giving the value at sea level $g = 981{\cdot}714$ or $981{\cdot}715$. according to the method of reduction.*

Pendulum observations and reductions.

ST. PAUL ISLAND, ALASKA.

Swing No.	Pendulum.	Position.	Knife edge.	Date.	Coincidence interval.	Total arc. Initial.	Total arc. Final.	Temperature.	Pressure.	Period uncorrected.	Corrections (7th decimal place). Arc.	Temp.	Pressure.	Rate.	Flexure.	Period corrected.
				1897.	*s.*	′	′	°*C.*	*mm.*	*s.*						*s.*
7	A4	R	II	June 12	254·04	53	10	4·55	64	·4990179	−6	+436	−4	+13700	−46	·5004259
6	A4	D	II	" 6	259·65	51	20	9·41	58	90390	−8	+233	+2	+13718	−46	4289
12	A4	D	II	" 20	258·33	56	22	7·75	63	90341	−9	+303	−3	+13706	−46	4292
2	A5	R	I	May 30	215·17	53	21	3·29	62	88403	−8	+489	−2	+13719	−46	2555
8	A5	R	I	June 13	215·29	50	22	3·43	61	88411	−8	+483	−1	+13695	−46	2534
5	A5	D	I	" 6	217·65	53	21	6·32	62	88540	−8	+362	−2	+13713	−46	2559
10	A5	D	I	" 19	215·77	51	23	3·81	61	88441	−8	+467	−1	+13701	−46	2554
3	A6	R	I	May 30	208·62	53	21	3·43	66	88045	−8	+483	−6	+13718	−46	2186
9	A6	R	I	June 13	209·45	51	22	3·91	60	88092	−8	+463	0	+13694	−46	2195
4	A6	D	I	" 5	208·78	55	20	4·65	60	88054	−9	+432	0	+13712	−46	2143
11	A6	D	I	" 20	210·77	52	20	5·40	64	88167	−8	+401	−4	+13700	−46	2210

WASHINGTON, D. C.

				1898.												
1	A4	R	II	Jan. 23	307·69	55	17	12·00	53	·5008138	−8	+126	+7	+148	−6	·5008405
2	A4	D	II	" 24	308·07	56	22	12·18	52	8128	−9	+118	+8	+148	−6	8387
3	A5	R	I	" 24	388·77	52	22	12·65	57	6439	−9	+ 98	+3	+148	−6	6673
4	A5	D	I	" 24	390·19	53	19	12·03	56	6415	−8	+124	+4	+168	−6	6697
5	A6	R	I	" 25	418·76	52	22	11·46	58	5977	−9	+148	+2	+168	−6	6280
6	A6	D	I	" 25	418·43	52	22	11·26	59	5982	−9	+157	+1	+168	−6	6293
7	A6	D	I	" 25	417·74	52	17	11·13	59	5992	−8	+162	+1	+168	−6	6309

* Pendulum observations were made at St. Paul Island in 1891 at almost the same identical spot. The result then obtained was involved in some uncertainty, however, as no time observations could be obtained. As the apparatus was then mounted on a wooden block the flexure correction might also easily account for the difference in the two results.

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APPENDIX No. 6. 1897-98.

PROCEEDINGS OF THE INTERNATIONAL GEODETIC ASSOCIATION CONFERENCE AND GEODETIC OPERATIONS IN THE UNITED STATES.

Report by E. D. PRESTON, Assistant,
Executive Officer, Coast and Geodetic Survey,
DELEGATE ON THE PART OF THE UNITED STATES.

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APPENDIX No. 6. 1897-98.

REPORT ON THE PROCEEDINGS OF THE INTERNATIONAL GEODETIC ASSOCIATION CONFERENCE AT STUTTGART, GERMANY, OCTOBER 3d TO 12th, 1898, AND ON GEODETIC OPERATIONS IN THE UNITED STATES.

Report by E. D. PRESTON, *Assistant, Executive Officer Coast and Geodetic Survey, Delegate on the part of the United States.*

SIR: I have the honor to present the following report on the meeting of the International Geodetic Association at Stuttgart, at which I was present as delegate on the part of the United States in obedience to your instructions of July 29, 1898. Mention is also made of certain institutions of interest visited on the way at Berlin, Potsdam, Paris, Sevres, and Southampton. I left Washington on September 19 and returned on October 29.

The International Geodetic Association is an organization for the measurement of the earth. Conferences are held every few years to consider projects, formulate methods, and direct the execution of work by which the aforesaid object may be attained. Although the name as used in English does not necessarily imply the determination of the earth's size and shape, this is, nevertheless, the governing idea, and the association follows loyally the lines marked out by the society of which it is the legitimate offspring, the German Gradmessung of sixty years ago. Now that the association is firmly established on a permanent and international basis, it is worth while to seek the origin and trace its interesting course of development. In 1829 the Russian Government expressed a desire to connect their triangulation with that of Prussia. Thus stimulated the German work was given greater expansion, and in 1838 the work of Bessel and Baeyer, "Gradmessung in Ostpreussen," appeared. This developed into the "Küstenvermessung," and the work was continued under that name. In 1861 Baeyer sounded the keynote of the scientific spirit of the age when he proposed cooperation with other nations and laid the foundation for what was called the middle European "Gradmessung." These limits held until 1867, when the word "middle" was dropped and the association was enlarged to comprise representatives from all Europe. The extension seemed for a time to satisfy the energy everywhere manifest, but the fact soon became apparent that the work fell short of its full usefulness in that its bounds of activity were still too

restricted. Perhaps the gigantic strides made by America and Australia in mental and material development had something to do with the change. At any rate, in 1886 the name was again changed, this time from the European "Gradmessung" to the international "Erdmessung." A convention was drawn up for ten years. The powers of the league were considerably enlarged, old fetters were broken, and for the first time the association reached its highest plane of usefulness and began to direct a homogeneous plan for the measurement of the earth.

The twelfth general conference was held at Stuttgart from the 3d to the 12th of October, 1898. Fifteen countries of the 19 composing the association were represented. Of the 37 delegates present, 15 came from Germany, 5 from France, 3 from Italy, 2 from Switzerland, 2 from Japan, and 1 each from Belgium, Great Britain, the Netherlands, Austria-Hungary, Russia, Sweden, Spain, Mexico, and the United States. Each Government has the privilege of sending as many delegates as it pleases, but in voting on questions coming before the conference for action but one ballot is allowed to each country. Besides the delegates, 18 invited guests appeared, making a total of 55 persons present at the meetings. By far the greater part of the time was naturally taken up in reading the regular reports by the delegates on the geodetic work accomplished in their respective countries since the last general conference. Of special interest was the contribution by Professor Helmert on the activity of the central bureau of the association at Potsdam. The following work was described:

I. The systematic deviations of the plumb line in connection with the European arc on the fifty-second degree of north latitude.
II. The international latitude service.
III. Absolute determinations of gravity.

Without going into details at this stage of our narrative, we may note in passing one or two points brought out. The geodetic connection between Switzerland and Italy is now satisfactorily made. It rests, however, on a single triangle, due to the fact that one of the points composing the quadrilateral proposed was not occupied identically by the two surveys.

The international latitude service will be inaugurated during the summer of 1899 at four stations, under the direct control and at the expense of the association. Observations at two additional stations will be undertaken, for which the central bureau will supply only a part of the funds necessary. Although the mathematical conditions are not essentially changed by the introduction of Cincinnati and Tschardjui, there is great advantage from the fact that any systematic errors in the regular stations will be more readily discovered. It is a fortunate coincidence that the observatory at Cincinnati happens to be precisely on the parallel of latitude chosen for this work, and it is, moreover, a matter for congratulation that Russia is ready and willing to aid in the undertaking, to the extent of establishing and superintending the station at Tschardjui.

The report also stated that in the absolute gravity work, measurement of the length of the pendulum—the most difficult operation in the whole problem—can be effected both in a horizontal and vertical position. The knife edges can be illuminated in any direction by means of movable mirrors, and the field of view is kept at the same time uniformly lighted. Experiments with an electric magnet have shown that the earth's magnetic force only exercises a retarding influence on the swinging, without having

any effect on the resulting length of the mathematical seconds pendulum. The possible slight movement of the agate plate, as well as the slip of the knives, is observed by a specially designed apparatus.

It is worthy of mention in this connection that up to the present time nearly 1 400 gravity stations have been occupied, of which 1 228 are different. Austria heads the list with 698, Germany follows with 162, and the United States comes next with 88. The greater part of the remainder falls to Denmark, Russia, Switzerland, France, and Italy. About fifteen different nationalities are represented in this work. The latest results from pendulum observations are with reference to changes of the force of gravity with elevation, and the derivation of a new formula for the length (L) of the seconds pendulum at the sea level. From a discussion of over five hundred stations the conclusion is reached that what is usually known as continental attraction amounts practically to nothing, and that in general the change of the force of gravity at any point on the earth's surface depends purely and simply on the Newtonian law of the inverse square of the distance. The introduction of a spherical function of the third order in the formula for L, alluded to above, foreshadows the determination of a different curvature for the northern and southern hemispheres of the earth; yet the coefficient appears so small that the inequality can not as yet be safely predicted. The compression given is 1/297 and the equatorial value of the force of gravity is about 1/13 000 greater than that now accepted. The investigation of the relation between disturbances in the force of gravity and deviations of the plumb line is one of the most interesting problems of the near future.

The reports read by the different delegates need not be taken up here. Although full of interest to the geodesist and astronomer, they are too voluminous to be analyzed or discussed in the short space at our disposal. They will, however, be published in full, and will appear in the proceedings of the conference, where they may be consulted and studied.

Three matters of universal interest were brought before the association, and suitable action was had thereon. These were:

I. The determination of the figure of the earth by the measurement of arcs and the determination of the force of gravity.
II. The remeasurement of the Peruvian arc.
III. The redetermination of the difference of longitude between Paris and Greenwich.

The first two subjects were introduced as resolutions by the United States delegate, and brought out interesting discussions. The first was proposed for the sake of directing the attention of the association more specifically to the prime object of its existence. No one doubts the utility or necessity of a complete study of the law governing the changes of latitude, but its ultimate bearing is rather one of astronomy than geodesy. The funds of the association are now being devoted largely to the latitude question, and the time seemed fitting to suggest work more directly in the line of its avowed purpose—the measurement of the earth. The object of the resolution was therefore in the nature of a recall to the original conception of its being, and bespoke in the interest of pure geodesy an application of its resources to a realization of the idea of its founders.

The remeasurement of the Peruvian arc now appears to be assured. It may be worth while just here to recall the essential features of this work. One hundred and

sixty years ago, when it was a disputed question whether the polar or equatorial diameter of the earth was the longer, the French Academy decided to make one supreme effort to settle the point. To this end, two arcs were measured; one on the equator (now known as the Peruvian arc, although it is really in Ecuador), and the other in Lapland, as near the pole as possible. These two arcs, confessedly inaccurate in the light of modern geodesy, have been employed continually in the determination of the earth's figure. Situated as they are near the extremities of the quadrant, their influence is great on the shape deduced, so that one of the pressing needs of the day in the measurement of the earth is a redetermination of their lengths. France having made the first measure, by common consent, should be given the first chance to repeat the equatorial work. At the conference in Paris in 1889 the matter was brought up, but was left to be disposed of by France. Efforts were made to accomplish the task, the officers were in part designated, and arrangements for cooperation by the Government of Ecuador were completed. At this juncture the revolution broke out in Ecuador and the matter came to an untimely end. It is now proposed to make a reconnoissance during the summer of 1899, report the results thereof to the Paris conference of 1900, and then decide definitely on the plans of final measurement. It is universally conceded that France should be given the first chance to act, not alone because the first measure was made by her, but also because the conference of 1889 relinquished in her interest further consideration of the subject.

The Russians and Swedes, in a quiet sort of way, are measuring an arc between the parallels of latitude 76° 26′ and 80° 49′, in Spitzbergen. The triangulation will require two summers and part of one winter, and will cost 100 000 kronen ($27 500) exclusive of cost of vessels furnished by the Governments. The field work will be finished in 1900, and the computations two years later. Twenty-four stations will be occupied, of which sixteen are astronomic. The sides range in length from 20 to 122 kilometers, and the bases, of which there will be only two, are to be measured with Jaederin's steel tapeline 20 meters long.

The difference of longitude between Paris and Greenwich comes up again for investigation. This question has been a sort of thorn in the side of European geodesy for ten years. In 1872 the United States Coast Survey made a determination, in order to have a check on the telegraphic longitude of our trigonometric points as determined independently from Paris and Greenwich. This was followed in 1888 by two separate determinations—one on the part of Great Britain, the other on the part of France. The results differed by more than two-tenths of a second. Our own result falls between them, and it is a matter for congratulation to all Americans that the best direct determination to the present day of this important quantity is the work done by the United States Coast Survey while incidentally checking its own longitude determinations. Nothing was done to improve the agreement until 1892, when the work was repeated both by the French and English, only to yield results practically identical with those previously obtained; so the unfortunate discrepancy still remains, and the five direct determinations already made leave the work in an unsatisfactory condition. Six indirect results may be had from combinations of general European work, through Brest, Vienna, Berlin, Bonn, and Leiden, the mean of which gives the same result as the mean of the direct determinations. Nothing seems to remain, therefore, but to study the conditions of

the work of 1888 and 1892 and reconcile, if possible, the outstanding difference. The matter has been referred by the International Geodetic Association to the directors of the two observatories, and a definitive result will doubtless soon be made known.

The variation of the latitude seems to be at present an absorbing question before the association, and there results from action taken at the Stuttgart meeting the following status:

Six stations will be established during the summer of 1899 on the parallel of latitude 39° 8′. These will be distributed in longitude as follows: One each in Japan, Turkestan, and Italy, and three in the United States. The American ones will be located at Gaithersburg, Md., Cincinnati, Ohio, and Ukiah, Cal. This gives a preponderance of weight to the determination of the coordinate Y (X passing through Greenwich), but a station in Portugal, which may possibly be secured later, would essentially increase the accuracy of X. Tschardjui in Russia and Ukiah in California are nearly opposite, and Mizusawa in Japan is in the only remaining unoccupied quadrant. The scheme proposed is, therefore, a favorable one for the study of the motion of the pole. No one knows as yet how long it will be desirable to continue the observations. The period now provided for is five years, but it is proposed to buy the land upon which the observatories will be located, or lease it for a long period. It is evident that at least twenty-one years would be desirable, because during the seven years of observations already made the pole has returned nearly to its mean position, and three of these cycles should be completed before any definite idea can be had as to its mean path. The cost of the entire work will be about $10 000 annually. The visual method is to be followed regularly, without, however, excluding the possibility of employing later the photographic one, which has already given excellent results. Twelve groups of stars, each comprising eight pairs, will be selected. Six pairs in each group are destined for the latitude determinations proper, while the two remaining pairs, having great zenith distances (about 60°), will, it is hoped, throw light on the question of refraction. The observing period for each night is four hours, and will vary from 7 p. m. to 3 a. m., depending on the situation of the group. The instrumental outfit will consist of a zenith telescope and astronomical clock for each station, except that of Japan. Here a chronometer will be substituted for the clock, on account of the frequency of earthquakes.

Although the object of the general conference was scientific discussion, a faithful historian can not ignore the social and humanitarian side of the function. From our entrance into the beautiful capital of Württemberg until the time of our departure we were the recipients of the most cordial hospitality. The first session was devoted to addresses of welcome on the part of the Government officials and replies thereto by the officers of the association. Cards of admission to the museums and public buildings were furnished, excursions to the fine old castles of the suburbs were given, and a final gala banquet marked the close of the convention. The official means of communication before the conference was either French or German. English, Spanish, and Italian were heard during recess, but not during debate. The Japanese, Russians, and Swedes spoke German, the Italians and Spanish French, the Swiss both. One delegate, in a moment of absent-mindedness, voted in his native tongue. The novelty of the proceeding seemed attractive, and forthwith each representative did likewise. This gave increased momentary interest to the balloting, which culminated in great hilarity

when the president, a distinguished Frenchman, who had never been known to use anything but his native tongue at the meetings, responded "Ja."

Before closing the present paper, attention should be called to a few points of interest noted during the trip to Stuttgart and return. A flying visit was made to the Royal Observatory at Berlin, the Reichsanstalt at Charlottenburg, and the Geodetic Institute at Potsdam. At Paris the offices of the geographic service and the International Bureau of Weights and Measures were examined, and part of one day was devoted to the English Ordnance Survey at Southampton.

An interesting object at the Berlin Observatory is the instrument with which Küstner discovered the variation of latitude; not alone because of the splendid result achieved, but on account of the conditions under which the work was done. It is mounted on a pier more than 20 feet above ground, on a subsoil of sand, in the middle of a city, with bad atmospheric conditions and about 100 feet from the public thoroughfares. In spite of these adverse circumstances a new fact was added to science, which had baffled the efforts of larger telescopes under immeasurably better conditions. There is much encouragement in this to investigators with scanty means at their disposal.

At the Aichungs-Kommission a balance was shown which easily determines the weight of a kilogramme with an error of 1/200 of a milligramme, being 1/200 000 000 part of the quantity sought. They have also a complete series of weights in quartz from one-half gramme to 1 kilogramme, and thermometers giving the temperature by estimation to 1/1 000 of a degree Centigrade.

At Charlottenburg the most striking feature was the extension and perfection of the organization. Nine buildings in all, of which the two larger are devoted one to theory and the other to practice, have cost, together with the running expenses since 1887, 3 000 000 marks. The annual outlay is at present about 360 000 marks ($90 000).

The Geodetic Institute at Potsdam has been much less expensive, and presents many admirable points of arrangement and administration. Among the details may be cited the clock room, always maintained at a temperature between 20° and 21° Centigrade; the pendulum room, artificially heated on all sides, including the floor; a pillar over 50 feet high, and correspondingly thick, with meridian marks several miles away, to study changes in azimuth and the movement of the earth's crust; and finally, a small photographic instrument, by means of which the occupation of a station only requires eight minutes, and gives a determination of the geographical latitude within two seconds of arc. The subsoil, as at Berlin, is nothing but sand.

At Sevres, near Paris, several interesting instruments were seen, among which may be specially mentioned that designed for the comparison of the meter with the wave length of light following Michelson's method, and the apparatus for the determination of coefficients of expansion according to the method of Fizeau. Some recent experiments have been made on a composition containing 36 per cent nickel and 64 per cent steel. It appears that the expansion from heat is thus reduced to about one-fiftieth of what we should expect from the individual components. This discovery will simplify enormously the solutions of problems where the temperature question has thus far been the great difficulty. It will, for example, be a comparatively easy matter to make pendulum clocks run with a daily correction of about one-tenth of a second per day under varying temperature conditions.

At the office of the geographic service of the army a noteworthy feature was the publication of charts. Six presses, each capable of turning out 600 maps per hour, are continually at work. Each year there are printed and distributed 1 200 000 maps, about as many as the Coast and Geodetic Survey has published since it came into existence. At Southampton, where the office of the English Ordnance Survey is located, the personnel consists of about nine hundred persons, of which probably one hundred belong to the army. The map-printing establishment has even greater capacity than that at Paris, 3 000 000 maps being delivered annually. Although the great trigonometric work may be considered as finished in England, nevertheless the topography goes on, and the effort is made to cover the whole kingdom once in twenty years with a new map on a scale 1/2500 and once in fifteen years with one on 1/10000. The latter is made from the former by making blue prints, tracing in black the detail required and photographing again, which leaves out everything in blue on the original sheet.

My report to the conference is hereto appended.

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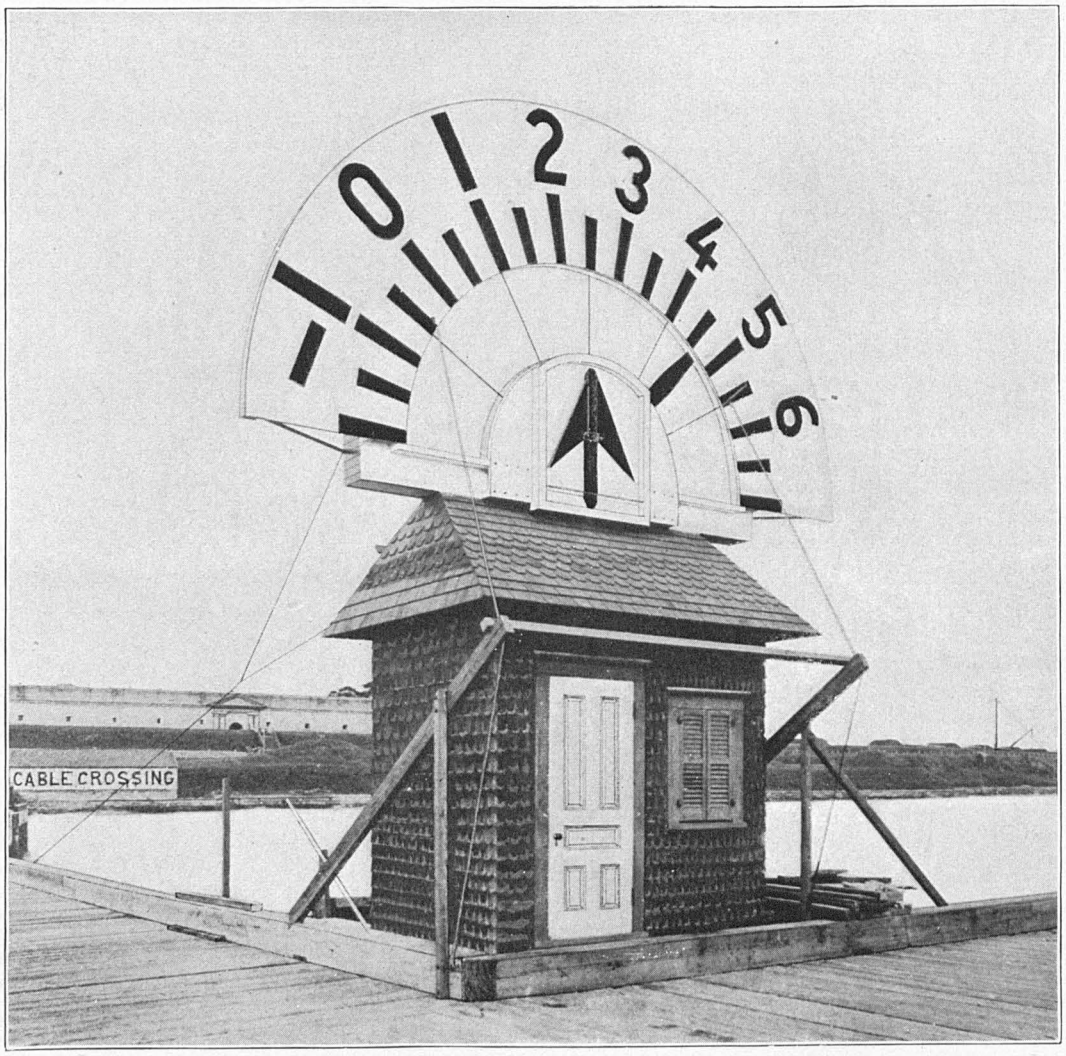


TIDAL INDICATOR AT ENTRANCE TO NEW YORK HARBOR.

GEODETIC OPERATIONS IN THE UNITED STATES—REPORT TO THE GENERAL CONFERENCE OF THE INTERNATIONAL GEODETIC ASSOCIATION, STUTTGART MEETING, OCTOBER 3 TO 12, 1898.

The geodetic operations in the United States, as executed by the Coast and Geodetic Survey, may be grouped into three distinct periods of time, The work was authorized by Congress in 1807, but a quarter of a century elapsed before anything was done in the field worthy of the name of geodesy. This closed the first period, which may be characterized as the era of preparation and education of public sentiment. In 1832 operations were begun with vigor, and the foundation was laid for a great national work. The Survey was conducted on the same general lines of policy for eleven years, when the reorganization of 1843 established its permanent status. No great deviation has since been made from this plan, which has now held for fifty-five years. If we eliminate the civil war period of five years, during which work was suspended, and regard operations before the reorganization as of a preliminary nature, we have half a century of geodesy. During its comparatively short existence the Survey has been three times under the control of the Treasury Department, twice under the Navy, and once under law requiring its personnel to be army or navy officers. The direction of the work has, however, remained throughout in the hands of a civilian, and civilian methods have been applied in the administration. At the present time it has been continuously under the Treasury for a period of sixty-two years. Although statistics do not always give an adequate conception of the work to which they are supposed to bear testimony, a general idea of the activity displayed may be had from the following statement of work done:

Three hundred and fifty thousand square miles (906 500 square kilometers) of triangulation, embracing 15 000 stations for horizontal measures and determining 28 500 geographical positions at which 1 000 astronomical coordinates have been observed.

Thirty-eight thousand five hundred square miles (99 710 square kilometers) of topography, embracing 11 600 miles (18 670 kilometers) of general coast line and more than 100 000 miles (160 900 kilometers) of shore line (rivers, etc.), also including 51 000 miles (82 080 kilometers) of roadways.

Five hundred and forty-five thousand miles (877 100 kilometers) of sounding, covering 164 000 square miles (424 800 square kilometers) of area, besides 93 000 miles (149 700 kilometers) of deep-sea sounding, in which 14 000 bottom specimens were obtained.

Four thousand six hundred original topographic and hydrographic sheets, from which 1 300 000 charts have been made and distributed; 30 000 original volumes of observations, including magnetic records from 1 100 stations.

BASE LINES.

Two hundred and three base lines have been measured, of which nineteen, on account of their accuracy, length, and geodetic connection, are classed as primary. The average length of these is 9 892 meters. The probable error, which includes both that of measurement and the comparison with the standard, is 22·2 millimeters, or about one four hundred and forty-five thousandth of the length stated. Speaking of the three types of apparatus used in the Survey, and referring now to errors of measurement purely, it may be said that with the different forms of metallic bars, compensating and otherwise, the error is one millionth part of the length measured. With the tapeline the accuracy may be increased to one two-millionth, while with a rod in melting ice one five-millionth is easily attainable. In the first form the contacts are material; in the last, optical. With the tape they are linear. The cost is greatest for the rod in melting ice and least with metallic bars.

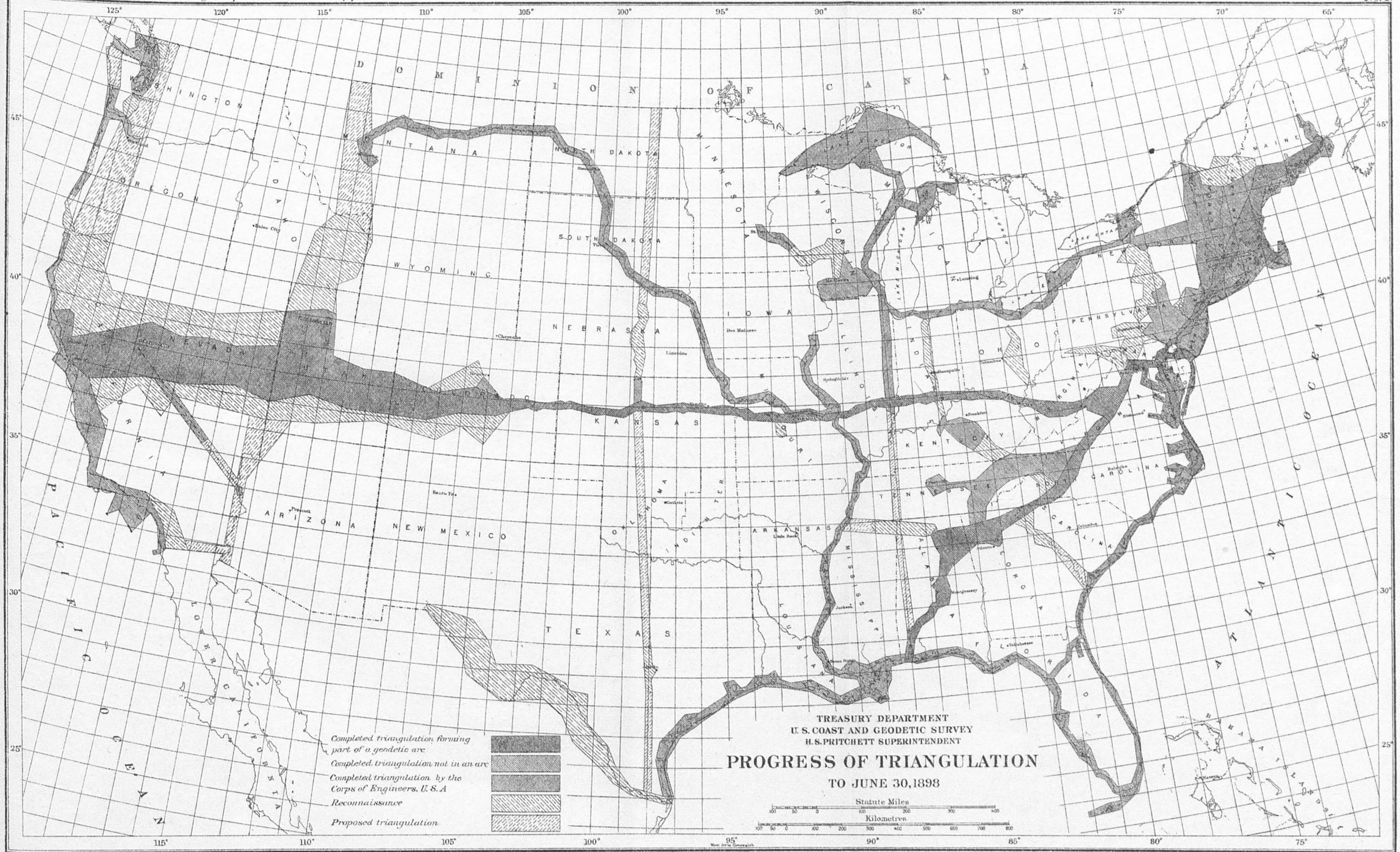
Attention may here be called to a new form of base apparatus named the "Duplex" and designed by Assistant William Eimbeck. It consists of two bars, brass and steel, 5 metres in length, so arranged that the measure may be made with each component separately and simultaneously. It may also be employed as a Borda scale, or the temperature may be directly observed. Some unique features which need not here be described are employed in its manipulation. The Salt Lake base, measured in 1896, gave results with either component having a probable error of less than one five-millionth part of the measured length.

TRIANGULATION AND ARCS.

(Illustration No. 2.)

The shore line of the United States, exclusive of Alaska, is 5 452 miles (8 774 kilometers). This has been covered by triangulation, with the exception of a few hundred miles on the northwest coast. An oblique arc of 22 degrees has been measured from the northeast boundary in Maine to the southwest limit of Alabama, on the Gulf of Mexico, and an arc of 49 degrees on the thirty-ninth parallel of latitude has been completed from the Atlantic to the Pacific. All of the New England States, a large part of the Middle ones, and considerable areas in the South and West have been covered with triangulation. Adjacent regions have had careful reconnaissance. The work in this direction has been executed on a large and accurate scale. The greatest triangle has sides of 133, 167, and 190 miles (214, 269, and 306 kilometers). The highest station is over 14 000 feet (4 267 meters). Operations of such magnitude justify the introduction of refinements not usually employed. The latitudes are corrected for elevation, and the horizontal directions are changed, to reduce them to the sea level of the observed station.

A distinctive feature in the final adjustment is the application of weights depending on both the station errors and those arising from the closing of figures. These are treated separately, but the final weights consist of two parts, one resulting from local conditions and varying with each direction, and the other deduced from the formation of triangles and remaining constant for the network under consideration. In the California work the probable error of a direction at any station was 0″·081, while that from the closing of triangles was about twice as much. The latter necessarily includes the



TREASURY DEPARTMENT
U. S. COAST AND GEODETIC SURVEY
H. S. PRITCHETT SUPERINTENDENT

PROGRESS OF TRIANGULATION

TO JUNE 30, 1898

Statute Miles
100 50 0 100 200 300 400

Kilometres
100 50 0 100 200 300 400 500 600 700 800

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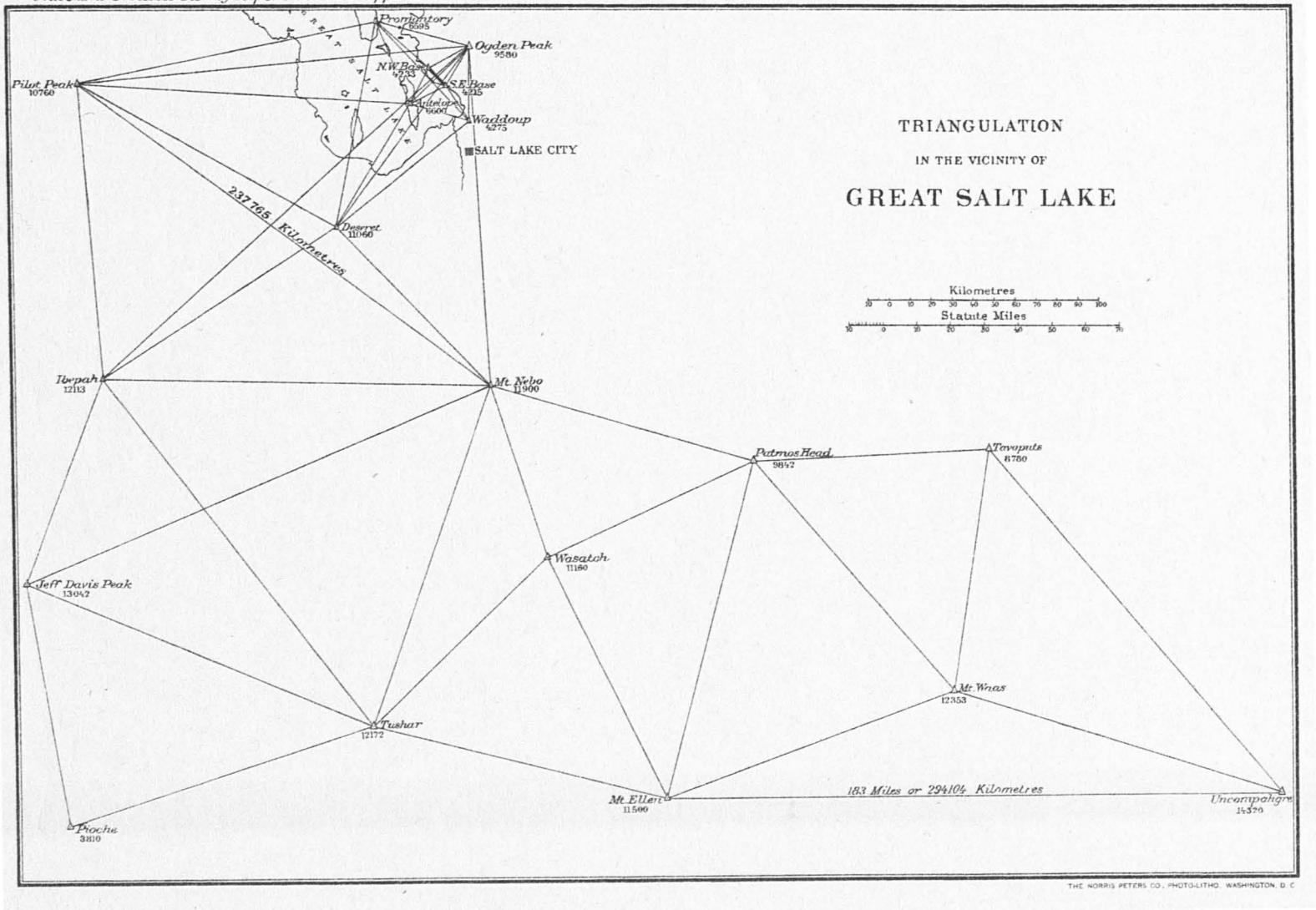

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former. The two are separated by means of the formula $e_c = \sqrt{e_t^2 - e_s^2}$, which gives the resulting combination error as $\pm 0''\cdot 169$ [e_t is the probable error of a direction from the closing of triangles, and e_s is the average probable error of an observed direction from station adjustment]. Each direction, therefore, enters the final adjustment with a weight derived from measures at its own station, added to the above value, which represents the constant part for the entire figure. The cost of the transcontinental arc from Cape May to San Francisco was $200 per linear mile ($124 per kilometer), $3·50 per square mile ($1·35 per square kilometer), and $2 000 per station.

A fine example of rapid expansion from the base to a fully developed net of triangulation is shown in Fig. 3. The sketch also gives a characteristic specimen of primary work as carried out in the Rocky Mountain region of the United States. The average height of the thirteen stations composing the main scheme here shown is 11 256 feet (3 431 meters), while the average length of the lines connecting them is 159·734 kilometers (99¼ miles). The distance between Mount Ellen and Uncompahgre is 294·104 kilometers (182¾ miles). This remains to the present day the longest line observed from both ends, and forming an integral part of a regular system of triangulation, executed by any trigonometric survey in existence. Indeed, the entire chain from the Sierra Nevada on the west to the Mississippi plateau on the east is without a parallel in similar work, when we consider the magnitude of the geometrical figures, the elevation of the stations, and the refinement of the individual measures.

Referring to a part of this work—the base net at Salt Lake, Utah—the following details are of interest:

The elevation of the base above sea level is about 4 224 feet, while the mean height of the stations composing the quadrilateral is 11 088 feet. (See Plate 3.) In only five steps we pass from a base 11·2 kilometres in length to a line 237·765 kilometers long (Pilot Peak, Mount Nebo). This involves an average multiplication of four and one-fourth times for each step of expansion, which is within the limit set for development in well-conditioned triangulation. The resulting quadrilateral in which the base line expansion culminates, and on which the transcontinental extension rests, contains nearly 10 500 square miles, and is the largest yet realized. The base net, including this figure (Ogden, Mount Nebo, Ibepah, and Pilot Peak), was adjusted separately and brought out the following criteria of accuracy:

FROM STATION ADJUSTMENT.

Average probable error of a single observation of a direction	0·71
Average probable error of an adjusted direction	0·10

FROM FIGURE ADJUSTMENT.

The largest correction is	0·84
And 55 per cent of the corrections are less than	0·25

The probable error of the side Ibepah-Nebo, depending on angular measures only, is one two-hundred-and-eighty-thousandth of its length.

Heliotropes were continually employed, and the angles were measured with a theodolite having a horizontal circle of 20 inches diameter and a magnifying power of 83. The approximate heights are given in feet in Sketch 3.

ASTRONOMICAL WORK.

Aside from the work in practical astronomy incident and necessary to the operations of every trigonometrical survey, attention has been given to various other phases of the subject. It has not alone sufficed to point out and demonstrate the utility of the method of equal zenith distances for latitude and of the application of the telegraph to longitude. The Coast and Geodetic Survey, feeling the necessity of better star places arising from the use of the methods just mentioned, has devoted some of its energy to the perfection of star catalogues. It is probably no exaggeration to say that the declinations given in our field lists are the best attainable anywhere. More than fifty of the best modern catalogues are corrected for their systematic errors, and each is given weight depending on the value of the work and number of observations. A collection of all these data and their consolidation into one homogeneous result eliminates as far as possible all known sources of inaccuracy and gives us finally the most reliable positions. A list so constructed of several thousand stars has already been published, many of which are especially adapted to southern work.

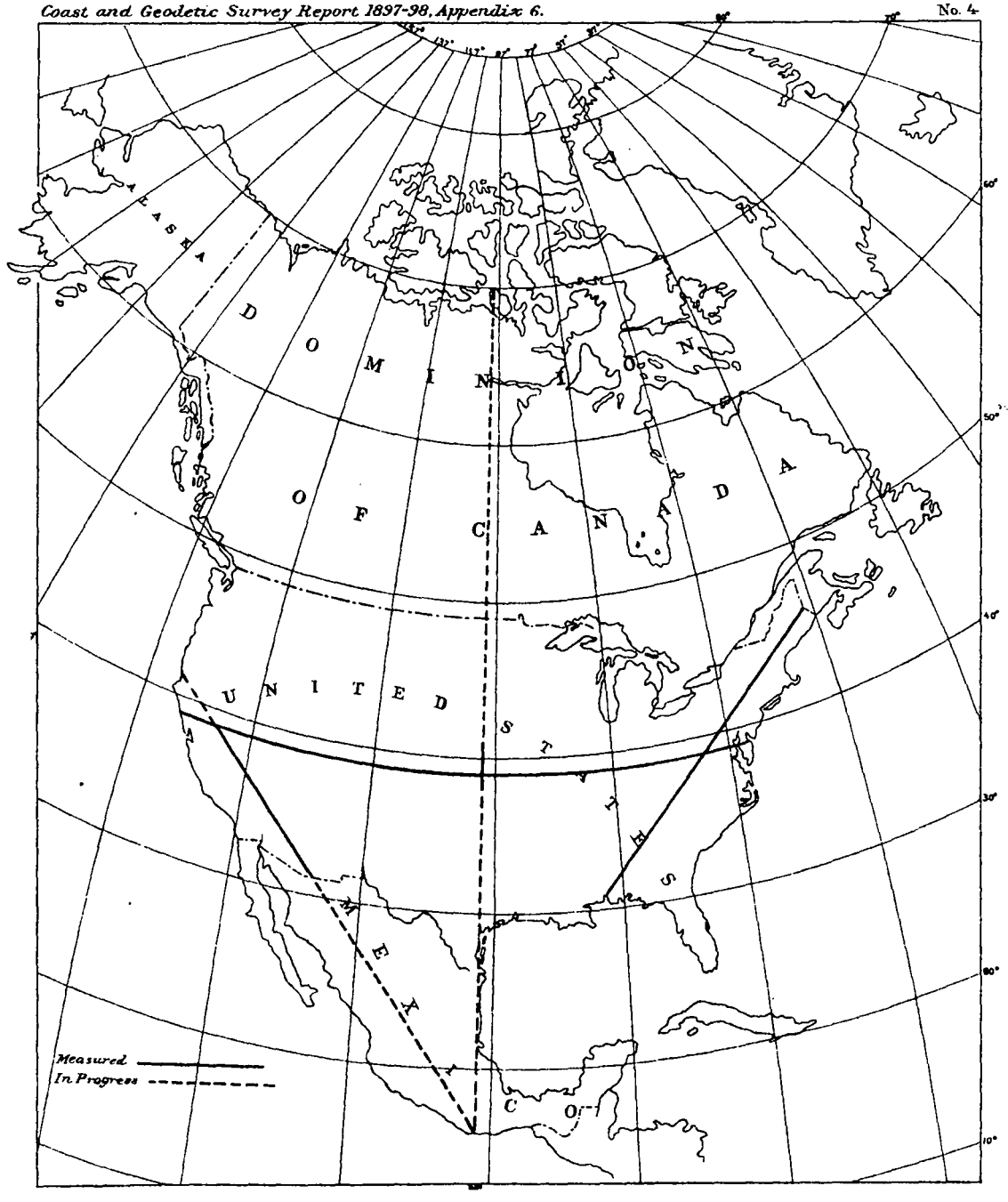
The average probable error of a declination may be given as rather less than one-fourth of a second, a degree of precision which enables an observer to determine his latitude from twenty pairs in one evening, with an uncertainty of only $\pm$ 10 feet. This is sufficient for the purposes of geodesy. Incidental to regular astronomic work, the Survey has equipped and sent out no less than thirty-five parties for the observation of solar eclipses and transits of the inferior planets, which work has required the occupation of stations in every continent and Polynesia. The variations of latitude have been determined at three stations, each one having been occupied more than a year.

MISCELLANEOUS OPERATIONS.

The legitimate field of investigation in a geodetic service embraces many subjects outside of those already specified. In the execution of the task before us a free interpretation has been given to the law authorizing the work, and the kindred subjects of hypsometry, magnetism, gravity, and physical hydrography have been pursued, along with others more strictly within our province.

Five thousand miles (8 047 kilometers) of precise leveling have been executed, including four independent determinations of the height of St. Louis. Two have been made from the Atlantic at Sandy Hook, and two from the Gulf of Mexico at Biloxi.

A comparison indicates that the surface of the Gulf is somewhat higher than the sea level at New York, and this has been verified in character, although not precisely in amount, by a line across the peninsula of Florida three times repeated. Other subsidiary lines have also been observed. The limit of error has been that usually adopted in similar work, viz, 5 mm. $\sqrt{K}$. The heights by spirit level have been supplemented and controlled by micrometric measurements of zenith distances. In the determination of elevations necessary to reduce the base lines along the transcontinental arc to sea level, the latter method has been employed across the Allegheny and Rocky mountains. The spirit levels are continuous from Sandy Hook to Denver and Colorado Springs. They are checked by zenith distances from the Chesapeake Bay to the Ohio River, which method has been exclusively employed from Denver to the Pacific coast, where the spirit levels are not yet completed.



PRINCIPAL ARCS MEASURED AND IN PROGRESS ON THE CONTINENT OF NORTH AMERICA.

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Permanent magnetic observations have been in operation at Philadelphia, Pa., Key West, Fla., Madison, Wis., Los Angeles, Cal., and San Antonio, Texas, and each one has furnished records for five consecutive years; with one exception a self-registering apparatus has been continuously employed in each locality. These data added to records from 1 100 widely distant points, many of which are secular variation stations, furnish precious material for the study of the earth's magnetism. The work of the Survey in the investigation of the force of gravity has been carried on both within and without the limits of the United States. Twenty-eight foreign stations have been occupied, including points in Europe, Asia, Africa, Australia, and many islands in both the Atlantic and Pacific. New light on the subject of volcanic formation, as well as on the constitution of the earth's crust, has come from this work. Fifty-nine stations have been observed at home, including a line across the continent. Half-second pendulums are now exclusively employed, and the determinations are purely differential. The period of oscillation is usually known to within a few millionths of a second.

In the field of physical hydrography most comprehensive studies have been made. The exploration of the Gulf Stream, including a study of its density, temperature, and currents, the geology of the sea bottom, the establishment of cotidal lines, the determination of the ocean depth from earthquake waves, and other specialties in the domain of hydrography have been made a part of the regular work. The hydrography of the coast to the head of tide water has been developed side by side with the triangulation and topography.

The practical results of the Survey are shown in the publication of the annual reports, the issue of charts, Notice to Mariners (corrected monthly), Coast Pilots for Atlantic, Pacific, and Alaskan waters, tide tables (now extended to foreign ports), and various miscellaneous publications in special lines of research.

PRESENT AND FUTURE OPERATIONS.

A resurvey of Chesapeake Bay, the measurement of an arc through the United States on the ninety-eighth meridian, and the development of Alaskan geography are among the projects of Dr. Pritchett, the present Superintendent of the organization. All these have been carried on during the last two years. The line of transcontinental precise levels is being pushed westward with all available means. Primary triangulation on the Pacific coast has been resumed, and will soon be completed from San Francisco to the Mexican boundary. Hydrographic surveys are in progress along the Atlantic seaboard, on the Pacific, and at the mouth of the Yukon in Alaska. Numerous topographic, astronomic, and magnetic parties are employed in the interior.

An extension of the great arcs of the United States into Mexico and the British possessions has been proposed by Dr. Pritchett, and diplomatic representations between the interested Governments looking toward concerted action in the near future have already been made. This will give to North America an additional meridian arc of about 55 degrees and an oblique one of 33 degrees. Together with existing arcs, the proposed material will practically exhaust our contribution to the determination of the earth's figure. Sketch 4 shows the location of the work completed and in progress.

In the ordinary prosecution of the field work since 1895 about fifty parties have been employed during the course of each year. Added to this, the purely hydrographic work has been carried on by a fleet of sixteen vessels, of which ten are steamers.

The operations have been widely distributed, extending as far as the Pribilof Islands, in the Bering Sea. A longitude determination was made from Sitka, of Kadiak and Unalaska, in which twenty-one chronometers were carried on four successive trips. The probable error of the resulting longitudes was $0^{s}.20$ for the former and $0^{s}.21$ for the latter. A tidal indicator, similar to the one in New York, has been erected at Philadelphia, and one is in process of construction at San Francisco. The mechanism, actuated by the vertical movement of the water, furnishes the navigator at any moment, at a distance of 1 mile, with necessary information as to the character and amount of the tide. Sketch 1 shows its general appearance.

Among the auxiliary duties of the service may be mentioned the establishment of trial speed courses for ships of the Navy (a number of which have been recently laid out); the exploration of oyster beds; the fauna of the Gulf Stream; the administration of an office of standard weights and measures, from which prototypes are issued to the different States; meteorological researches for the use of the Coast Pilot; the study of astronomical refraction; mathematical investigations on the theory of projections, on the equations of steady motion, on errors of observations; and, finally, in experimental researches in engraving, electrotyping, and lithography; all of which knowledge finds application in the various fields of activity now covered by the Coast and Geodetic Survey.

WORK OF THE UNITED STATES ENGINEERS.

Geodetic surveys have also been carried on by the Corps of Engineers of the United States Army. That of the Great Lakes was completed in 1882. The work was reorganized in 1892, and resurveys and extensions thereto are now in progress. Changes in the original plan have been introduced, chiefly in the direction of rapidity of execution. Fewer positions on the circle are now used for horizontal angles, and adjustment is effected by separate small figures, rather than through any extended scheme. In the measure of the Mackinaw base three tapes were used, each a kilometer in length. Each section of the tape was compared with a standard length of 100 meters established on the ground. This standard length was determined by means of an 8-meter bar packed in ice, which in turn was compared with the Repsold meter, R. 1878.

The Engineer Corps of the Army has also had charge of the Mexican Boundary Survey and of the work done by the Missouri and Mississippi River commissions. The report on the Mexican boundary is already in type, but is not ready for distribution.

The Missouri River Commission has completed a triangulation from St. Louis to Three Forks, in Montana, a distance of 2 551 miles. The work follows the river and covers the valley from bluff to bluff. Precise levels have been run over 807 miles of it and ordinary levels cover the remainder. Ten base lines have been measured with a standardized steel tape.

The Mississippi River Commission, utilizing some work already done by the Lake Survey and the Coast and Geodetic Survey, has now a complete connection from the Gulf of Mexico to St. Paul, in Minnesota. The total distance is about 1 600 miles. Twenty-seven bases have been used, of which eighteen have been measured by the Commission with a steel tape 300 feet long. The work has been adjusted by quadrilaterals, employing the method of least squares.

Very respectfully, your obedient servant,

E. D. PRESTON.

To the SUPERINTENDENT COAST AND GEODETIC SURVEY.

APPENDIX No. 7. 1897-98.

DETERMINATION OF TIME, LONGITUDE, LATITUDE, AND AZIMUTH.

By J. F. HAYFORD, Assistant,
Inspector of Geodetic Work.

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APPENDIX No. 7. 1897-98.

DETERMINATION OF TIME, LONGITUDE, LATITUDE, AND AZIMUTH.

By J. F. HAYFORD, *Assistant, Inspector of Geodetic Work.*

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 of the Survey.

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, etc. 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.

The third edition of these papers appeared as Appendix No. 14 to the report for 1880, under the title "Determination of time, longitude, latitude, and azimuth."

The continued demand for this edition, which has been exhausted for some time, by those officially connected with the Survey, as well as by others engaged on work of this character, has made it desirable to issue the present fourth edition.

The subject matter is, in general, the same as that of the third edition, viz, the determination of time and longitude by the use of the transit and the meridian telescope,

of latitude by the use of the zenith telescope, and of azimuth by the use of the theodolite, transit, and meridian telescope. The most important additions made to the previous edition are an account of the method of determining differences of longitude by transportation of chronometers as now used on this Survey, and an account of the micrometric method of determining azimuth by means of a theodolite or transit furnished with an eyepiece micrometer.

New illustrations have been provided, and considerable new matter bearing upon the relative magnitude of errors to be expected from various sources and upon the economics of observing have been introduced. The discussions of errors are meant to be suggestive rather than exhaustive. They will serve to indicate to the inexperienced observer the precautions which must be taken to secure accurate results, and especially to put him on his guard against making the mistake of taking extraordinary precautions against some small and unimportant class of errors while at the same time failing to realize that he is leaving the way open for the entrance of much larger errors of some other class. The bearing of such discussions upon the problem of attaining a given degree of accuracy with a minimum amount of observing and computing is obvious.

The writer takes pleasure in acknowledging here his indebtedness to Dr. H. S. Pritchett, Superintendent, and Mr. D. L. Hazard, computer, for valuable criticisms, suggestions, and data; to Assistant G. R. Putnam for a criticism in detail of Parts I and II, and for the preparation of certain pages of those parts which are due entirely to him; to Assistant William Eimbeck for valuable suggestions in regard to Part IV, and to various other members of the field and office force who have contributed suggestions and data. The main portions of this appendix are due to Assistant C. A. Schott, who prepared the three previous editions.

It has not been deemed necessary to insert the derivation of formulæ, except in the few rare cases in which such derivation can not readily be found in text-books on astronomy. For derivation of formulæ the reader is therefore referred to Chauvenet's Astronomy, to Doolittle's Practical Astronomy, and to the writer's Text-Book of Geodetic Astronomy. As the latter text was completed but a year ago, certain ideas and sentences incorporated in it naturally find themselves repeated here. It has not been considered necessary to use quotation marks in those cases.

JOHN F. HAYFORD,
Inspector of Geodetic Work.

PART I.

DETERMINATION OF TIME BY MEANS OF THE TRANSIT INSTRUMENT.

GENERAL REMARKS ON THE USE OF THE TRANSIT INSTRUMENT.

1. This part 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 the 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. (See § 6.) The observations are either made by the method of "eye and ear" or by chronographic registration—the former being used for nearly all purposes, excepting in telegraphic longitude work, for which 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.

DESCRIPTION OF LARGE PORTABLE TRANSIT.

2. Several sizes of portable transits are employed on the Survey. The larger and older ones, made by Troughton and Simms, of London, were almost exclusively used for telegraphic determination of astronomical longitudes, but have generally been replaced for this purpose by the transits made at the Survey office in 1888 (described in the following paragraph), while the smaller ones known as meridian telescopes (described in § 3) serve for the determination of the local time needed for observing astronomical azimuths, latitudes, or other 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 strains or temporary instability of the instrument due to 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.

Illustration No. 1 shows Transit No. 18,* one of the larger portable transits. It was made at the Survey office in 1888. It has a focal length of 94 cm. and a clear aperture of 76 mm. The magnifying power with the diagonal eyepiece ordinarily used is 104 diameters. It is provided with a convenient reversing apparatus. The value of one division (=2 mm.) of the striding level =1″·35. The instrument when packed in two boxes ready for transportation weighs about 350 pounds. The setting circles are 4 inches in diameter, are graduated to 20′ spaces, and are read to minutes by verniers.

The glass diaphragm carries two horizontal lines, simply to define limits within which all observations should be made, and thirteen vertical lines, eleven of which are used in making time observations with the chronograph, and five of which (longer than the others) are used in making eye and ear observations. The shortest time interval between lines for chronographic observations is about two and one-half seconds and for eye and ear observations about ten seconds. This transit is provided with a sub-base of iron which is to be firmly cemented to the supporting pier. The transit proper is supported upon this sub-base by three foot screws. At the left of the base in the illustration is shown a pair of opposing screws which serve to adjust the instrument in azimuth. One of these screws carries a graduated head which enables one to set the instrument very nearly in the meridian as soon as the azimuth error is known.

This instrument may serve as a typical illustration of the class of large portable transits.

DESCRIPTION OF MERIDIAN TELESCOPE.

3. Certain instruments are commonly known on this Survey as meridian telescopes.† They are fitted both for time observations and for latitude observations by the Horrebow-Talcott method (see § 42) and are provided with a frame which may be folded up for convenience in transportation. Illustration No. 2 shows Meridian Telescope No. 13, which may serve as a type of the smaller instruments used for time on this Survey.

This telescope has a focal length of 66 cm., a clear aperture of 5 cm., and a magnifying power of 72. The value of one (2 mm.) division of the striding level is about 2½″. During time observations the telescope is reversed by hand; during latitude observations it may be reversed by turning the upper half of the double base upon the lower half. One of the two setting circles carries a delicate level for use in making latitude observations, and the eyepiece is fitted with a micrometer for measuring differences of zenith distance, in addition to the diaphragm carrying fixed vertical lines for use in making time observations. On the left-hand portion of the base, as seen in the illustration, is a slow-motion screw for accurate adjustment in azimuth.

THE CHRONOGRAPH.

4. Illustration No. 3 shows the form of chronograph now in use in the Survey. The train of gears seen at the right is driven by a falling weight. It drives the speed governor (seen above the case containing the gears), the cylinder upon which the record

* For a full description of this instrument see Appendix No. 9, Report for 1889, by Edwin Smith, Assistant.

† See Appendix No. 7, Report for 1879, for a "Description of the Davidson Meridian Instrument."

sheet is wound, and the screw which gives the pen carriage a slow motion parallel to the axis of the record cylinder. When the speed governor is first released, the speed continually increases until the governor balls have moved far enough away from the axis of revolution to cause a small projection upon one of them to strike a small hook. This impact and the effect of the friction at the base of the weight attached to the hook causes the speed to decrease continually until the hook is released. The speed then increases again until the hook is engaged, decreases until it is released, and so on. The total range of variation in the speed is, however, surprisingly small, so small that in interpreting the record of the chronograph the speed is assumed to be uniform during the intervals between chronometer breaks. The speed may be regulated by screwing or unscrewing the movable weights which are above the governor balls and attached to the same arm. This moves them nearer to or farther from the axis, and thus decreases or increases the critical speed at which the hook is engaged. To get a convenient record it is desirable to adjust the speed so that the record cylinder makes just one revolution per minute with the ordinary arrangement of the train of gears. The gears may also be changed quickly to another combination which will run the record cylinder at double speed. This will require additional driving weights.

The electric circuit, as shown in the illustration, passes from the battery through the chronometer, through an observing key* which normally keeps the circuit closed and breaks it only when the key is pressed, and through a magnet on the pen carriage which controls an armature fastened to the rear part of the lever carrying the pen. If the current in this circuit is continuous, the pen draws a continuous helix on the record sheet wound upon the record cylinder. Whenever the current is broken, the pen armature is released and the pen moves to the left (as seen in the illustration). It returns to the helix when the current is made. In operation the chronometer breaks the circuit automatically every second (or every two seconds) and the pen records the breaks upon the moving record sheet, at equal or very nearly equal linear intervals. The chronometer is usually arranged to indicate the beginning of each minute by omitting one break. The hours and minutes may be identified by writing upon some point upon the record sheet the corresponding reading of the face of the chronometer. To record the exact time of transit of a star image across a given line of the diaphragm of a transit instrument, the observer presses the key at that instant, which breaks the circuit, and so produces an additional offset from the helix of which the *position* indicates accurately the *time* at which it was made,—the chronograph being assumed to run at a uniform rate between the two adjacent chronometer breaks. To read the fractions of seconds from the chronograph sheet, it is convenient to use a glass scale divided into intervals corresponding to tenths of seconds and formed by converging lines so as to fit varying lengths of seconds. The process of reading is also facilitated by writing the number of the second at the head of each column, and of the minute on each line of the unrolled sheet. The *beginning* of each break made by the chronometer or observer is the exact point upon which the reading is to be made, the time being always defined by the break of the circuit and not by the make, which is of course indefinite. Star transits are generally read from the sheet to the nearest half tenth (·05) of a second, but time signals in longitude work are read to the nearest hundredth (·01), the chronograph being then run

*This key is attached to much longer wires than those shown in the illustration, so that it may be used at the transit and on either side of it.

at double speed. There will occasionally be a slight interference by overlapping between the chronometer and the observation record on the sheet, but the time of observation can generally be closely estimated by comparing the lengths of succeeding breaks.

A condenser should be placed in the circuit across the terminals of the chronometer to prevent sparking and the consequent injury at the points at which the circuit is broken in the chronometer. The strength of current,* the tightness of the spring which draws back the pen armature, the distance of that armature from the magnet core, and the range of movement of the armature must all be adjusted relatively to each other so that the pen will furnish a neat and complete record of all breaks in the circuit. The driving weight must be heavy enough to overcome all friction and cause the governor hook to be engaged frequently, but must not be so heavy as to cause the hook to be carried forward continuously after it is once engaged.

THEORY OF THE TRANSIT INSTRUMENT.

5. If a transit instrument were in perfect adjustment the line of collimation† of the

*The modern dry cells have been found most convenient for use with the chronograph in field work. To save the break-circuit points in the chronometer no greater number of cells should be used than are actually necessary. As these cells run down somewhat quickly on a circuit of low resistance, it has been found most advantageous to have high-resistance magnets to work the pen armature, thus insuring a more constant current. As the cells are now inexpensive they should be discarded on showing signs of deterioration. When more than one cell is used, their grouping in series or in parallel should depend on the resistance of the circuit.

†There is a confusion in text-books on astronomy and surveying as to the meaning of the phrase "line of collimation," which is much to be regretted. Two different meanings are given to the phrase, and it is not at all rare to find both meanings implicitly used within the covers of a single book. The dictionaries also contradict each other. They agree that the word collimation is derived from the Latin *collineare*, or from some other form of that word, as *collimare*, or from the Italian *collimare*. According to any of these roots the "line of collimation" is the aiming line or pointing line. The line of collimation of an astronomical transit may be defined, in accordance with this derivation, to be either that line which in theory, that is, in a perfectly adjusted instrument, is pointed at the object, or that line defined by the cross lines at the focus of the objective which is actually used as an aiming line. In an astronomical transit, according to the first of these two definitions, it is the line through the optical center of the objective at right angles to the horizontal axis upon which the telescope rotates. According to the second definition it is the line which passes through the optical center of the objective and the middle of the mean line of the reticle, this being the point corresponding to the intersection of cross wires in the reticle of a theodolite or in an engineer's transit. The Century and Standard dictionaries give the first of the two definitions indicated above. Worcester, Webster's International, and the Encyclopædic Dictionary all give the second definition. Among standard text-books of astronomy, Chauvenet, Volume II, page 12, gives the second definition, but afterwards, page 160, uses the expression "collimation axis" with the meaning contained in the first definition. Loomis, page 47, gives the second definition. Doolittle, pages 280, 481, implies the second definition by asserting that the line of collimation may be adjusted; and again, on page 525, apparently contradicts himself by using the expression collimation axis with the meaning of the first definition.

Though not presuming to render a decision in this matter, in which dictionaries and experts each disagree among themselves, the writer finds it necessary for the sake of clearness to adhere consistently to one or the other of these definitions throughout this appendix, and has chosen the second definition. In this appendix, then, the line of collimation of a telescope is the pointing line actually used, namely, the line passing through the optical center of the objective and the intersection of the cross lines in a theodolite, or the middle point of the middle vertical line in a zenith telescope, or the middle point of the mean (vertical) line in an astronomical transit. In each case the error of collimation is the angle between the line of collimation and the line through the center of the objective at right angles to the horizontal axis of the telescope.

telescope as defined by the mean line of the diaphragm would be at right angles to the transverse axis, upon which the telescope rotates, and that transverse axis would be in the prime vertical and horizontal. Under these circumstances the line of collimation would always lie in the meridian plane, and the local sidereal time at the instant when a given star crossed the line of collimation would necessarily be the same as the right ascension of that star. The difference, then, between the *chronometer* time of transit of a given star across the line of collimation and the right ascension of that star would be the error of the chronometer on local sidereal time. Before observing meridian transits for the determination of time the conditions stated in the first sentence of this paragraph are, by careful adjustment of the instrument, fulfilled as nearly as possible. The time observations themselves and certain auxiliary observations are then made in such a manner as to furnish determinations of the small remaining errors of adjustment; and the observed times of transit are corrected as nearly as may be to what they would have been if the observations had been made with a perfectly adjusted instrument. The observed chronometer time of transit of any star across the line of collimation *as thus corrected* being subtracted from the right ascension of that star gives the correction (on local sidereal time) of the chronometer with which the observation was made.

ADJUSTMENTS.

6. Let it be supposed that observations are about to be commenced at a new station at which the pier and shelter for the transit have been prepared. By daylight make the following preparations for the work of the night.

By whatever means are available determine the direction of the meridian, mark it upon the top of the pier or by an outside natural or artificial signal, and put the sub-base or the foot plates of the instrument in such positions that the transit telescope will swing as nearly as may be in the meridian. It is well to fix the sub-base or foot plates rigidly in position by cementing them to the pier with plaster of Paris. The meridian may be determined with sufficient accuracy for this purpose by means of a compass needle, the magnetic declination being known and allowed for. A known direction from triangulation or from previous azimuth observations may be utilized. All that is required is that the telescope shall be so nearly in the meridian that the final adjustment may be made by means of the screws provided upon the instrument for the azimuth adjustment.

Set up the instrument and inspect it. The pivots and wyes of both transit and level should be cleaned with oil, which is to be wiped off to prevent its accumulating dust. The lens should occasionally be examined to see that it is tight in its cell. The lens may be dusted with a camel's hair brush, and when necessary may be cleaned by rubbing gently with soft tissue paper, first moistening the glass slightly by breathing on it.*

Focus the eyepiece by turning the telescope up to the sky and moving the eyepiece in and out until that position is found in which the most distinct vision of the lines of the diaphragm is obtained. If any external objects are visible through the eyepiece in addition to the lines of the diaphragm seen projected against a uniform background (of sky for example) the eye will attempt in spite of its owner to focus upon those objects

* If unusual difficulty is had with the illumination at night, it is sometimes advisable to remove the eyepiece and look directly at the reflecting mirror in the telescope tube, seeing that it is in the proper position and its whole surface illuminated.

as well as upon the lines, and the object of the adjustment, namely, to secure a focus corresponding to a minimum strain upon the eye, will in general be defeated to a certain extent.

Focus the objective by directing the telescope to some distant well-defined object (not less than a mile away) and changing the distance of the objective from the diaphragm until there is no apparent change of relative position (or parallax) of the lines of the diaphragm and the image of the object when the eye is shifted about in front of the eyepiece. The object of the adjustment, namely, to bring the image formed by the objective into coincidence by the diaphragm, is then accomplished. If the eyepiece has been properly focused this position of the objective will also be the position of most distinct vision. The focus of the objective will need to be inspected again at night, using a star as the object, and corrected if necessary. Unless the focus is made nearly right by daylight none but the brightest stars will be seen at all at night and the observer may lose time in trying to find out what is the matter. A scratch upon the draw tube to indicate its approximate position for sidereal focus will be found a convenience. The draw tube is clamped in position with the screws provided for that purpose, after a satisfactory focus is obtained.

Adjust the striding level in the ordinary manner, placing it on the pivots direct and reversed. If in adjustment, the difference of the two east (or west) end readings will be zero for a level numbered in both directions from the middle,* or the sum of the two east (or west) end readings will be double the reading of the middle of the tube for a level numbered continuously from one end. It is also to be adjusted for wind. If the axis of the level tube is not parallel with the wyes the bubble will move longitudinally when the level is rocked back and forth on the pivots, and the end provided with the side adjusting screws is to be moved until this test is satisfactory. In placing the level upon the pivots it should always be rocked slightly to insure its being in a central position and in good contact.

Level the horizontal axis of the telescope. This adjustment may of course be combined with that of the striding level.

To test the verticality of the lines of the diaphragm point upon some well-defined distant object, using the apparent upper part of the middle vertical line of the diaphragm. Rotate the telescope slightly about its horizontal axis until the object is seen upon the apparent lower part of the line. If the pointing is no longer perfect the diaphragm must be rotated about the axis of figure of the telescope until the line is in such a position that this test fails to discover any error.

To adjust the collimation point upon some well-defined distant object with the middle vertical line, reverse the telescope in its wyes, and direct it again to the object. If the pointing is now perfect the line of sight defined by the *middle* line of the diaphragm is at right angles to the horizontal axis and the *mean* line may be assumed to be sufficiently near that position. If necessary, make the adjustment by moving the diaphragm sidewise half way back to the object, clamping it in position when satisfactory. As the collimation adjustment should be made with the telescope at sidereal focus, when no object sufficiently distant is visible at the station, it will be necessary

* It is as well to use a striding level thus numbered, slightly out of adjustment, so that the readings direct and reversed will differ somewhat, thus enabling errors in these readings, and especially an interchange of readings, to be more easily detected.

either to make this adjustment at another place, or to use a collimating telescope. For the latter a theodolite or surveying transit may be employed, to be set up immediately in front of the astronomical transit. Both instruments are adjusted to sidereal focus and pointed toward each other. If necessary, the lines in the theodolite are artificially illuminated, and one of them is used as a reference in the same manner as a distant mark.

To test a finder circle which is supposed to read zenith distances, point upon an object by placing its image midway between the horizontal lines of the diaphragm, read the circle, reverse the telescope, and point upon the same object again and read the same finder circle as before. The mean of the two readings is the zenith distance of the object, and their half difference is the index error of the circle. This index error may be made zero by setting the circle to the true zenith distance, pointing on the object, and bringing the vernier bubble to the center with the level adjusting screw. At night this adjustment may be made by keeping a known star between the horizontal lines as it transits across the meridian. While the telescope remains clamped in this position set the finder circle to read the known zenith distance of the star and then bring the bubble to the middle position as before. A quick test when there are two finding circles is to set them at the same angle and see if the bubbles come to the center for the same position of the telescope.

The preceding adjustments can not always be made in the order named, as, for instance, when a distant mark can not be seen in the meridian, nor need they all be made at every station. The observer must examine and correct them often enough to make certain that the errors are always within allowable limits.

The azimuth adjustment.—In the evening, before the regular observations are commenced, it will be necessary to put the telescope more accurately in the meridian. If the chronometer correction is only known approximately, say within one or two minutes, set the telescope for some bright star which is about to transit within 10°, say, of the zenith. Observe the chronometer time of transit of the star. This star being nearly in the zenith, its time of transit will be but little affected by the azimuth error of the instrument. *

The collimation and level errors having previously been made small by adjustment, the right ascension of this star minus its chronometer time of transit will be a close approximation to the chronometer correction. Now set the telescope for some star of large declination (slow-moving) which is about to transit well to the northward of the zenith. Compute its chronometer time of transit, using the chronometer correction just found. As that time approaches bisect the star with the middle vertical line of the diaphragm and keep it bisected, following the motion of the star in azimuth by the slow-motion screws provided for that purpose, until the chronometer indicates that the star is on the meridian.

The adjustment may be tested by repeating the process; that is, by obtaining a closer approximation to the chronometer error by observing another star near the zenith and then comparing the computed chronometer time of transit of a slow-moving northern star with the observed chronometer time of transit. If the star transits apparently

* To avoid waiting for stars close to the zenith the chronometer correction may also be estimated closely by comparing observations of two stars not very distant from the zenith, one north and one south, and these at the same time will give some idea of the amount and direction of the azimuth error.

too late, the objective is too far west (if the star is above the pole), and *vice versa*. The slow-motion azimuth screw may then be used to reduce the azimuth error. This process of reducing the azimuth error will be much more rapid and certain if, instead of simply guessing at the movement which must be given the azimuth screw, one computes roughly what fraction of a turn must be given to it. This may be done by computing the azimuth error of the instrument roughly by the method indicated in § 16, having previously determined the value of one turn of the screw.*

If from previous observations the chronometer correction is known within, say, 5 seconds, the above process of approximation may be commenced by using a northern star at once, instead of first observing a zenith star as indicated above.

Or, the chronometer correction being known approximately, and the instrument being furnished with a screw or graduated arc with which a small horizontal angle may be measured, the first approximation to the meridian may be made by observing upon Polaris, computing the azimuth approximately by use of the tables of azimuth of Polaris at different hour angles given in Appendix No. 10 of the Report for 1895, then by means of the screw or graduated arc swinging the instrument into the meridian. Where saving of time is an important consideration, the latter method has the advantage that Polaris may be found in daylight, when the sun is not too high, by setting the telescope at the computed altitude and moving it slowly in azimuth near the meridian. It is advisable to use a hack chronometer and the eye and ear method in making the azimuth adjustments, the chronograph being unnecessary for this purpose, even when available.

OBSERVING LIST.

7. The following is an example of a list of stars selected for time observations, consisting of two sets of five stars each. Such a list prepared in easily legible figures (and without the star factors) should be posted in the observatory.

Star list for Washington, D. C.—Latitude 38° 54′ N.

Star.	Catalogue.	Magnitude.	Right ascension. α	Declination. δ	Zenith distance. ζ	Diurnal aberration. κ	Star factors.		
							Inclination. B	Collimation. C	Azimuth. A
			h. *m.* *s.*	° ′	° ′	*s.*			
17 H. Can. Ven.	B	5·5	13 30 12	+37 43	+ 1 11	—·02	1·26	1·26	+·02
η Ursæ Maj.	B	2·0	43 30	+49 50	—10 56	—·02	1·53	1·55	—·30
η Bootis	B	3·0	49 47	+18 55	+19 59	—·02	0·99	1·06	+·36
11 Bootis	B	6·0	56 31	+27 53	+11 01	—·02	1·11	1·13	+·22
α Draconis	B	3·3	14 01 39	+64 52	—25 58	—·04	2·12	2·36	—1·03
d Bootis	B	5·0	05 42	+25 35	+13 19	—·02	1·08	1·11	+·25
α Bootis	B	1·0	10 58	+19 43	+19 11	—·02	1·01	1·06	+·35
λ Bootis	B	4·0	12 29	+46 34	— 7 40	—·02	1·44	1·46	—·19
θ Bootis	B	3·8	21 43	+52 20	—13 26	—·03	1·59	1·64	—·38
5 Ursæ Min.	A	4·5	27 51	+76 09	—37 15	—·06	3·33	4·18	—2·53

B = Berliner Astronomisches Jahrbuch. A = American Ephemeris.

*Some of the meridian telescopes carry a small graduated arc on the double base of the frame, which may be used for measuring the small angle here required.

On account of the greater number of time stars given it is generally more convenient to select observing lists from the Berliner Jahrbuch, supplementing it by additional stars from the American Ephemeris when necessary.

For the principles which should guide one in selecting stars to be observed, see § 21.

DIRECTIONS FOR OBSERVING.

8. Everything being in readiness and the instrument completely adjusted set the telescope for the first star. It is not advisable to use the horizontal axis clamp during observations, for its action may have a slight tendency to raise one end of the axis. See to it, loading one end if necessary, that the center of gravity of the telescope is at its horizontal axis, and then depend upon the friction at the pivots to keep the telescope in whatever position it is placed. Watch the chronometer* so as to know when to expect the star to appear in the field of view of the telescope. When the star enters the field, bring it between the horizontal lines of the diaphragm, if it is not already there, by tapping the telescope lightly. If a longitudinal motion is provided for the eyepiece, it should be centered so that the vertical line nearest the star is in the middle of the field of view, and during the progress of the observations it should be kept approximately centered over the lines being observed upon.

If a chronograph is being used the process of observing the transit of the star image across a line of the diaphragm consists simply of waiting, key in hand, until the instant when the star is apparently bisected by the line and then pressing the key as soon as possible thereafter. The time record thus made upon the chronograph will always *follow* the event by a time interval, known as personal equation, which depends mainly upon the rapidity of action of the nerves and brain.

It will usually occur to a new observer to attempt to make this time interval zero by estimating the rate of progress of the star image by eye, and beginning the brain and nerve action which ultimately results in pressure upon the key, at a sufficient interval before the star is actually seen bisected to insure that the apparent bisection and breaking of the circuit occur at the same instant. It is true that by this process the time interval in question may be reduced to zero or may even become negative. But the accumulated experience of many observers indicates that with such a process of observing the accidental errors are much larger than with the process recommended above. The personal equation may be eliminated from results, whenever that is sufficiently desirable, by special observations, or by programmes of observing devised for that purpose (see § 33). It is much more important to make the personal equation constant than to make it small. Hence the method of observing stated in the preceding paragraph is to be used rather than that described in this paragraph.

At about the middle of the observations which are to constitute a set the telescope should be reversed, so that the effects of error of collimation and inequality of pivots upon the apparent times of transit may be reversed in sign. Three or four readings of the striding level, in each of its positions (direct and reversed) should be taken during each half set. To eliminate, in part at least, the effect of irregularities in the figure of the

* When a chronograph is being used, it is customary to keep the chronometer which is connected with the chronograph protected as carefully as possible from rapid changes of temperature and from jars. During the observations it is not usually removed from its protecting box, but instead, an extra chronometer (sometimes called a hack chronometer) is used at the instrument.

pivots upon the determination of the inclination of the axis, it is desirable to take the level readings with the telescope inclined at the various practicable angles at which stars are observed, and to make half of them with the objective to the northward and half with the objective southward. Great care should be taken to avoid unequal heating of the two ends of the striding level. The level readings may be checked and possible errors often detected by the fact that the bubble length should be constant except for the effect of change of temperature (the bubble shortens with rise of temperature), and in observing and computing this should be kept in mind. A very short length of bubble should not be used on account of increased tendency to stick, and either extreme of length should be avoided because of danger of running off the graduation. In using the striding level it is important that the bubble be given time to come to rest refore reading.

The only difference between the eye and ear method of observing time and the chronographic method just described is in the process of observing and recording the times of transit of the star image across the separate lines of the diaphragm.

Before using the eye and ear method the observer must first learn to pick up the beat of a chronometer and to carry it even while paying attention to other matters. To pick up the beat of a chronometer, first look at some second's mark two or more seconds ahead of the second hand. Fix the name of that second in mind as the second hand approaches it. Name it exactly with the tick at which the second hand reaches it. Then, keeping the rythm of the chronometer beat, count the seconds and half seconds (aloud, in a whisper, or mentally), always keeping the count exactly with the tick of the chronometer. In counting it will be found easier to keep the rythm if the names of the numerals are elided in such a way as to leave but a single staccato syllable in each. The half-second beat should be marked by the word "half," thus: one, half, two, half, three ..... *twenty*, half, twenty-*one*, half, twenty-*two* ..... and so on.* With practice, an observer can carry the count of the beat for an indefinite period without looking at the chronometer face if he can hear the tick. If he becomes expert he will even be able to carry the count for a half minute or more during which he has not even heard the tick. The chronometer should of course be placed where it can be seen and heard by the observer with as little effort as possible.

To observe the time of transit of a star across a given line the observer first picks up the beat of the chronometer as the star approaches the line. At the last tick of the chronometer occurring before the transit he notes mentally the number of the tick and also carefully observes the apparent distance of the star from the line. At the next tick the star is on the other side of the line and the observer notes again the apparent distance of the star from the line. By a mental comparison of these two *distances* he estimates fifths of the *time interval* between the two ticks of the chronometer and obtains his estimate of the time of transit to the nearest tenth of a second. Though the mental processes involved may seem difficult at first, practice soon makes them easy. An experienced observer using this process is able to estimate the time of transit of a star's image across a line of the diaphragm with a probable error of about $\pm 0^{s}.1$. It is conducive to accuracy for the observer to acquire the habit of deciding definitely, at once, without hesitation, upon the second and tenth as soon as the event is complete. In this matter he who hesitates is inaccurate.

* Another method often used is to count only to ten (thus using only words of one syllable) and to glance at the chronometer after the observation to show the position in the minute.

EXAMPLE OF RECORD AND COMPUTATION.*

9. Below is an example of a set of time observations recorded chronographically, the star transits having been read from the chronograph sheet and recorded in this form, on which also the computation is carried as far as the application of the rate, aberration, and level corrections and the derivation of $\alpha - t_1$. Explanation of the formulæ and methods used in this computation follow in §§ 10–13.

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* The constants of the instrument used in this example are as follows:
1 division of striding level = 1″·674 (= 0ˢ·0279 × 4).
Pivot inequality = − 0ˢ·010, band west.
Equatorial intervals of lines, band west,

	s.		s.
Line 1	+15·20	Line 7	− 2·52
2	+12·69	8	− 5·11
3	+10·15	9	−10·09
4	+ 5·06	10	−12·65
5	+ 2·52	11	−15·15
6	− 0·09		

Station, Washington, D. C. Date, May 17, 1896. Observer, G. R. P.

Star.	17 H. Can. Ven.		η Urs. Maj.		η Bootis.		11 Bootis.		α Draco.	
Position of band.	West.		West.		West.		West.		West.	
Direction of objective for level reading.	S.				S.				N.	
	W. end.	E. end.			W. end.	E. end.			W. end.	E. end.
	d.	*d.*			*d.*	*d.*			*d.*	*d.*
	22·7	24·1			27·8	20·0			28·0	19·9
Level readings.	27·1	19·9			22·9	24·8			22·9	24·9
ΣW. and ΣE.	49·8	44·0			50·7	44·8			50·9	44·8
ΣW. − ΣE.	+5·8				+5·9				+6·1	
Remarks and computation of *b*.			Means of levels. *d.* N. +6·10 S. +5·85 +5·98 × ·0279 = *s.*		+ ·167 = βw (*s.*) − ·010 = pivot inequality. + ·157 = bw					
Observed transit.	*h. m. s.*		*h. m. s.*		*h. m. s.*		*h. m. s.*		*h. m. s.*	
Line 1	13 29 56·90		13 43 10·60		13 49 34·45		13 56 17·20		14 01 07·55	
2	13 30 00·10	Mean. *s.* 14·20	14·35		37·05		20·00		13·30	
3	03·30		18·30		39·70		22·80		19·35	
4	09·70		26·15		45·00		28·40		31·25	
5	12·90	Correction.	30·15	*s.*	47·75	*s.*	31·50	*s.*	37·30	*s.*
6	16·00		33·80	33·80	50·25	50·25	34·30	34·30	43·00	43·00
7	19·30		37·95	68·10	52·95	100·70	36·90	68·40	49·00	86·30
8	22·60	15·15 / 10	41·70	7·85	55·70	0·70	40·05	8·45	55·20	6·45
9	29·00		49·70	8·00	13 50 00·90	0·60	45·65	8·45	14 02 06·90	6·25
10	32·20	× 1·26	53·60	7·95	03·75	0·80	48·60	8·60	12·90	6·20
11	—	= + 1·92	57·55	8·15	06·50	0·95	51·50	8·70	18·85	6·40
Mean.	16·12		33·99	10·85	50·36	4·00	34·26	2·90	43·15	1·60
Cor. for rate, = R	+ ·03		+ ·02		+ ·01		+ ·01		·00	
Cor. for diur. aberration, = κ	− ·02		− ·02		− ·02		− ·02		− ·04	
Cor. for inclination, = Bb	+ ·20		+ ·24		+ ·16		+ ·17		+ ·33	
t_1	13 30 16·33		13 43 34·23		13 49 50·51		13 56 34·42		14 01 43·44	
α	13 30 12·26		13 43 30·14		13 49 46·82		13 56 30·53		14 01 38·92	
$\alpha - t_1$	−4·07		−4·09		−3·69		−3·89		−4·52	

Instrument, transit No. 18. Chronometer, Negus, 1836 (daily rate, ^{s}1·51 gaining).

d Bootis.		α Bootis.		λ Bootis.		θ Bootis.		5 Urs. Min.	
East.		East.		East.		East.		East.	
S.				*N.*				*N.*	
W. end.	E. end.			W. end.	E. end.			W. end.	E. end.
d.	*d.*			*d.*	*d.*			*d.*	*d.*
27·1	20·9			27·2	20·9			22·2	26·0
22·7	25·2			22·9	25·3			27·2	21·0
49·8	46·1			50·1	46·2			49·4	47·0
+3·7				+3·9				+2·4	
		Means of levels. *d.* N. +3·15 S. +3·70 +3·42×·0279= ^{s}		^{s} +·095=βe + ·010=pivot inequality. + ·105=be				Thin clouds and hazy. Temperature 76° F.	
h. m. s.		*h. m. s.*		*h. m. s.*		*h. m. s.*		*h. m. s.*	
14 05 29·40	Mean.	14 10 45·50		14 12 11·15		14 21 22·30		14 26 53·15	
32·20	*s.*	48·20		14·80		26·40		27 03·15	
34·85	44·76	50·90		18·60		30·60		14·25	
40·60	Correction.	56·20		25·95		38·90		35·30	
43·35	12·69	58·90	*s.*	29·50	*s.*	42·90	*s.*	45·85	*s.*
46·20		14 11 01·65	01·65	33·45	33·45	47·35	47·35	57·15	57·15
48·90	10	04·30	03·20	37·00	66·50	51·35	94·25	14 28 07·00	112·85
51·90	× 1·11	07·10	3·30	40·70	6·65	55·40	4·30	18·00	3·30
57·30	= 1·41	12·30	3·20	48·00	6·60	14 22 03·60	4·20	38·70	2·95
—		15·20	3·40	51·80	6·60	07·80	4·20	49·50	2·65
14 06 02·90		17·70	3·20	55·25	6·40	11·95	4·25	14 29 00·05	3·20
46·17		01·63	6·95	33·29	3·20	47·14	1·55	56·55	72·10
·00		− ·01		− ·01		− ·02		− ·03	
− ·02		− ·02		− ·02		− ·03		− ·06	
+ ·11		+ ·11		+ ·15		+ ·17		+ ·35	
14 05 46·26		14 11 01·71		14 12 33·41		14 21 47·26		14 27 56·81	
14 05 42·32		14 10 57·90		14 12 29·18		14 21 42·97		14 27 51·37	
−3·94		−3·81		−4·23		−4·29		−5·44	

CORRECTION FOR INCLINATION OF AXIS.

10. If the horizontal axis of the telescope is slightly inclined to the horizon but the telescope is otherwise in perfect adjustment the line of collimation will, when the telescope is rotated about its horizontal axis, describe a plane which passes through the north and south points of the horizon and makes an angle with the meridian plane equal to the inclination of the axis to the horizon. If the eastern end of the axis is too high the transits of all stars above the pole (apparently moving westward) will be observed too late, and the transits of all subpolars will be observed too early, and it is therefore necessary to correct the observed times of transit by means of the observed readings of the striding level.

Let w and e be the readings of the west and east ends, respectively, of the bubble of the striding level for a given position of the telescope axis. Let w' and e' be the corresponding west and east readings after the level is reversed, the telescope axis remaining as it was. Let d be the value of a division of the level in seconds of arc. Then for β, the apparent inclination of the telescope axis, expressed in seconds of time, we may write, if the level divisions are numbered in both directions from the middle.

$$\beta = \tfrac{1}{4}\left\{(w+w')-(e+e')\right\}\frac{d}{15} = \left\{(w+w')-(e+e')\right\}\frac{d}{60}$$

in which $\frac{d}{60}$ is a constant for the level.

If the level divisions are numbered continuously from one end of the level to the other the above formula takes the form

$$\beta = \left\{(w-w')+(e-e')\right\}\frac{d}{60}$$

in which the primed letters refer to that position of the level in which the division marked zero is at the western end.*

The level readings give a determination of the inclination of the line joining the highest points of the two pivots, but do not directly give the required inclination of the axis of rotation of the telescope, which is the line joining the centers of the pivots, unless the pivots are of the same size. Let p, the pivot inequality, be the angle, expressed in seconds of time, between the line joining the centers of the pivots and the line joining their highest points, and let this angle be called positive if the pivot through which the illumination passes (or nearest the bright band, if the ends of the telescope axis are so distinguished) is the smaller.

*As w is greater than w' and e less than e', the former difference is always + and the latter −, so that when the differences are taken vertically the resulting sign of the level correction will at once be apparent, as shown in the following example:

West	East
d.	*d.*
14	30
29	13
+15	−17

d.
−2

Then

$$b_w = \beta_w + p \text{ and } b_e = \beta_e - p^*$$

in which b is the required inclination of the axis of rotation of the telescope, and the subscripts indicate the position, to westward or to eastward, of the bright band, or the illumination, or whatever mark is used to distinguish between the two positions of the telescope axis. The pivot inequality, p, is ordinarily derived from a special series of observations taken for that purpose. For an example of such a series with the corresponding formula, see § 24.

The correction for inclination to the observed time of transit of any star is

$$b \cos \zeta \sec \delta = bB,$$

in which δ is the declination of the star and ζ is its zenith distance ($= \phi - \delta$ for stars above the pole and $= \phi + \delta - 180°$ for subpolars). The factor $B = \cos \zeta \sec \delta$ is tabulated on pages 308–319. It is positive for stars above the pole and negative for subpolars.

In the example given in § 9 the inclination, b, is assumed to be constant for each half set. Within each half set the mean of the observed values of β with objective northward was first derived, then the corresponding mean with objective southward, and finally the mean of these two means was taken as the β for the half set. This is the present practice of the longitude parties. For a discussion of this matter see § 26.

The value of B for each star, as taken from the table on pages 308–319, is shown in the observing list § 7.

REDUCTION OF INCOMPLETE TRANSITS.

11. If the transit of a star across every line of the diaphragm is observed, the mean of the times is the required time of transit across the mean line. In obtaining the sum of the several observed times any gross error in any one of the times may be detected by using the auxiliary sums, shown in the example in § 9 in the little column just after the observed times, namely, the sum of the first and last times, of the second and last but one, third and last but two, etc. These auxiliary sums should be nearly the same and nearly equal to double the time on the middle line. This is also a convenient method of taking means, as it is in general only necessary to sum the decimal columns.

When the star was observed on some of the lines but missed upon the others, the time of transit over the mean of all the lines may be found as follows:

$$t = \text{mean of observed times} - \frac{(\text{sum of equatorial intervals of observed lines})\ (\sec \delta)}{\text{number of observed lines.}} \dagger$$

$$\text{or } t = \text{mean of observed times} + \frac{(\text{sum of equatorial intervals of missed lines})\ (\sec \delta)}{\text{number of observed lines.}}$$

The first of these formulæ is the more convenient if but few lines were observed and the second the more convenient if but few lines were missed. The two incomplete transits shown in the example in § 9 were reduced by the second formula.

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*These formulæ are exact only in case the angle of the level wyes is the same as the angle of the supporting wyes.

†The collimation factor C (as given in the star list § 7) is the sec δ.

t is the time of transit across the mean of all the lines of the diaphragm. The equatorial interval of a given line is the time which would elapse between the transit of an equatorial star over the mean line of the diaphragm and the transit over the line in question. It is, in seconds of time, $\frac{1}{15}$ the angular interval between the lines expressed in seconds of arc. An equatorial interval is called positive when the transit across the line in question occurs later than the transit across the mean line. The signs of all the equatorial intervals are therefore reversed when the horizontal axis of the telescope is reversed.

For an example of the method of computing the equatorial intervals see § 23.

The above formulæ for reduction to the mean line are approximate, and the maximum possible error of the approximation increases with an increase in the declination of the star and with an increase in the equatorial intervals of the extreme lines. If the extreme equatorial interval is 60^s, the maximum error is less than $0^s.01$ for a star of which $\delta = 70°$, and is only $0^s.3$ if $\delta = 85°$. If the extreme interval is 15^s, the maximum error is less than $0^s.01$ if $\delta = 85°$.

The more exact formula for use with circumpolar stars is the same as that given above, except that for each equatorial interval, i, must be substituted $i\sqrt[3]{\sec \tau}$, in which τ is the hour angle of the star at transit across the line, or with sufficient accuracy $\tau = i \sec \delta$ = the actual time interval from the mean line.

The following table will be found useful in connection with this formula.

τ	$\log. \sqrt[3]{\cos. \tau}$	$\log. \sqrt[3]{\sec. \tau}$.	τ	$\log. \sqrt[3]{\cos. \tau}$.	$\log. \sqrt[3]{\sec. \tau}$.	τ	$\log. \sqrt[3]{\cos. \tau}$.	$\log. \sqrt[3]{\sec. \tau}$.
m.			*m.*			*m.*		
1	9·99999	0·00000	16	9·99965	0·00035	31	9·99867	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

If the chronometer rate exceeds 15^s per day it will be desirable to take it into account in making the reduction of incomplete transits to the mean line.

Another method of reducing incomplete transits is to construct from the known equatorial intervals a table similar to that of which a portion is printed below showing the interval of each line from the mean line corresponding to various declinations. The correction of each observed line to the mean line is then taken out directly from the table and the mean of the various corrected transits taken.

Intervals of lines of Transit No. 18 from mean line. The numbering of the lines is for band west.

δ.	Line I.	Line II.	Line III.	Line IV.	Line V.	Line VI.	Line VII.	Line VIII.	Line IX.	Line X.	Line XI.
0	+15·20	+12·69	+10·15	+5·06	+2·52	−0·09	−2·52	−5·11	−10·09	−12·65	−15·15
10	15·43	12·89	10·31	5·14	2·56	0·09	2·56	5·19	10·25	12·84	15·38
15	15·74	13·14	10·51	5·24	2·61	0·09	2·61	5·29	10·45	13·10	15·68
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
36	18·79	15·69	12·55	6·25	3·11	0·11	3·11	6·32	12·47	15·64	18·73
38	19·29	16·10	12·88	6·42	3·20	0·11	3·20	6·48	12·80	16·05	19·23
40	19·84	16·57	13·25	6·61	3·29	0·12	3·29	6·67	13·17	16·51	19·78
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
51	24·15	20·17	16·13	8·04	4·00	0·14	4·00	8·12	16·03	20·10	24·07
52	24·69	20·61	16·49	8·22	4·09	0·15	4·09	8·30	16·39	20·55	24·61
53	25·26	21·09	16·87	8·41	4·19	0·15	4·19	8·49	16·77	21·02	25·17
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Transit No. 18 was the instrument used for the observations shown in § 9. The incomplete transit of the star 17 H. Can. Ven., of which the declination is 37° 43′, may be computed as indicated below:

Line.	Correction.	Corrected transit.
I	+19·22	16·12
II	+16·04	16·14
III	+12·83	16·13
IV	+ 6·40	16·10
V	+ 3·19	16·09
VI	− 0·11	15·89
VII	− 3·19	16·11
VIII	− 6·46	16·14
IX	−12·75	16.25
X	−15·99	16·21

Mean = 16·12, agreeing with the result shown in the example in § 9.

The special advantage of this method of reducing incomplete transits is that a wild observation upon any one line is at once detected. Such wild observations are apt to occur under the conditions which produce incomplete transits, clouds, haste, or difficulty with illumination.

CORRECTION FOR RATE.

12. If the chronometer rate is not zero the chronometer correction changes during the progress of the time set. To reduce each observed chronometer time of transit across the mean line to what it would have been if the rate had been zero (and the correction equal to the correction which actually existed at the mean epoch of the set) apply the correction

$$R=(t_i-T_0)r_h$$

in which T_0 is the mean epoch of the time set (the mean of the chronometer times of transit, t_i) (t_i-T_0 is expressed in hours) and r_h is the hourly rate of the chronometer on sidereal time, + when losing and − when gaining.

CORRECTION FOR DIURNAL ABERRATION.

13. The effect of the annual aberration due to the motion of the earth in its orbit is taken into account in computing apparent star places, and so need not be considered here.

The correction for diurnal aberration to be applied to an observed time of transit across the meridian

$$\kappa = 0^s.021 \cos \phi \sec \delta$$

is shown in the following table, and is *minus* for all stars observed at upper culmination and *plus* for lower culmination.

Latitude $= \phi$.	Declination $= \delta$.										
	0°.	10°.	20°.	30°.	40°.	50°.	60°.	70°.	75°.	80°.	85°.
	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.	s.
0°	0·02	0·02	0·02	0·02	0·03	0·03	0·04	0·06	0·08	0·12	0·24
10°	·02	·02	·02	·02	·03	·03	·04	·06	·08	·12	·24
20°	·02	·02	·02	·02	·03	·03	·04	·06	·08	·11	·23
30°	·02	·02	·02	·02	·02	·03	·04	·05	·07	·10	·21
40°	·02	·02	·02	·02	·02	·03	·03	·05	·06	·09	·18
50°	·01	·01	·01	·02	·02	·02	·03	·04	·05	·08	·15
60°	·01	·01	·01	·01	·01	·02	·02	·03	·04	·06	·12
70°	·01	·01	·01	·01	·01	·01	·01	·02	·03	·04	·08
80°	·00	·00	·00	·00	·00	·01	·01	·01	·01	·02	·04

The corrections for rate, diurnal aberration, and inclination being applied to the observed time of transit across the mean line, as shown in example of computation in § 9, the result is t_1, an approximate time of transit across the meridian. The apparent right ascension at the time of observation is taken from the American Ephemeris or the Berliner Jahrbuch (preferably the latter).* The value of $\alpha - t_1$ from each star as shown in the example of § 9 is an approximate value for the chronometer correction,† to which must still be applied corrections for collimation error and azimuth error.

THE COLLIMATION CORRECTION.

14. If the instrument is otherwise in perfect adjustment but has a small error of collimation, the mean line describes a small circle parallel to the meridian and at an angular distance c, the error of collimation, from it, when the telescope is rotated about its horizontal axis.

$$\text{The collimation correction} = c \sec \delta = Cc$$

c is the angle, expressed in seconds of time, between the line of sight defined by the mean line of the diaphragm and a plane perpendicular to the horizontal axis of the telescope. c is to be considered positive for a given telescope if the line of sight is too far east (and stars at upper culmination are therefore observed too soon) when the illumination (or bright band) is to the westward.‡ c is to be derived from the time observations by one of the processes stated in §§ 16, 19, 22. The factor C is written for sec δ and is

* Or the apparent right ascension must be computed where only the mean place at the beginning of the year is given (as in the case of the bracketed stars in the Berliner Jahrbuch). An example of computation of apparent places is given in § 49.

† For subpolars, 12^h must first be added to or subtracted from α to make this statement true.

‡ This convention as to the sign of c is arbitrary. It might equally well be called positive if the stated conditions hold when the illumination (or bright band) is to the *eastward.*

tabulated on pp. 308–319. For observations made with illumination (or bright band) to the westward C must be considered *positive* for stars at upper culmination, and *negative* for stars at lower culmination. For observations made with illumination (or bright band) to the eastward C must be considered *negative* except for subpolars.

THE AZIMUTH CORRECTION.

15. If the instrument is otherwise in adjustment, but has a small error in azimuth, the mean line of the diaphragm will describe a vertical circle on the celestial sphere, making an angle, a, with the meridian. The correction in seconds to an observed time of transit for this azimuth error is

$$a \sin \zeta \sec \delta = aA$$

a is to be expressed in seconds of time and is to be considered positive when the line of sight is too far east when looking southward.

For convenience A is written for sin ζ sec δ and will be found tabulated on pp. 308–319. The factor A is considered positive except for stars between the zenith and the pole.

a is to be derived from the time observations by one of the processes stated in §§ 16, 19, 22.

COMPUTATION OF $\triangle T$, a, AND c, WITHOUT LEAST SQUARES.

16. The method of computation shown below has been in use in the field by the parties of this Survey for many years.*

[Station, Washington, D. C. Date, May 17, 1896.]

Star.	Band.	$\alpha - t_1$	C	A	Cc	Aa	ΔT† $\alpha - t_1 - Cc - Aa$	Δ	
		s.			s.	s.	s.	s.	
17 H. Can. Ven.	W	−4 ·07	+1 ·26	+ ·02	+ ·04	+ ·01	−4 ·12	+ ·10	
η Urs. Maj	W	−4 ·09	+1 ·55	− ·30	+ ·05	− ·17	−3 ·97	− ·05	
η Bootis	W	−3 ·69	+1 ·06	+ ·36	+ ·03	+ ·20	−3 ·92	− ·10	
II Bootis	W	−3 ·89	+1 ·13	+ ·22	+ ·04	+ ·12	−4 ·05	+ ·03	at $14^h\ 02^m\cdot0$
α Draconis	W	−4 ·52	+2 ·36	−1 ·03	+ ·08	− ·58	−4 ·02	·00	$\Delta T = -04^s\cdot024$
d Bootis	E	−3 ·94	−1 ·11	+ ·25	− ·04	+ ·13	−4 ·03	·00	
α Bootis	E	−3 ·81	−1 ·06	+ ·35	− ·03	+ ·18	−3 ·96	− ·07	
λ Bootis	E	−4 ·23	−1 ·46	− ·19	− ·05	− ·10	−4 ·08	+ ·05	
θ Bootis	E	−4 ·29	−1 ·64	− ·38	− ·05	− ·19	−4 ·05	+ ·02	
5 Urs. Min	E	−5 ·44	−4 ·18	−2 ·53	− ·13	−1 ·28	−4 ·03	·00	
		$\alpha - t_1$	C	A	Cc	$\alpha - t_1 - Cc$	Aa	$\alpha - t_1 - Cc - Aa$	
First approximation:									s.
Mean of time stars	W	−3 ·94	+1 ·25	+ ·08	+ ·06	−4 ·00	+ ·05	−4 ·05	$c = +\cdot051$
Azimuth star	W	−4 ·52	+2 ·36	−1 ·03	+ ·12	−4 ·64	− ·59	−4 ·05	$a_W = +\cdot577$
Mean of time stars	E	−4 ·07	−1 ·32	+ ·01	− ·07	−4 ·00	·00	−4 ·00	$a_E = +\cdot484$
Azimuth star	E	−5 ·44	−4 ·18	−2 ·53	− ·21	−5 ·23	−1 ·23	−4 ·00	
Second approximation:									
Mean of time stars	W				+ ·04	−3 ·98	+ ·04	−4 ·02	$c = +\cdot032$
Azimuth star	W				+ ·08	−4 ·60	− ·58	−4 ·02	$a_W = +\cdot559$
Mean of time stars	E				− ·04	−4 ·03	·00	−4 ·03	$a_E = +\cdot504$
Azimuth star	E				− ·13	−5 ·31	−1 ·28	−4 ·03	

* It was devised in the seventies by Assistant Edwin Smith, then an Aid upon the Survey.

† The complete formula for the chronometer correction is $\Delta T = \alpha - (t + R + \kappa + Bb + Cc + Aa)$. Let $t_1 = t + R + \kappa + Bb$, then $\Delta T = (\alpha - t_1) - Cc - Aa$, so that it will be seen that the corrections Cc and Aa are to be subtracted algebraically from $\alpha - t_1$.

The first five columns of the upper portion of the computation were compiled from the record and computation shown in § 9 and from the observing list shown in § 7. The remaining columns were filled out after the computation of a and c, shown in the lower portion of the form, was completed.

It should be noted that the five stars of each group, observed in one position of the instrument, have been so selected that one is a slowly moving northern star at a considerable distance from the zenith, while the other four are all comparatively near the zenith, some transiting to the northward of it and some to the southward, and at such distances from it that their mean azimuth factor (A) is nearly zero. These four stars of each group may be, for convenience called *time stars*, since the determination of time falls mainly upon them, while the slowly moving northern star serves to determine the azimuth error of the instrument, and may be called the *azimuth star*.

In this computation to derive c and a the time stars in each position of the instrument are combined and treated as one star by taking the means of their $(\alpha - t_1)$'s, and of their star factors C and A, respectively, these means being written below the separate stars in the form, together with the azimuth stars. On the assumption that the means of the time stars in the two positions of the instrument are equally affected by the azimuth correction, the first approximation to c is found by dividing the difference between the mean $(\alpha - t_1)$'s by the difference between the C's. In the example,

$$c \text{ (first approximation)} = \frac{(\alpha - t_1)_w - (\alpha - t_1)_e}{C_w - C_e} = \frac{-3^s.94 - (-4^s.07)}{+1^s.25 - (-1^s.32)} = \frac{+0^s.13}{+2^s.57} = +0^s.051$$

Using this approximation to c, the correction Cc is then subtracted from the $\alpha - t_1$ of each mean of the time stars and of each azimuth star, and the values of $\alpha - t_1 - Cc$, in the seventh column on the fifth to eighth lines from the bottom of the form, are obtained.

Separate values for the azimuth error of the instrument are then derived for each position of the instrument as follows:

$$a_w = \frac{(\alpha - t_1 - Cc)_{\text{time stars}} - (\alpha - t_1 - Cc)_{\text{azimuth star}}}{A_{\text{time stars}} - A_{\text{azimuth star}}} = \frac{-4^s.00 - (-4^s.64)}{+0^s.08 - (-1^s.03)} = \frac{+0^s.64}{+1^s.11} = +0^s.577$$

$$a_e = \frac{-4^s.00 - (-5^s.23)}{+0^s.01 - (-2^s.53)} = \frac{+1^s.23}{+2^s.54} = +0^s.484$$

With these values of a_w and a_e the corrections Aa are applied, giving the values $\alpha - t_1 - Cc - Aa$ in the last column. If these do not agree for the stars east and west it indicates that the mean values $\alpha - t_1$, used in deriving c, were not equally affected by the azimuth error, so that their difference was not entirely due to c, as was assumed. An improved value of c may now be obtained by treating the difference in the last column as still an error of collimation, and thus obtaining a correction to the first approximate value of c. Thus, in the example,

$$\frac{-4^s.05 - (-4^s.00)}{+1^s.25 - (-1^s.32)} = \frac{-0^s.05}{+2^s.57} = -0^s.019$$

Applying this correction to the first approximate value of $c = +0^s.051$, we have for a second approximation $c = +0^s.032$. Proceeding as before, improved values for a_w and a_e are found. If the star sets are well chosen and the instrumental errors small the first

approximation will generally suffice. If the values of $\alpha - t_1 - Cc - Aa$ differ by but a few hundredths, east and west, there is little gained by making a closer adjustment. The chronometer correction will probably not be changed at all, but the instrumental errors and star residuals will be slightly altered, as is apparent from the example, where the closer adjustment is made for the purpose of illustrating the method.

In the first approximation the value of c may at once be derived more closely when there is much difference between the mean A's for the time stars, by estimating the effect of this difference in A on the $\triangle T$, and allowing for this effect when deriving c in the first place. The formula for c then becomes

$$c = \frac{(\alpha - t_1)_w - (\alpha - t_1)_e - (A_w - A_e) \times a}{C_w - C_e}.$$

It is here necessary to estimate the azimuth of the instrument, a, roughly in advance, and this may be done by inspection. Thus, in the example, assuming $a = +0^s.5$, we have

$$c = \frac{-3.94 + 4.07 - (+.07) \times (+0.5)}{+1.25 + 1.32} = \frac{+.09}{+2.57} = +0^s.037$$

agreeing closely with the value given by the second approximation.

When satisfactory values of c, a_w, and a_e have been obtained, the corrections Cc and Aa are applied separately to each star, as shown in the upper part, and the values of the chronometer correction ($\triangle T$) derived separately. The residuals are taken for each group from the mean of that group, and thus furnish a convenient check on the computation, as their sums for each group should approximate zero. Unusual residuals also point to possible errors in $\alpha - t_1$. The mean of the $\triangle T$'s from the separate stars gives the final chronometer correction at the epoch of the mean of the right ascensions of the stars observed.

This whole computation may be made with rapidity by the use of Crelle's multiplication tables.

The field computation having been made as outlined above* the more refined office computation may be made as indicated in §§ 19, 20. It is desirable in this office computation to introduce weights dependent upon the declination of the star and the number of lines of the reticle upon which the star was observed.

RELATIVE WEIGHTS FOR INCOMPLETE TRANSITS.

17. Sometimes the transit of a star is observed over some of the lines of the diaphragm and missed over the others. Obviously the deduced time of transit over the mean line from such an incomplete transit should be given less weight than that from a complete transit.

For observations made by the *eye and ear method* the relative weights given by Chauvenet may be used, viz:

$$p = \frac{n\,(N+3)}{N\,(n+3)}$$

in which p is the weight to be assigned to the computed time of transit over the mean line, N is the total number of lines in the diaphragm, and n is the number of lines upon

*For a more complete account of this method of computation see Appendix No. 9, Report for 1896. The above account is largely taken from that Appendix.

which observations were made.* This formula is based upon the assumption that $\varepsilon^2 = 3\ \varepsilon_1^2$, in which ε = the probable error of an observed transit of an equatorial star over a *single* line and ε_1 = the probable culmination error referred to the equator, a constant for all the lines of the diaphragm for any one star, but variable from star to star, and supposed to be due mainly to atmospheric displacement, to outstanding instrumental errors, to irregularities in clock rate, and to changes in personal equation.

The following table shows the values of p and $\sqrt{p}$ for the two cases of 5 and 7 lines in the diaphragm:

For use with eye and ear observations.

n	p	$\sqrt{p}$	p	$\sqrt{p}$
1	0·40	0·63	0·36	0·60
2	0·64	0·80	0·57	0·75
3	0·80	0·89	0·71	0·84
4	0·92	0·96	0·82	0·91
5	1·00	1·00	0·90	0·95
6			0·95	0·97
7			1·00	1·00

The relative weights to be assigned to incomplete transits observed by the *chronograph method* may be derived as follows:

$$r^2 = \varepsilon_1^2 + \frac{\varepsilon^2}{n}$$

in which r = the probable error of the time of transit over the mean line, arising from the combined effect of the culmination error referred to the equator (ε_1) and of the probable error of the transit of an equatorial star over a single line (ε).

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, it was found that $r = \pm 0^s{\cdot}034$. 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 for our larger and smaller transits, respectively, there is obtained $r = \pm 0^s{\cdot}051$ and $r = \pm 0^s{\cdot}060$. For the larger transits $\varepsilon = \pm 0^s{\cdot}063$, and for the smaller $\varepsilon = \pm 0^s{\cdot}080$ (see § 18). Substituting these values in the above formula, together with the values 25 and 15 for n as actually used in the observations cited in § 18, there is obtained

$$(0{\cdot}051)^2 = \varepsilon_1^2 + \frac{(0{\cdot}063)^2}{25} \text{ and } (0{\cdot}060)^2 = \varepsilon_1^2 + \frac{(0{\cdot}080)^2}{15}$$

which give

$$\varepsilon_1 = \pm 0^s{\cdot}049 \text{ and } \varepsilon_1 = \pm 0^s{\cdot}056$$

for the larger and smaller instruments, respectively.

* See Chauvenet's Astronomy, Vol. II, p. 198. The derivation of this formula follows the same lines as that given on the following pages for weights to be assigned to incomplete transits taken by the chronographic method.

If the weight for a complete transit is unity, the weight for an incomplete transit is

$$p=\frac{\varepsilon_1^2+\frac{\varepsilon^2}{N}}{\varepsilon_1^2+\frac{\varepsilon^2}{n}}$$

Hence, for the larger instruments, using the above values for ε_1 and ε,

$$p=\frac{1+\frac{1.6}{N}}{1+\frac{1.6}{n}}$$

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, and are shown in the following table.

For use with chronographic observations.

Number of lines.	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														

RELATIVE WEIGHTS TO TRANSITS DEPENDING ON THE STAR'S DECLINATION

18. The following tables of the probable error (ε) of an observation of a transit of a star over a *single* line have been derived from a discussion of 1 047 transits taken in February and March, 1869, at San Francisco, by Assistant G. Davidson, with the large transit C. S. No. 3 (aperture 2¾ 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 2¾ 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 1¾ 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, $\varepsilon = \sqrt{(0{\cdot}060)^2 + (0{\cdot}036)^2 \tan^2 \delta}$

Transit, No. 5, $\varepsilon = \sqrt{(0{\cdot}066)^2 + (0{\cdot}036)^2 . \tan^2 \delta}$

Meridian telescope, No. 13, $\varepsilon = \sqrt{(0{\cdot}069)^2 + (0{\cdot}078)^2 \tan^2 \delta}$

Meridian telescope, No. 13, $\varepsilon = \sqrt{(0{\cdot}087)^2 + (0{\cdot}055)^2 \tan^2 \delta}$

Combining these expressions for the larger and smaller instruments, we obtain

$$\varepsilon = \sqrt{(0{\cdot}063)^2 + (0{\cdot}036)^2 \tan^2 \delta} \text{ and } \varepsilon = \sqrt{(0{\cdot}080)^2 + (0{\cdot}063)^2 \tan^2 \delta}$$

respectively,* from which the following tables of probable errors (ε), of relative weights

*The following formula has been published by Dr. Albrecht on page 23 of his Formeln und Hülfstafeln, etc., Leipzig, 1894, viz:

$$\varepsilon = \sqrt{(0{\cdot}05)^2 + \left(\frac{3{\cdot}18}{v}\right)^2 \sec^2 \delta}$$

Putting $v = 85$ for the magnifying power and changing sec into tan, this expression is equivalent to

$$\varepsilon = \sqrt{(0{\cdot}062)^2 + (0{\cdot}037)^2 \tan^2 \delta}$$

(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 37	0·61	0·011	0·103	1·1	0·006	0·075
51 Cephei	87 12	0·74	0·007	0·085	1·3	0·004	0·062
α Ursæ Minoris.....	88 46	1·7	0·001	0·037	2·9	0·001	0·027
λ Ursæ Minoris.....	88 59	2·0	0·001	0·031	3·5	0·001	0·023

COMPUTATION OF ΔT AND a BY LEAST SQUARES.

19. A field computation made by the approximate method indicated in § 16 gives values for ΔT, a, and c, which are of a high degree of accuracy. It should be noted that the derived values of a and c depend upon *all* the observations and not simply upon observations on a few stars only of the set, as is frequently the case with other approximate methods. Experience shows that the value of c especially, as thus derived in the field computation, is so accurate that a value derived from a subsequent rigid least square adjustment will in general be substantially identical with it, provided the stars of the set are chosen as indicated in the first part of § 16 and in § 21. Accordingly in the office computation, as usually made,* only the unknowns a_w, a_e, and ΔT are determined by least squares, while c is taken from the field computation revised and corrected if necessary. That method of computation is shown below.

Let $\tau = (\alpha - t_1) - Cc$ in which t_1 is the chronometer time of transit across the mean line of the diaphragm corrected for rate, diurnal aberration and inclination and $\alpha - t_1$ is therefore the quantity on the last line of the field record and computation as shown in § 9. Let ΔT be an assumed value of the chronometer correction and δT a correction to ΔT to be derived from the computation. The final value of the chronometer correction will then be $\Delta T_0 = \Delta T + \delta T$. Let d, for each star $= \tau - \Delta T$.

Then for each star observed an observation equation of the form

$$\sqrt{p}\,\delta T + \sqrt{p}\,Aa = \sqrt{p}\,d,$$

in which the weights p are assigned according to §§ 17–18, may be written.

* For one class of exceptions see § 20.

In forming the normal equations each half of the set, made with the horizontal axis in one position, is treated independently of the other half set.

The normal equations corresponding to the half set made with illumination (or bright band) to the westward are

$$\Sigma p\,\delta T + \Sigma p\,Aa_w = \Sigma pd$$
$$\Sigma p\,A\delta T + \Sigma p\,A^2a_w = \Sigma p\,Ad$$

and similarly for the other half set.

The most convenient arrangement of this computation is shown below, this example being a computation of the time set treated in §§ 7, 9, and 16

WASHINGTON, D. C., *May 17, 1896.*

$c = +\cdot032$ $\qquad\qquad$ $\Delta T = -4^s\cdot01$

Star.	Band.	$a-t_1$	C	Cc	τ	d	A	p*	pA	pA^2	pd	pAd	Aa	$\Delta T'$	Δ	$p\Delta$	$p\Delta^2$
17 H. Can. Ven.	W	−4·07	+1·26	+·04	−4·11	− ·10	+ ·02	·83	+·02	·00	−·08	·00	+ ·01	−4·12	+·10	+·08	·0083
η Urs. Maj.	W	−4·09	+1·55	+·05	−4·14	− ·13	− ·30	·69	−·21	·06	−·09	+·03	− ·18	−3·96	−·06	−·04	25
η Bootis.	W	−3·69	+1.06	+·03	−3·72	+ ·29	+ ·36	·98	+·35	·13	+·28	+·10	+ ·22	−3·94	−·08	−·08	63
11 Bootis.	W	−3·89	+1·13	+·04	−3·93	+ ·08	+ ·22	·93	+·20	·04	+·07	+·02	+ ·13	−4·06	+·04	+·04	15
α Draconis.	W	−4·52	+2·36	+·08	−4·60	− ·59	−1·03	·40	−·41	·42	−·24	+·24	− ·62	−3·98	−·04	−·02	06
								3·83	−·05	·65	−·06	+·39					
d Bootis.	E	−3·94	−1·11	−·04	−3·90	+ ·11	+ ·25	·93	+·23	·06	+·10	+·03	+ ·14	−4·04	+·02	+·02	04
α Bootis.	E	−3·81	−1·06	−·03	−3·78	+ ·23	+ ·35	·98	+·34	·12	+·23	+·08	+ ·19	−3·97	−·05	−·05	25
λ Bootis.	E	−4·23	−1·46	−·05	−4·18	− ·17	− ·19	·74	−·14	·03	−·13	+·02	− ·10	−4·08	+·06	+·04	27
θ Bootis.	E	−4·29	−1·64	−·05	−4·24	− ·23	− ·38	·65	−·25	·09	−·15	+·06	− ·21	−4·03	+·01	+·01	01
5 Urs. Min.	E	−5·44	−4·18	−·13	−5·31	−1·30	−2·53	·16	−·40	1·02	−·21	+·53	−1·37	−3·94	−·08	−·01	10
								3·46	−·22	1·32	−·16	+·72					·0259

* These weights are taken from the column headed "For large portable transits," § 18.

Normal equations:

$$+3\cdot83\,\delta T - \cdot05\,a_w = -\cdot06 \qquad +3\cdot46\,\delta T - \cdot22\,a_e = -\cdot16$$
$$-\cdot05\,\delta T + \cdot65\,a_w = +\cdot39 \qquad -\cdot22\,\delta T + 1\cdot32\,a_e = +\cdot72$$
$$a_w = +^s\cdot601 \qquad a_e = +^s\cdot543$$
$$\delta T = -^s\cdot008 \qquad \delta T = -^s\cdot012$$

At $14^h\,02^m$ $\Delta T_0 = -4^s\cdot020$

$$+7\cdot29\,Q - \cdot27\,q = 1 \qquad Q = 1\cdot38 \qquad \varepsilon_1 = \pm^s\cdot044$$
$$-\cdot27\,Q + 1\cdot97\,q = 0 \qquad\qquad \varepsilon = \pm^s\cdot016$$

In the above computation a check on the correctness of the assumed value of c is furnished by the nearness of agreement of the two values of δT resulting from the two groups of stars. The normal equations are solved most conveniently by successive approximations, as, for instance, in the second equation the value of a_w can be closely derived at once on the assumption that δT is small. The residuals (Δ) are taken for each group separately, using its own δT* to derive a ΔT_0 for this purpose, and the

* The two δT's here happen to be so nearly equal that Δ's are the same as if taken by using the ΔT_0 for the whole group.

sums of the $p\Delta$'s should of course nearly equal zero for each set. The probable error of a single observation of unit weight is

$$\varepsilon_1 = 0.674\sqrt{\frac{\Sigma p\Delta^2}{n_o - n_e}}$$

where $\Sigma p\Delta^2$ is the sum of the weighted squares of the residuals (last column in form), n_o is the number of stars and n_e is the number of unknown quantities or number of normal equations, remembering in this example that there are four unknowns, δT, a_w, a_E, and c, the latter being taken from the field computation. To obtain the probable error ε of the computed ΔT_o, add the corresponding normal equations of the two sets, put Q in place of δT, q in place of a, 1 in place of Σpd, and 0 in place of ΣpAd, as shown. Then $\varepsilon = \varepsilon_1 \sqrt{Q}$.

THE COMPLETE LEAST SQUARE COMPUTATION.

20. When time observations are taken in Alaska unusual conditions are encountered, arising from the high latitude of the station—from 55° to 65° for the regions in which the Survey observers are called upon to observe most frequently. Zenith stars are there slow-moving stars (and consequently have light weight); for stars between the zenith and the pole pA is comparatively small; the rapidly moving stars are far to the southward of the zenith; and it is easy to observe subpolars, as the northern horizon is far below the pole. Moreover the very prevalent cloudy weather is apt to break in upon any previously arranged programme. The combined result of these conditions is in general that the sets of stars actually observed are poorly balanced; that is, the algebraic sum of the A factors for each half set and of the C factors for the whole set will differ considerably from zero. In extreme cases it is sometimes desirable to resort to the complete least square computation in which c, a_w, a_e, and ΔT are all derived by the principle of least squares.

We here place $\tau = \alpha - t_1$ (as shown in § 9), and the remaining notation stands as in §19 except that we must here distinguish by the subscripts $_w$ and $_e$ between A factors belonging to the two half sets.

An observation equation of one of the following forms may be written for each star observed:

$$\begin{array}{llll} \sqrt{p}\delta T & +\sqrt{p}A_e a_e & & +\sqrt{p}Cc = \sqrt{p}d \\ \sqrt{p}\delta T & & +\sqrt{p}A_w a_w & +\sqrt{p}Cc = \sqrt{p}d \end{array}$$

The normal equations will be—

$$\begin{array}{lllll} \Sigma p\delta T & +\Sigma pA_e a_e & +\Sigma pA_w a_w & +\Sigma pCc & =\Sigma pd \\ \Sigma pA_e\delta T & +\Sigma pA_e^2 a_e & & +\Sigma pA_e Cc & =\Sigma pA_e d \\ \Sigma pA_w\delta T & & +\Sigma pA_w^2 a_w & +\Sigma pA_w Cc & =\Sigma pA_w d \\ \Sigma pC\delta T & +\Sigma pA_e Ca_e & +\Sigma pA_w Ca_w & +\Sigma pC^2 c & =\Sigma pCd \end{array}$$

The following will serve as a concrete illustration of this method of computation. The only preliminary assumption in this computation is an approximate value of the chronometer correction, ΔT.

Owing to the high latitude of St. Michaels, 63° 29′, the time stars are all south of the zenith, and the average value of A is far from zero.

ST. MICHAELS, ALASKA, *March 19, 1891.*

$$\Delta T = -20^{s}.10.$$

Star.	Clamp.	$a - t_1$	d	A	C	p	pA	pC	pA^2	pAC	pC^2	pd	pAd	pCd	Aa	Cc	$\Delta T'$	Δ	$p\Delta$	$p\Delta^2$
		s.	s.																	
1	E	-21·27	−1·17	+ ·66	−1·13	0·9	+ ·59	−1·02	·39	− ·67	1·15	−1·05	− ·69	+1·19	− ·89	− ·21	−20·17	+·05	+·04	·0022
2	E	−21·22	−1·12	+ ·72	−1·08	0·9	+ ·65	− ·97	·47	− ·70	1·05	−1·01	− ·73	+1·09	− ·97	− ·20	−20·05	−·07	−·06	44
3	E	−21·40	−1·30	+ ·76	−1·05	0·9	+ ·68	− ·94	·52	− ·72	·99	−1·17	− ·89	+1·23	−1·02	− ·19	−20·19	+·07	+·06	44
4	E	−23·09	−2·99	+2·89	+4·58	0·08	+ ·23	+ ·37	·66	+1·06	1·68	− ·24	− ·69	−1·10	−3·88	+ ·84	−20·05	−·07	−·01	04
5	E	−21·23	−1·13	+ ·73	−1·07	0·9	+ ·66	− ·96	·48	− ·70	1·03	−1·02	− ·74	+1·09	− ·98	− ·20	−20·05	−·07	−·06	44
							+2·81		2·52	−1·73			−3·74							
6	W	−20·98	−0·88	+ ·85	+1·01	1·0	+ ·85	+1·01	·72	+ ·86	1·02	− ·88	− ·75	− ·89	−1·05	+ ·18	−20·11	−·01	−·01	01
7	W	−20·86	−0·76	+ ·72	+1·08	0·9	+ ·65	+ ·97	·47	+ ·70	1·05	− ·68	− ·49	− ·73	− ·89	+ ·20	−20·17	+·05	+·04	22
8	W	−20·70	−0·60	+ ·64	+1·14	0·9	+ ·58	+1·03	·37	+ ·66	1·17	− ·54	− ·35	− ·62	− ·79	+ ·21	−20·12	·00	·00	00
9	W	−20·95	−0·85	+ ·85	+1·01	1·0	+ ·85	+1·01	·72	+ ·86	1·02	− ·85	− ·72	− ·86	−1·05	+ ·18	−20·08	−·04	−·04	16
10	W	−25·39	−5·29	+3·46	−5·83	0·05	+ ·17	− ·29	·60	−1·01	1·70	− ·26	− ·92	+1·54	−4·27	−1·07	−20·05	−·07	·00	02
						7·53	+3·10	+0·21	2·88	+2·07	11·86	−7·70	−3·23	+1·94						·0199

Normal equations:

$$\begin{aligned}
+ 7{\cdot}53\,\delta T + 2{\cdot}81\,a_e + 3{\cdot}10\,a_w + 0{\cdot}21\,c &= -7{\cdot}70\\
+ 2{\cdot}81\,\delta T + 2{\cdot}52\,a_e - 1{\cdot}73\,c &= -3{\cdot}74\\
+ 3{\cdot}10\,\delta T + 2{\cdot}88\,a_w + 2{\cdot}07\,c &= -3{\cdot}23\\
+ 0{\cdot}21\,\delta T - 1{\cdot}73\,a_e + 2{\cdot}07\,a_w + 11{\cdot}86\,c &= +1{\cdot}94\\
c &= +0{\cdot}183\\
a_e &= -1{\cdot}342\\
a_w &= -1{\cdot}233\\
\delta T &= -0{\cdot}02
\end{aligned}$$

At $8^{h}.5$ $\Delta T_0 = -20^{s}.12$

$Q = {\cdot}79$

$$\varepsilon_1 = \pm {\cdot}^{s}039$$
$$\varepsilon = \pm {\cdot}035$$

The remarkably large value for Q arises from the fact that azimuth errors, a_w and a_e, are but feebly determined, see column headed pA and the normal equations.

Sometimes it is assumed that the azimuth error is the same for both halves of a set, and the distinction between a_w and a_e is dropped and a single a derived from the whole set, the normal equations being modified accordingly. This procedure is entirely justifiable if the azimuth error during the two half sets is actually the same. If the two azimuths really differ, some error will be introduced into the computed result by this procedure, and the error so introduced will be larger the greater is said difference. Experience shows that the instability of the instrument in azimuth is in general sufficient to make it desirable to distinguish between the two azimuth errors if accurate results are desired, except when there are but *few* stars observed in the set, say seven or less.

THE SELECTION OF STARS.

21. The stars shown in the observing list in § 7 and used in the examples of record and computation §§ 16, 19 were chosen by the method which has usually been followed upon the telegraphic longitude parties for several years past. There are five stars in each half set, so chosen that they follow each other in rapid succession, but are never too close to permit complete observations upon each star; that the algebraic sum of the A factors for the four time stars (each near the zenith) is nearly zero; that the azimuth star is between the zenith and the pole and sufficiently far north to make its A greater than unity, and yet so far from the pole that its transit across all the lines of the diaphragm may be observed without too long a wait on account of the apparently slow motion of the star.

In a time set chosen as above the observation upon the azimuth star in each half set serves to determine the azimuth error of the instrument, but has little or no effect upon the computed time, since this is almost independent of the azimuth error (the sum of the A factors for the time stars being nearly zero). It seems, then, that the azimuth star serves mainly to give an accurate determination of an azimuth error of which only an approximate determination is needed under *normal* conditions. This suggests that it is desirable to substitute a *fifth time star* in each half set in the place of the azimuth star and to make the sum of the A factors for the *five time stars* nearly zero. All *ten* stars of each complete set will then be influential in determining the time instead of *eight* out of the ten, as in the set shown in §§ 7 and 16. The azimuth error will be determined with a minor degree of accuracy, which, however, will be sufficient, in so far as the time alone is concerned, if the algebraic sum of the five A factors for each half set is nearly zero.

The relative merits of the first method, in which there are four time stars and one azimuth star in each half set, and of the second method, in which there are five time stars in each half set, may be stated as follows:

Under favorable circumstances, when clouds or other conditions do not make the balancing of the A factors difficult, the second method will give the time from a single set with greater accuracy than the first, in about the ratio of $\sqrt{5}$ to $\sqrt{4}$, or 1·12 to 1·00.

On the other hand, the preservation of the balance of A factors is much more important in the second method than in the first because the azimuth error is not so well determined. If, when using the second method, clouds interfere and force the observer to abandon his prearranged programme and make a new and hasty selection of stars, or if one of the five stars in a half set is missed and not replaced by another, the lack of balance of A factors combined with a comparatively feeble determination of azimuth error may reduce the accuracy to or below that of the first method. In the first method, if a time star is missed, or if one is forced to use an unbalanced set of time stars, the lack of balance is not serious, because the azimuth is well determined. If, on the other hand, the azimuth star is missed on account of clouds, the observer is then using the second method (all time stars).

In making a telegraphic longitude determination the same stars should be observed at both stations. This will prevent an accurate balancing of A factors if the two stations

are in very different latitudes and so tend to reduce the accuracy of the second method to that of the first.

In time observations in Alaska ($\phi = 55°$ to $65°$ or more) it is not feasible to secure time sets with balanced A factors, since the stars between the zenith and the pole have comparatively small A factors, which become relatively still smaller after weights are assigned. This fact, combined with the fact that cloudy weather is the normal condition in Alaska, prevents the use of the second method there. The first method also becomes somewhat unsatisfactory because of the comparatively small A factors of stars between the zenith and the pole and the consequent comparatively feeble determination of the azimuth error.

The following third method of selecting stars is, therefore, recommended for use in Alaska: In each half set select four time stars lying between the limits $\delta =$ about $65°$ (observed above the pole) and $45°$ south zenith distance, or these limits extended if necessary to avoid waits, and select one azimuth star of declination between $55°$ and $75°$ (preferably near the upper limit, $75°$) to be observed *below* the pole.

EXAMPLE OF COMPUTATION OF TIME FROM A SET OF STARS SELECTED BY THE SECOND METHOD (ALL TIME STARS).

22. The time set treated below was observed by Assistant E. Smith, at Washington, D. C., January 25, 1899. The approximate field computation is shown in the same form as in § 16, except for the slight modifications due to the fact that no azimuth stars were observed.

Star.	Band.	$\alpha - t_1$	C	A	Cc	Aa	$\Delta T' = \alpha - t_1 - Cc - Aa$	Δ*	
		s			s	s	s	s	
α Aurigæ	E	+32·73	−1·44	−·18	+·42	− ·02	+32·33	+ ·06	
β Tauri	E	+32·71	−1·13	+·21	+·33	+ ·02	·36	+ ·03	
χ Aurigæ	E	+32·79	−1·18	+·14	+·35	+ ·02	·42	− ·03	
ζ Tauri	E	+32·72	−1·07	+·32	+·31	+ ·03	·38	+ ·01	at $5^h\ 40^m{\cdot}5$
o Aurigæ	E	+32·87	−1·56	−·30	+·46	− ·03	·44	− ·05	$\Delta T = +32^s{\cdot}382$
υ Aurigæ	W	+31·95	+1·29	−·02	−·38	− ·00	·33	+ ·05	
δ Aurigæ	W	+31·84	+1·71	−·46	−·50	− ·07	·41	− ·03	
θ Aurigæ	W	+32·03	+1·25	+·04	−·37	+ ·01	·39	− ·01	
υ Orionis	W	+32·11	+1·04	+·42	−·31	+ ·07	·35	+ ·03	
η Geminorum	W	+32·14	+1·08	+·31	−·32	+ ·05	·41	− ·03	
		$\alpha - t_1$	C	A	Cc	$\alpha - t_1 - Cc$	Aa	$\alpha - t_1 - Cc - Aa$	
First approximation:									$c = -·294$
Mean of south stars	E	+32·74	−1·13	+·22	+·33	+32·41	+ ·02	+32.39	$a_E = +·109$
Mean of north stars	E	+32·80	−1·50	−·24	+·44	+32·36	− ·03	+32.39	$a_W = +·160$
Mean of group	E	+32·76	−1·28						
Mean of south stars	W	+32·09	+1·12	+·26	−·33	+32·42	+ ·04	+32.38	
Mean of north stars	W	+31·90	+1·50	−·24	−·44	+32·34	− ·04	+32.38	
Mean of group	W	+32·01	+1·27						

* These residuals are derived by using the means of the separate half sets.

The first approximation was sufficient in the above example. The instrumental errors were derived as follows:

$$c = \frac{(\alpha - t_1)\text{ mean of group } E - (\alpha - t_1)\text{ mean of group } W}{C\text{ mean of group } E - C\text{ mean of group } W} = \frac{+32\cdot76 - 32\cdot01}{-1\cdot28 - 1\cdot27} = -0\cdot294.$$

$$a_E = \frac{(\alpha - t_1 - Cc)\text{ mean of } S \text{ stars } E - (\alpha - t_1 - Cc)\text{ mean of } N \text{ stars } E}{A\text{ mean of } S \text{ stars } E - A \text{ mean of } N \text{ stars } E}$$

$$= \frac{+32\cdot41 - 32\cdot36}{+0\cdot22 + 0\cdot24} = +0\cdot109.$$

$$a_W = \frac{(\alpha - t_1 - Cc)\text{ mean of } S \text{ stars } W - (\alpha - t_1 - Cc)\text{ mean of } N \text{ stars } W}{A\text{ mean of } S \text{ stars } W - A \text{ mean of } N \text{ stars } W}$$

$$= \frac{+32\cdot42 - 32\cdot34}{+0\cdot26 + 0\cdot24} = +0\cdot160.$$

It will be noted that c is derived from the means of all the stars in each group, and that a is derived by comparing the means of the north and south stars in each group separately.

Below is given a least square computation of the same time set

WASHINGTON, D. C., *January 25, 1899.*

$c = -\cdot294.$ $\qquad \Delta T = +32^s\cdot38.$

Star	Band	$\alpha - t_1$	C	Cc	τ	d	A	p	pA	pA^2	pd	pAd	$\Delta\alpha$	$\Delta T'$	Δ	$p\Delta$	$p\Delta^2$
α Aurigæ	E	+32·73	−1·44	+·42	+32·31	−·07	−·18	·75	−·14	·02	−·05	+·01	−·01	+32·32	+·07	+·05	·0037
β Tauri	E	+32·71	−1·13	+·33	+32·38	·00	+·21	·92	+·19	·04	·00	·00	+·02	+32·36	+·03	+·03	08
χ Aurigæ	E	+32·79	−1·18	+·35	+32·44	+·06	+·14	·89	+·12	·02	+·05	+·01	+·01	+32·43	−·04	−·04	14
ζ Tauri	E	+32·72	−1·07	+·31	+32·41	+·03	+·32	·97	+·31	·10	+·03	+·01	+·02	+32·39	·00	·00	00
o Aurigæ	E	+32·87	−1·56	+·46	+32·41	+·03	−·30	·69	−·21	·06	+·02	−·01	−·02	+32·43	−·04	−·03	11
								4·22	+·27	·24	+·05	+·02					
υ Aurigæ	W	+31·95	+1·29	−·38	+32·33	−·05	−·02	·83	−·02	·00	−·04	·00	·00	+32·33	+·06	+·05	30
δ Aurigæ	W	+31·84	+1·71	−·50	+32·34	−·04	−·46	·62	−·29	·13	−·02	+·01	−·06	+32·40	−·01	−·01	01
θ Aurigæ	W	+32·03	+1·25	−·37	+32·40	+·02	+·04	·84	+·03	·00	+·02	·00	·00	+32·40	−·01	−·01	01
υ Orionis	W	+32·11	+1·04	−·31	+32·42	+·04	+·42	·99	+·42	·17	+·04	+·02	+·05	+32·37	+·02	+·02	04
η Geminorum	W	+32·14	+1·08	−·32	+32·46	+·08	+·31	·96	+·30	·09	+·08	+·02	+·04	+32·42	−·03	−·03	09
								4·24	+·44	·39	+·08	+·05					·0115

Normal equations:

$$+4\cdot22\,\delta T + \cdot27\,a_e = +\cdot05 \qquad +4\cdot24\,\delta T + \cdot44\,a_w = +\cdot08$$
$$+\cdot27\,\delta T + \cdot24\,a_e = +\cdot02 \qquad +\cdot44\,\delta T + \cdot39\,a_w = +\cdot05$$
$$a_e = +\cdot076 \qquad a_w = +\cdot122$$
$$\delta T = +\cdot007 \qquad \delta T = +\cdot006$$

At $5^h\ 40^m$ $\Delta T = +32^s\cdot386.$

$$+8\cdot46\,Q + \cdot71\,q = 1 \qquad Q = \cdot131 \qquad \varepsilon_1 = \pm\cdot030$$
$$+\cdot71\,Q + \cdot63\,q = 0 \qquad \varepsilon = \pm.011$$

The quantity Q, fixing the relation between the probable errors of an observation of unit weight and of the computed result, is an accurate index of the effectiveness of the selected stars in fixing the chronometer correction. The smaller is Q the greater is

the effectiveness. Compare this Q (=0·131) with that in the set given in § 19, =0·138. Compare also with the Q of § 20, =0·79 (large mainly because of the high latitude of the station).

DETERMINATION OF EQUATORIAL INTERVALS.

23. The equatorial intervals of the lines of the diaphragm are needed to reduce incomplete transits (see § 11).

To determine these, select complete transits of stars of large declination.

Let $t_1, t_2, t_3 \ldots\ldots t_n$ be the observed times of transit over the successive lines, t their mean, and $i_1, i_2, i_3 \ldots\ldots i_n$ their equatorial intervals from the mean line and δ the declination of the star:

$$t = \frac{1}{n}(t_1 + t_2 + t_3 \ldots\ldots + t_n)$$

$$i_1 = (t_1 - t)\cos\delta$$

$$i_2 = (t_2 - t)\cos\delta$$

etc.

$$i_n = (t_n - t)\cos\delta$$

also $$0 = i_1 + i_2 + i_3 \ldots\ldots + i_n$$

The intervals of the lines $\left\{\begin{matrix}\text{east}\\ \text{west}\end{matrix}\right\}$ of the mean line 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 $\tau_1, \tau_2, \tau_3 \ldots\ldots \tau_n$ are the hour angles of the circumpolar star for the successive lines.

When it is necessary to use the more exact formula for circumpolars as given above, the table at the end of § 11 will be found convenient.

If the chronometer rate exceeds 15^s per day it will be desirable to take it into account in computing the equatorial intervals.

A convenient form for the computation of equatorial intervals follows. The observations used were made by Assistant Fremont Morse at Sitka, Alaska, in 1894, with Meridian Telescope No. 7, and by the eye and ear method.

$\varkappa$ Draconis. $\delta = 70°22'27''$ Log cos δ = 9·52618 Clamp West

Line		May 14.	May 15.	May 16.	May 18.	Mean.	Log. mean.	Log. i.	i (equatorial interval).
		s.	s.	s.	s.	s.			s.
1	$t_1 - t$	−87·60	−88·00	−87·10	−87·60	−87·575	1·94238	1·46856	−29·414
2	$t_2 - t$	−44·60	−44·00	−44·60	−44·60	−44·450	1·64787	1·17405	−14·930
3	$t_3 - t$	− 0·10	0·00	+ 0·40	+ 0·40	+ 0·175	9·24304	8·76922	+ 0·059
4	$t_4 - t$	+43·90	+44·00	+43·90	+43·40	+43·800	1·64147	1·16765	+14·711
5	$t_5 - t$	+88·40	+88·00	+87·40	+88·40	+88·050	1·94473	1·47091	+29·574

The quantities (t_1-t), (t_2-t), etc., for each date were taken directly from the record of observations.

The equatorial intervals were thus computed from observations upon three different stars and the means taken.

It is not necessary to make special observations to determine the equatorial intervals. Complete transits observed during the regular progress of time observations may be utilized for that purpose. If observations upon stars of large declination are not available, observations upon stars of small declination may be used, and will be found to give almost as accurate values for the equatorial intervals as the former.

When pressed for time in the field an incomplete transit of a star may be reduced by assuming that actual intervals between lines on that star are the same as on some preceding date on which a complete transit of that star was observed at that station. The formulæ of § 11 may then be used by dropping the factor sec δ and substituting actual intervals for equatorial intervals.

PIVOT INEQUALITY.

24. The pivot inequality should be determined with the instrument mounted upon a very stable pier in a room in which the rate of change of temperature is small during the observations. The observations consist of a series of readings of the striding level as indicated in the example of record and computation given below. The notation is the same as in § 10, that is, β_w and β_e indicate the apparent inclination of the telescope axis in each of its two positions as given directly by the readings of the striding level. Then the pivot inequality

$$p=\frac{\beta_e-\beta_w}{4}$$

and is to be expressed in seconds of time.

Observations for inequality of pivots of transit, No. 19. Station, Atlanta, Ga., March 12, 1896. G. R. P., observer.

Zenith distance.	Time.	Temperature.	Band west. Object glass south. Level. W. end.	Band west. Object glass south. Level. E. end.	$\frac{\Sigma w - \Sigma e}{4} = \beta w$.	Band east. Object glass north. Level. W. end.	Band east. Object glass north. Level. E. end.	$\frac{\Sigma w - \Sigma e}{4} = \beta e$.	$\frac{\beta e - \beta w}{4} = p$.
°	*h. m.*	°*F.*	*div.*	*div.*	*div.*	*div.*	*div.*	*div.*	*div.*
38	9 43 a. m.	33	33·5	22·0		33·4	21·7		
			20·8	34·8	— ·625	21·0	34·0	—·325	+·075
43			20·4	33·9		21·0	34·0		
			32·4	21·9	— ·750	33.1	21·8	—·425	+·081
48			20·2	33·9		20·3	33·4		
			32·2	21·9	— ·850	32·1	21·8	—·700	+·038
43			31·8	21·9		32·7	21·1		
			19·7	33·9	—1·075	20·1	33·3	—·400	+·169
38	10 03 a. m.	35	19·7	33·8		20·1	33·1		
			31·9	21·3	— ·875	32·0	21·1	—·525	+·088
					Mean, band west, object glass south				+·090

Zenith Distance.	Time.	Temperature.	Band west. Object glass north. Level. W. end.	Band west. Object glass north. Level. E. end.	$\frac{\Sigma w - \Sigma e}{4} = \beta w$	Band east. Object glass south. Level. W. end.	Band east. Object glass south. Level. E. end.	$\frac{\Sigma w - \Sigma e}{4} = \beta e$	$\frac{\beta e - \beta w}{4} = p$
°	*h. m.*	°*F.*	*div.*	*div.*	*div.*	*div.*	*div.*	*div.*	*div.*
38	10 07 a. m.	35	19·7	33·1		19·4	33·6		
			31·9	20·9	—·600	31·9	20·9	—·800	—·050
43			31·9	20·9		31·7	20·9		
			19·1	33·3	—·800	19·1	33·2	—·825	—·006
48			19·3	33·0		19·1	33·3		
			31·5	20·9	—·775	31·7	20·9	—·850	—·019
43			31·3	20·9		31·1	21·0		
			19·0	33·2	—·950	18·9	33·2	—1·050	—·025
38	10 27 a. m.	36	19·0	33·1		18·8	33·7		
			31·7	20·5	—·725	31·2	20·9	—1·150	—·106
					Mean, band west, object glass north				—·041
					Mean, band west, object glass south				+·090
								Mean	+·024
					1 division of striding level = 1″·850 = 0ˢ·123				
					div.				
					p = + ·024 = 0ˢ·123 × ·024 = +0·003 second of time.				

In determining the pivot inequality the level readings are made as in observing time, reversing the telescope between the readings. Observations should be made in two groups, reversing the relation between the positions of the band and object glass as shown in the example. This is done to partially eliminate the effect of the pivots not being truly circular in cross section. In the example shown there is a systematic though unimportant difference in p for the two positions. A complete investigation of the pivots would involve level readings at all angles from the zenith, from 0° to 90°, but the ordinary form of level will not permit readings closer than 30° to 40°, and

stars are not often observed more than 50° from the zenith. In the example given the observations were from 38° to 48° zenith distance, less weight being given to the latter angle at which few star observations are made.

A less satisfactory value for the pivot inequality may be obtained from the level readings made in connection with the time observations.

DETERMINATION OF LEVEL VALUE.

25. The most accurate way of determining the value of one division of a level is by means of a level-trier, which consists of a bar the support of which at one end is a micrometer screw. The level tube to be tested is placed on this bar. The method of observing and computing is shown in the example. In the level-trier used one division of the micrometer head equals one second of arc; that is, a movement of one division changes the angular position of the bar by one second. The first part of these observations was simply for the purpose of testing the uniformity of the tube, changing the angle by 5″ intervals. In determining the level value about the same length of bubble is employed that is used in the field observations.

Determination of value of one division of stride level of meridian telescope No. 9. Chamber vial 175 mm. by 15 mm., marked 7526, 2″·02 K. and E., mounted by springs. Length of bubble used, 35 div. = 70 mm. E. G. F., observer. Mean temperature 12°·3 C.

Chamber left.						Chamber right.					
Level-trier reading.	Bubble reading.		Movement.		Value of one division of level.	Level-trier reading.	Bubble reading.		Movement.		Value of one division of level.
	Left end.	Right end.	Level-trier.	Bubble mean of two ends.			Left end.	Right end.	Level-trier.	Bubble mean of two ends.	
″	*div.*	*div.*	″	*div.*	″	″	*div.*	*div.*	″	*div.*	″
25	—0·1	35·2	5	2·5		75	60·4	25·8	5	2·7	
30	2·4	37·7	5	2·5		80	57·7	23·1	5	2·4	
35	4·9	40·2	5	2·5		85	55·3	20·7	5	2·4	
40	7·4	42·7	5	2·7		90	52·9	18·3	5	2·7	
45	10·1	45·4	5	2·6		95	50·2	15·6	5	2·7	
50	12·7	48·0	5	2·6		100	47·5	12·9	5	2·6	
55	15·3	50·6	5	2·6		105	44·9	10·3	5	2·7	
60	17·9	53·2	5	2·4		110	42·2	7·6	5	2·6	
65	20·3	55·6	5	2·6		115	39·6	5·0	5	2·6	
70	22·9	58·2	5	2·6		120	37·0	2·4	5	2·5	
75	25·5	60·8				125	34·5	—0·1			
25	—0·2	35·0	50	25·7	1·945	75	60·9	26·3	50	26·3	1·901
75	25·5	60·7				125	34·6	0·0			
35	4·7	39·9	30	15·8	1·899	85	55·9	21·2	30	16·1	1·863
65	20·5	55·7				115	39·8	5·1			
40	7·4	42·6	20	10·5	1·905	90	53·2	18·5	20	10·8	1·852
60	17·9	53·1				110	42·4	7·7			
45	10·1	45·3	10	5·3	1·887	95	50·4	15·8	10	5·5	1·818
55	15·4	50·6				105	44·9	10·3			
		Mean, chamber left			1·909			Mean, chamber right			1·859
						Final mean 1 div. = 2 mm. = 1″·884 at 12°·3 C.					

If the level vial is so held in its metallic mounting that there is any possibility that it may be put under stress by a change of temperature, it is advisable to determine the value of a division *with the tube in its mounting* at two or more widely different temperatures. Level vials are now usually mounted with springs, so as to avoid such stresses.

If an observer is forced to determine the value of a level division in the field, remote from a level-trier—after some accident, for example—he must devise some method of utilizing whatever apparatus is at his disposal for that purpose.

If a telescope having an eyepiece micrometer fitted for measuring altitudes or zenith distances is available, the unknown angular value of a level division may be found by comparison with the known angular value of a division of the micrometer. Place the level in an extemporized mounting fixed to the telescope so that the level vial is parallel to the plane in which the telescope rotates (about its horizontal axis). Point with the micrometer upon some distant well-defined fixed object and read the micrometer and level. Change the micrometer reading by an integral number of divisions, point to the same object again by a movement of the telescope as a whole, and note the new reading of the level. Every repetition of this process gives a determination of the level value in terms of the micrometer value.

If another level of sufficient sensibility and of which the value is well known is available, it may be used as a standard with which to compare the unknown level. Put the unknown level in an extemporized mounting, fastened to that of the known level in such a way that the two level vials are parallel or nearly so. Adjust so that both bubbles are near the middle at once. Compare corresponding movements of the two bubbles for small changes of inclination common to the two levels.*

DISCUSSION OF ERRORS.

26. The various errors which affect the final result of any astronomical observation may be grouped into three separate classes with respect to their sources, and consequently the precautions which must be taken against them fall under the same general heads. They are: (1) *External errors*, or errors arising from conditions outside the instrument and observer; (2) *instrumental errors*, due to the instrument, and arising from imperfect construction† or imperfect condition of instrument, from instability of the relative positions of different parts, etc.; (3) *observer's errors*, due directly to the observer, arising from his unavoidable errors of judgment as to what he sees and hears and from the fact that his nerves and brain do not act instantaneously. By the phrase *errors of observation* is meant the combined errors arising from all these sources.

The principal *external errors* in transit observations for time arise from errors in the assumed right ascensions of the stars and from lateral refraction of the light from the stars.

If the right ascensions of all stars observed are taken from the Berliner Jahrbuch or the American Ephemeris, the probable error of a right ascension will be upon an average about $\pm 0^{s}.03$, except for stars of large declination, for which this estimate must be

* For a full description of an ingenious method of determining the value of a level by attaching it to the horizontal circle of a theodolite and observing its reading in various azimuths, when the vertical axis of the theodolite is inclined by an amount which is approximately known, see Bulletin of the University of Wisconsin, Science Series, Vol. I, No. 3, pp. 68–74.

† By imperfect construction is here meant the failure to satisfy fully the rigid geometric conditions imposed by theory, but necessarily attained but imperfectly by the instrument maker, as, for example, the condition that the cross section of a pivot should be a perfect circle and remain so. *Imperfect* construction is therefore not meant to imply *poor* construction; that is, construction much below the attainable order of excellence.

increased. The right ascensions are also subject to small constant errors with which the geodesist is hardly concerned, because of their smallness and because they are almost completely eliminated from his final results. For example, the deduced rate for a chronometer, or a difference of longitude observed by the present telegraphic method, is almost independent of the constant errors of the adopted right ascensions.

If one considers how small are the lateral refractions which affect measurements of horizontal angles and azimuth observations, in which lines of sight are close to the ground, it seems certain that the effects of lateral refraction upon transit time observations in which all lines of sight are elevated high above the horizon must be almost or quite inappreciable. This is probably the case whenever proper precautions are taken to avoid local refraction within a few feet of the instrument. If, however, the temperature within the observatory is much above that outside, or if active chimneys or other powerful sources of heat are near the observatory, warm columns of air rising from or passing over the observatory may produce a sensible lateral refraction. The lateral refraction is included, with many other errors from which it can not be separated, in the culmination error, ε_1, estimated in § 18.

In addition to the lateral refraction referred to in the preceding paragraph and tacitly assumed to be constant during the interval of a few seconds in which a star is being observed upon the various lines of the diaphragm, there are usually momentary lateral refractions which serve merely to make the apparent rate of progress of the star variable and to make the observer's errors greater than they otherwise would be.

Among the *instrumental errors* in transit observations for time may be mentioned those arising from the chronograph and the reading of the chronograph sheet, from poor focusing, from nonverticality of the lines of the diaphragm, from changes in azimuth and collimation, from errors in the measured inclination, from irregularity of pivots, and from changes in the rate of the chronometer.

All of these, except the first two, are included in the culmination error, ε_1, as estimated in § 18.

As already noted, the chronographs of the form now used operate so well that no appreciable error is introduced by the assumption that the speed of the chronograph is constant between successive breaks of the chronometer. It is possible to read the chronograph sheet to hundredths of seconds, but it is usually read to the nearest $0^s.05$.* By so doing a probable error of about $\pm 0^s.01$ on each single line is introduced into the readings; but this is too small in comparison with the other errors concerned in transit work to warrant closer reading.

Poor focusing of either the objective or the eyepiece leads to increased accidental errors because of poor definition. But poor focusing of the objective is especially objectionable because it puts the diaphragm and the star image in different planes, and so produces parallax. The parallax errors may be avoided to a large extent by keeping the eyepiece centered carefully over the part of the diaphragm which is being observed upon, if the proper longitudinal motion of the eyepiece is provided for that purpose.

If the lines of the diaphragm are not accurately adjusted to define vertical planes, a star will be observed too early or too late if observed above or below the middle of the diaphragm. Such errors may be made very small by careful adjustment and by always observing within the narrow limits given by the two horizontal lines of the diaphragm.

* Except during the exchange of arbitrary signals between stations in telegraphic longitude determinations.

The *mean errors of azimuth and of collimation*, being determined from the time observations themselves, are canceled out from the final results with a thoroughness which depends upon the success attained in selecting stars. (See § 21.) The process of elimination depends upon the assumption that the error of azimuth remains constant during each half set and that the collimation error remains constant during a whole set. The *changes* in these errors during the intervals named, arising from changes of temperature, shocks to the instrument, or other causes, produce errors in the final result. It is in this connection that the stability of the pier upon which the instrument rests is of especial importance. The errors produced by changes in azimuth and collimation will evidently be smaller the more rapidly the observations are made, the more carefully the instrument is handled, and the more symmetrical and constant are the temperature conditions. In general, these errors are probably small, but not inappreciable.

It is mainly in the light of the preceding paragraph that the number of stars to be observed in a time set must be determined. If the number of stars in a time set and the length of the time interval over which it extends is increased, the errors due to accumulated changes in the azimuth and collimation are increased. On the other hand, if the number of stars observed is decreased much below ten (the present standard) the number of observations rapidly approaches equality with the number of unknowns (4), and the accuracy with which the unknowns are determined decreases very rapidly. From these considerations it seems that ten stars per set is about the most advantageous number when the highest degree of accuracy is desired,* five being observed in each half set between reversals. This number involves the necessity of depending upon the constancy of the instrument in azimuth for about 30^m and in collimation for about an hour, under favorable circumstances. If greater accuracy is desired than can be obtained from a set of ten stars, it is desirable to continue observing half sets of five stars each, with a reversal of the horizontal axis at the beginning of each half set, but not to increase the number of stars in a half set.

To a considerable extent the preceding two paragraphs also apply to the *inclination error*. The *changes* in inclination during each half set produce errors in addition to those arising from uncertainty as to the mean inclination, hence again the desirability of rapid manipulation. The mean inclination is determined from the indications of the striding level, which are more or less in error. Different observers seem to differ radically as to the probable magnitude of errors from this source, but the best observers are prone to use the striding level with great care. However small this error may be under the best conditions and most skillful manipulations, there can be no doubt that careless handling of the striding level, or a little heedlessness about bringing a warm reading lamp too near it,† may easily make this error one of the largest affecting the result. An error of 0·0002 inch in the determination of the difference of elevation of the two pivots of a transit like that shown in illustration No. 1 produces an error of more than $0^s{\cdot}1$ in the deduced time of transit of a star near the zenith.

The method of treating the level readings given in §10 is based upon two assump-

* When only a minor degree of accuracy is desired, the number of stars may, of course, be much less than ten.

† The longitudinal section of the upper inner surface of a level vial is made as nearly a perfect circle as possible. If an observer will consider how great this radius of curvature is in a sensitive striding level he will understand why very small deformations of the level vial by unequal changes of temperature have a marked effect upon the position of the bubble. The radius of curvature for a level of which each division is 2^{mm} long and is equivalent to 1¼ seconds of arc is more than 300^m (about 1 000 feet).

tions: First, that the indications of the striding level are not sufficiently accurate to determine the small *changes* of inclination during the progress of a half set, and, second, that if (as is generally the case) there is any systematic difference between the inclination as defined by level readings with objective northward and with objective southward the mean of these two inclinations is the required most probable value corresponding to intermediate positions of the telescope in which it points to stars near the zenith (time stars). There may be individual cases in which the first of these assumptions should be reversed and each star transit reduced by using the level reading which is nearest to it in time, upon the supposition that the actual changes of inclination are so large that the level indications furnish a real measure of them. In general, however, the method of treating the level readings shown in §§ 9, 10 is probably the best.

The errors in the computed time arising from *inequality and irregularity of pivots* are probably negligible for first-class instruments in good condition. Any small error in the adopted mean value of the inequality will appear in the computation with nearly its full value in the derived error of collimation, but will be almost completely eliminated from the computed chronometer correction. It is only the *difference* of the irregularities of the two pivots which affect the observed times, and it should be noted that corresponding points on the two pivots are always under about the same pressure at the same time, and that therefore irregularities due to wear tend to be the same for the two pivots.

Changes in the rate of the chronometer during the progress of a set of observations evidently produce errors in the computed chronometer correction at the mean epoch of the set. Under ordinary circumstances such errors must be exceedingly small. If, however, an observer is forced to use a poor timepiece, or if clouds interfere so as to extend the time required to make a set of observations over several hours, this error may become appreciable.

The *observer's errors* are by far the most serious of any class of errors in transit time observations. The observer is subject to both accidental and constant errors* in

*In discussing errors, and especially when discussing them with reference to their ultimate effects, it is quite important to keep clearly in mind the distinctions between accidental errors, constant errors, and systematic errors. A *constant error* is one which has the same effect upon all the observations of the series or portion of a series under consideration. *Accidental errors* are not constant from observation to observation; they are as apt to be minus as plus, and they presumably follow the law of error which is the basis of the theory of least squares. A *systematic error* is one of which the algebraic sign, and, to a certain extent, the magnitude, bears a fixed relation to some condition or set of conditions. Thus, for example, the phase error in observations of horizontal directions is systematic with respect to the azimuth of the sun and of the line of sight. The expression "constant error" is often used loosely in contradistinction to "accidental error," in such a way as to include both strictly constant errors and systematic errors. The effect of accidental errors upon the final result may be diminished by continued repetition of the observations and by the least square method of computation. The effects of constant errors and of systematic errors must be eliminated by other processes; for example, by changing the method or programme of observations, by special investigations or special observations designed to evaluate a constant error or to determine the exact law of a systematic error. The above discussion applies with full force, in so far as the observer is directly concerned, to errors arising from imperfect perception or judgment rather than to blunders or mistakes, such as reading a level five divisions wrong or estimating a time one second wrong. If a mistake is so large that it is caught by the checks which are used for that purpose it is usually without effect upon the computed result, since it is either corrected or the observation concerned is rejected. A mistake which is not caught is, in its effect upon the computed result, an accidental error and, if proper checks have been used to detect mistakes, will lie within the limits of magnitude of the accidental errors. A similar distinction between instrumental errors and instrumental blunders may be drawn; for example, a blunder rather than error is caused by the movement of an objective which is loose in its cell.

his observations of the times of transit and in his readings of the striding level. The level reading errors (such as errors in estimating tenths) are inappreciable in their effect upon the computed time, but the errors in observations of times of transit enter into the computed time with full value. The observer's accidental errors are estimated in § 18. His constant error in estimating the time of transit is known as personal equation and may amount to a half second or even a whole second in an extreme case. The personal equation and methods of measuring it and eliminating it from final results will be treated more fully in connection with longitude determinations.

To sum up, it may be stated that the *accidental* error in the determination of a chronometer correction from observations with a portable transit instrument upon ten stars may be reduced within the limits indicated by a probable error of from $\pm 0^s.01$ to $\pm 0^s.10$, but that the chronometer correction is subject to a large *constant* error, the observer's absolute personal equation, which may be ten times as great as the probable (accidental) error.

OTHER METHODS OF DETERMINING TIME.

27. In the field it is sometimes necessary to use other instruments as transits for the determination of time. A theodolite, when so used, is apt to give results of a higher degree of accuracy than would be expected from an instrument of its size, unless one has it in mind that the principal errors in transit time observations are those due directly to the observer. On the other hand, zenith telescopes of the form in which the telescope does not swing in a plane passing through the vertical axis of the instrument have been found to give disappointing results when used in the meridian for time, perhaps because of the asymmetry of the instrument and of the fact that there can be no reversal of the horizontal axis in its bearings, but only of the instrument as a whole. The time may, however, be thus determined with sufficient accuracy for use in connection with determinations of latitude with the zenith telescope. *

The determination of time by the use of the transit in any position out of the meridian has been advocated, but has not seemed advisable. The additional difficulty of making the computation, over that for a transit nearly in the meridian, and other incidental inconveniences, much more than offset the fact that the adjustment for putting the transit in the meridian is then unnecessary.

The use of the transit in the vertical plane passing through Polaris at the time of observation has been advocated, and has been used to a considerable extent in Europe and in Canada. It is not used on this Survey. The advantage of this method over the meridian method is that the stability of the instrument is depended upon for only about five minutes instead of thirty minutes or more. This method is open, though to a less extent, to the objections stated in the preceding paragraph against the method of observing in any position out of the meridian.

Sextant observations for time by measuring the altitude of the sun give sufficiently accurate results for many purposes.† For example, the chronometer correction may

* For methods of determining time with a zenith telescope by using it as an equal-altitude instrument, see Coast Survey Report for 1869, Appendix No. 12, pp. 226–232.

† For convenient instructions, formulæ and tables for sextant observations for time and other approximate astronomical methods, see Bowditch's American Practical Navigator, published by the U. S. Navy Department.

thus be determined with sufficient accuracy for use in zenith telescope determinations of latitude or in observations for azimuth made upon a circumpolar star within an hour of elongation. One advantage of this procedure is that the hours of darkness are left entirely free for other astronomical observations.

If a mark nearly in the meridian of a transit instrument has been established and its azimuth determined (by the method of § 69, for example) the chronometer correction may be determined at noon within $0^{s}.5$ or less by observing the transit of the sun as follows: Point on the meridian mark just before apparent noon; observe the transit of the preceding limb of the sun across the lines of the diaphragm; reverse the horizontal axis of the telescope and observe the transit of the following limb across the diaphragm lines. The striding level should be read just before the transit of the preceding and just after the transit of the following limb. The mean of all the observed times is the chronometer time of transit of the sun's center across the plane of the instrument. This time corrected for azimuth error, as determined by the pointing upon the meridian mark, and for inclination, is the chronometer time of transit across the meridian, whence the chronometer correction on apparent solar time becomes known. During the observations the instrument should be sheltered from the direct rays of the sun. This may be done by hanging up a cloth in front of it having a hole cut in it opposite the objective. This method of determining time may sometimes be found desirable in connection with chronometric determinations of longitude in Alaska when continuous cloudy weather prevents star observations.

A, B, C, FACTORS.

28. The following table of factors will be found to be sufficiently accurate whenever the errors of adjustment a, b, c are not allowed to exceed one second of time. In 1874 the Coast Survey published separately more extended tables, entitled "The star-factors A, B, C, for reducing transit observations." These give the factors to three decimal places. Where, from any cause, observations are made with any instrumental error abnormally large it is desirable to take the corresponding star factors from this table, or to compute them to the requisite degree of accuracy.

The signs of the factors are as follows:

A is plus except for stars between the zenith and the pole.

B is plus except for stars observed at lower culmination.

C for observations with illumination (bright band or clamp) *west* is plus for stars at upper culmination and minus at lower culmination.

C for observations with illumination *east* is minus for stars at upper culmination and plus at lower culmination.

The arithmetical values of the factors (but not the algebraic signs) are given by these formulæ: $A = \sin \zeta \sec \delta$; $B = \cos \zeta \sec \delta$; $C = \sec \delta$; where δ = declination, and ζ = zenith distance = $\varphi - \delta$ or $\varphi - (180^{\circ} - \delta)$ for stars observed at upper or lower culmination respectively.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT = STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	0°	10°	15°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	41°	42°	43°	44°	45°	46°	ζ
°																					°
1	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	·02	89
2	·04	·04	·04	·04	·04	·04	·04	·04	·04	·04	·04	·04	·04	·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	87
4	·07	·07	·07	·07	·08	·08	·08	·08	·08	·08	·08	·09	·09	·09	·09	·09	·10	·10	·10	·10	86
5	·09	·09	·09	·09	·09	·10	·10	·10	·10	·10	·10	·11	·11	·11	·11	·12	·12	·12	·12	·13	85
6	·11	·11	·11	·11	·11	·11	·12	·12	·12	·12	·13	·13	·13	·14	·14	·14	·14	·15	·15	·15	84
7	·12	·12	·13	·13	·13	·13	·14	·14	·14	·14	·15	·15	·15	·16	·16	·16	·17	·17	·17	·18	83
8	·14	·14	·14	·15	·15	·15	·16	·16	·16	·16	·17	·17	·18	·18	·18	·19	·19	·19	·20	·20	82
9	·16	·16	·16	·17	·17	·17	·17	·18	·18	·18	·19	·19	·20	·20	·21	·21	·21	·22	·22	·22	81
10	·17	·18	·18	·19	·19	·19	·19	·20	·20	·21	·21	·21	·22	·23	·23	·23	·24	·24	·25	·25	80
11	·19	·19	·20	·20	·21	·21	·21	·22	·22	·23	·23	·24	·24	·25	·25	·26	·26	·27	·27	·28	79
12	·21	·21	·22	·22	·22	·23	·23	·24	·24	·25	·25	·26	·26	·27	·27	·28	·28	·29	·29	·30	78
13	·22	·23	·23	·24	·24	·25	·25	·26	·26	·27	·27	·28	·29	·29	·30	·30	·31	·31	·32	·32	77
14	·24	·25	·25	·26	·26	·27	·27	·27	·28	·29	·29	·30	·31	·32	·32	·33	·33	·34	·34	·35	76
15	·26	·26	·27	·28	·28	·28	·29	·29	·30	·31	·31	·32	·33	·34	·34	·35	·35	·36	·37	·37	75
16	·28	·28	·29	·29	·30	·30	·31	·31	·32	·33	·33	·34	·35	·36	·37	·37	·38	·38	·39	·40	74
17	·29	·30	·30	·31	·31	·32	·33	·33	·34	·34	·35	·36	·37	·38	·39	·39	·40	·41	·41	·42	73
18	·31	·31	·32	·33	·33	·33	·34	·35	·36	·36	·37	·38	·39	·40	·41	·42	·42	·43	·44	·44	72
19	·33	·33	·34	·35	·35	·36	·36	·37	·38	·38	·39	·40	·41	·42	·43	·44	·45	·45	·46	·47	71
20	·34	·35	·35	·36	·37	·37	·38	·39	·40	·40	·41	·42	·43	·45	·45	·46	·47	·48	·48	·49	70
21	·36	·36	·37	·38	·39	·39	·40	·41	·41	·42	·43	·44	·45	·47	·47	·48	·49	·50	·51	·52	69
22	·37	·38	·39	·40	·40	·41	·42	·42	·43	·44	·45	·46	·48	·49	·50	·50	·51	·52	·53	·54	68
23	·39	·40	·41	·42	·42	·43	·44	·44	·45	·46	·47	·48	·50	·51	·52	·53	·53	·54	·55	·56	67
24	·41	·41	·42	·43	·44	·45	·45	·46	·47	·48	·49	·50	·52	·53	·54	·55	·56	·57	·58	·59	66
25	·42	·43	·44	·45	·46	·46	·47	·48	·49	·50	·51	·52	·54	·55	·56	·57	·58	·59	·60	·61	65
26	·44	·45	·45	·47	·47	·48	·49	·50	·51	·52	·53	·54	·56	·57	·58	·59	·60	·61	·62	·63	64
27	·45	·46	·47	·48	·49	·50	·51	·51	·52	·54	·55	·56	·58	·59	·60	·61	·62	·63	·64	·65	63
28	·47	·48	·49	·50	·51	·51	·52	·53	·54	·55	·57	·58	·60	·61	·62	·63	·64	·65	·66	·68	62
29	·48	·49	·50	·52	·52	·53	·54	·55	·56	·57	·58	·60	·61	·63	·64	·65	·66	·67	·69	·70	61
30	·50	·51	·52	·53	·54	·55	·56	·57	·58	·59	·60	·62	·63	·65	·66	·67	·68	·69	·71	·72	60
31	·52	·52	·53	·55	·56	·56	·57	·58	·59	·61	·62	·64	·65	·67	·68	·69	·70	·72	·73	·74	59
32	·53	·54	·55	·56	·57	·58	·59	·60	·61	·63	·64	·65	·67	·69	·70	·71	·72	·74	·75	·76	58
33	·55	·55	·56	·58	·59	·60	·61	·62	·63	·64	·66	·67	·69	·71	·72	·73	·74	·76	·77	·78	57
34	·56	·57	·58	·59	·60	·61	·62	·63	·65	·66	·67	·69	·71	·73	·74	·75	·76	·78	·79	·80	56
35	·57	·58	·59	·61	·62	·63	·64	·65	·66	·68	·69	·71	·73	·75	·76	·77	·78	·80	·81	·83	55
36	·59	·60	·61	·63	·63	·64	·65	·67	·68	·69	·71	·73	·75	·77	·78	·79	·80	·82	·83	·85	54
37	·60	·61	·62	·64	·65	·66	·67	·68	·70	·71	·73	·74	·76	·79	·80	·81	·82	·84	·85	·87	53
38	·62	·63	·64	·66	·66	·67	·69	·70	·71	·73	·74	·76	·78	·80	·82	·83	·84	·86	·87	·89	52
39	·63	·64	·65	·67	·68	·69	·70	·71	·73	·74	·76	·78	·80	·82	·83	·85	·86	·87	·89	·91	51
40	·64	·65	·67	·68	·69	·70	·72	·73	·74	·76	·77	·79	·82	·84	·85	·86	·88	·89	·91	·93	50
41	·66	·67	·68	·70	·71	·72	·73	·74	·76	·77	·79	·81	·83	·86	·87	·88	·90	·91	·93	·94	49
42	·67	·68	·69	·71	·72	·73	·74	·76	·77	·79	·81	·83	·85	·87	·89	·90	·91	·93	·95	·96	48
43	·68	·69	·71	·73	·74	·75	·76	·77	·79	·80	·82	·84	·86	·89	·90	·92	·93	·95	·96	·98	47
44	·69	·71	·72	·74	·75	·76	·77	·79	·80	·82	·84	·86	·88	·91	·92	·93	·95	·97	·98	1·00	46
45	·71	·72	·73	·75	·76	·77	·79	·80	·82	·83	·85	·87	·90	·92	·94	·95	·97	·98	1·00	1·02	45

46	·72	·73	·74	·77	·78	·79	·80	·82	·83	·85	·87	·89	·91	·94	·95	·97	·98	1·00	1·02	1·04	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	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	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	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	**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	39
52	·79	·80	·82	·84	·85	·86	·88	·89	·91	·93	·95	·97	1·00	1·03	1·04	1·06	1·08	1·10	1·11	1·13	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	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	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	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	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	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	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	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	**30**
61	·87	·89	·91	·93	·94	·96	·97	·99	1·01	1·03	1·05	1·08	1·11	1·14	1·16	1·18	1·20	1·22	1·24	1·26	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	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	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	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	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	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	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	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	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	**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	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	18
73	·96	·97	·99	1·02	1·03	1·05	1·06	1·08	1·10	1·13	1·15	1·18	1·21	1·25	1·27	1·29	1·31	1·33	1·35	1·38	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	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	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	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	1·29	1·31	1·33	1·35	1·38	1·40	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	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	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	**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	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	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	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	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	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	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	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	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
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	**0**

The bottom line on this page is the factor C.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT=STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	47°	48°	49°	50°	51°	52°	53°	54°	55°	56°	57°	58°	58½°	59°	59½°	60°	60½°	61°	61½°	62°	ζ
°																					°
1	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·03	·04	·04	·04	·04	89
2	·05	·05	·05	·05	·06	·06	·06	·06	·06	·06	·06	·07	·07	·07	·07	·07	·07	·07	·07	·07	88
3	·08	·08	·08	·08	·08	·08	·09	·09	·09	·09	·10	·10	·10	·10	·10	·10	·11	·11	·11	·11	87
4	·10	·10	·11	·11	·11	·11	·12	·12	·12	·12	·13	·13	·13	·14	·14	·14	·14	·14	·15	·15	86
5	·13	·13	·13	·13	·14	·14	·14	·15	·15	·16	·16	·16	·17	·17	·17	·17	·18	·18	·18	·19	85
6	·15	·16	·16	·16	·17	·17	·17	·18	·18	·19	·19	·20	·20	·20	·21	·21	·21	·22	·22	·22	84
7	·18	·18	·19	·19	·19	·20	·20	·21	·21	·22	·22	·23	·23	·24	·24	·24	·25	·25	·26	·26	83
8	·20	·21	·21	·22	·22	·23	·23	·24	·24	·25	·26	·26	·27	·27	·27	·28	·28	·29	·29	·30	82
9	·23	·23	·24	·24	·25	·25	·26	·27	·27	·28	·29	·29	·30	·30	·31	·31	·32	·32	·33	·33	81
10	·25	·26	·26	·27	·28	·28	·29	·30	·30	·31	·32	·33	·33	·34	·34	·35	·35	·36	·36	·37	80
11	·28	·28	·29	·30	·30	·31	·32	·32	·33	·34	·35	·36	·36	·37	·38	·38	·39	·39	·40	·41	79
12	·30	·31	·32	·32	·33	·34	·35	·35	·36	·37	·38	·39	·40	·40	·41	·42	·42	·43	·44	·44	78
13	·33	·34	·34	·35	·36	·36	·37	·38	·39	·40	·41	·42	·43	·44	·44	·45	·46	·46	·47	·48	77
14	·35	·36	·37	·38	·38	·39	·40	·41	·42	·43	·44	·46	·46	·47	·48	·48	·49	·50	·51	·52	76
15	·38	·39	·39	·40	·41	·42	·43	·44	·45	·46	·48	·49	·50	·50	·51	·52	·53	·53	·54	·55	75
16	·40	·41	·42	·43	·44	·45	·46	·47	·48	·49	·51	·52	·53	·54	·54	·55	·56	·57	·58	·59	74
17	·43	·44	·45	·45	·46	·47	·48	·50	·51	·52	·54	·55	·56	·57	·58	·58	·59	·60	·61	·62	73
18	·45	·46	·47	·48	·49	·50	·51	·53	·54	·55	·57	·58	·59	·60	·61	·62	·63	·64	·65	·66	72
19	·48	·49	·50	·51	·52	·53	·54	·55	·57	·58	·60	·61	·62	·63	·64	·65	·66	·67	·68	·69	71
20	·50	·51	·52	·53	·54	·56	·57	·58	·60	·61	·63	·64	·65	·66	·67	·68	·69	·70	·72	·73	70
21	·52	·54	·55	·56	·57	·58	·59	·61	·62	·64	·66	·68	·69	·70	·71	·72	·73	·74	·75	·76	69
22	·55	·56	·57	·58	·60	·61	·62	·64	·65	·67	·69	·71	·72	·73	·74	·75	·76	·77	·78	·80	68
23	·57	·58	·60	·61	·62	·63	·65	·66	·68	·70	·72	·74	·75	·76	·77	·78	·79	·81	·82	·83	67
24	·60	·61	·62	·63	·65	·66	·68	·69	·71	·73	·75	·77	·78	·79	·80	·81	·83	·84	·85	·87	66
25	·62	·63	·64	·66	·67	·69	·70	·72	·74	·76	·78	·80	·81	·82	·83	·85	·86	·87	·89	·90	65
26	·64	·65	·67	·68	·70	·71	·73	·75	·76	·78	·80	·83	·84	·85	·86	·88	·89	·90	·92	·93	64
27	·67	·68	·69	·71	·72	·74	·75	·77	·79	·81	·83	·86	·87	·88	·89	·91	·92	·94	·95	·97	63
28	·69	·70	·72	·73	·75	·76	·78	·80	·82	·84	·86	·89	·90	·91	·93	·94	·95	·97	·98	1·00	62
29	·71	·72	·74	·75	·77	·79	·81	·82	·84	·87	·89	·91	·93	·94	·96	·97	·98	1·00	1·02	1·03	61
30	·73	·75	·76	·78	·79	·81	·83	·85	·87	·89	·92	·94	·96	·97	·99	1·00	1·01	1·03	1·05	1·07	60
31	·75	·77	·78	·80	·82	·84	·86	·88	·90	·92	·95	·97	·99	1·00	1·01	1·03	1·05	1·06	1·08	1·10	59
32	·78	·79	·81	·82	·84	·86	·88	·90	·92	·95	·97	1·00	1·01	1·03	1·04	1·06	1·08	1·09	1·11	1·13	58
33	·80	·81	·83	·85	·87	·88	·91	·93	·95	·97	1·00	1·03	1·04	1·06	1·07	1·09	1·11	1·12	1·14	1·16	57
34	·82	·84	·85	·87	·89	·91	·93	·95	·97	1·00	1·03	1·05	1·07	1·09	1·10	1·12	1·14	1·15	1·17	1·19	56
35	·84	·86	·87	·89	·91	·93	·95	·98	1·00	1·03	1·05	1·08	1·10	1.11	1·13	1·15	1·16	1·18	1·20	1·22	55
36	·86	·88	·90	·91	·93	·95	·98	1·00	1·03	1·05	1·08	1·11	1·12	1·14	1·16	1·18	1·19	1·21	1·23	1·25	54
37	·88	·90	·92	·94	·96	·98	1·00	1·02	1·05	1·08	1·10	1·14	1·15	1·17	1·19	1·20	1·22	1·24	1·26	1·28	53
38	·90	·92	·94	·96	·98	1·00	1·02	1·05	1·07	1·10	1·13	1·16	1·18	1·20	1·21	1·23	1·25	1·27	1·29	1·31	52
39	·92	·94	·96	·98	1·00	1·02	1·05	1·07	1·10	1·12	1·15	1·19	1·20	1·22	1·24	1·26	1·28	1·30	1·32	1·34	51
40	·94	·96	·98	1·00	1·02	1·04	1·07	1·09	1·12	1·15	1·18	1·21	1·23	1·25	1·27	1·29	1·31	1·33	1·35	1·37	50
41	·96	·98	1·00	1·02	1·04	1·07	1·09	1·12	1·14	1·17	1·20	1·24	1·26	1·27	1·29	1·31	1·33	1·35	1·37	1·40	49
42	·98	1·00	1·02	1·04	1·06	1·09	1·11	1·14	1·17	1·20	1·23	1·26	1·28	1·30	1·32	1·34	1·36	1·38	1·40	1·42	48
43	1·00	1·02	1·04	1·06	1·08	1·11	1·13	1·16	1·19	1·22	1·25	1·29	1·30	1·32	1·34	1·36	1·39	1·41	1·43	1·45	47
44	1·02	1·04	1·06	1·08	1·10	1·13	1·15	1·18	1·21	1·24	1·28	1·31	1·33	1·35	1·37	1·39	1·41	1·43	1·46	1·48	46
45	1·04	1·06	1·08	1·10	1·12	1·15	1·17	1·20	1·23	1·26	1·30	1·33	1·35	1·37	1·39	1·41	1·44	1·46	1·48	1·51	45

46	1'05	1'07	1'10	1'12	1'14	1'17	1'19	1'22	1'25	1'29	1'32	1'36	1'38	1'40	1'42	1'44	1'46	1'48	1'51	1'53	44
47	1'07	1'09	1'11	1'14	1'16	1'19	1'21	1'24	1'27	1'31	1'34	1'38	1'40	1'42	1'44	1'46	1'49	1'51	1'53	1'56	43
48	1'09	1'11	1'13	1'16	1'18	1'21	1'23	1'26	1'30	1'33	1'36	1'40	1'42	1'44	1'46	1'48	1'51	1'53	1'55	1'58	42
49	1'11	1'13	1'15	1'17	1'20	1'23	1'25	1'28	1'32	1'35	1'39	1'42	1'44	1'47	1'49	1'51	1'53	1'56	1'58	1'61	41
50	1'12	1'14	1'17	1'19	1'22	1'24	1'27	1'30	1'34	1'37	1'41	1'44	1'47	1'49	1'51	1'53	1'56	1'58	1'60	1'63	**40**
51	1'14	1'16	1'18	1'21	1'23	1'26	1'29	1'32	1'35	1'39	1'43	1'47	1'49	1'51	1'53	1'55	1'58	1'60	1'63	1'66	39
52	1'15	1'18	1'20	1'23	1'25	1'28	1'31	1'34	1'37	1'41	1'45	1'49	1'51	1'53	1'55	1'58	1'60	1'63	1'65	1'68	38
53	1'17	1'19	1'22	1'24	1'27	1'30	1'33	1'36	1'39	1'43	1'47	1'51	1'53	1'55	1'57	1'60	1'62	1'65	1'67	1'70	37
54	1'19	1'21	1'23	1'26	1'29	1'31	1'34	1'38	1'41	1'45	1'49	1'53	1'55	1'57	1'59	1'62	1'64	1'67	1'69	1'72	36
55	1'20	1'22	1'25	1'27	1'30	1'33	1'36	1'39	1'43	1'46	1'50	1'55	1'57	1'59	1'61	1'64	1'66	1'69	1'72	1'74	35
56	1'22	1'24	1'26	1'29	1'32	1'35	1'38	1'41	1'45	1'48	1'52	1'56	1'59	1'61	1'63	1'66	1'68	1'71	1'74	1'77	34
57	1'23	1'25	1'28	1'31	1'33	1'36	1'39	1'43	1'46	1'50	1'54	1'58	1'61	1'63	1'65	1'68	1'70	1'73	1'76	1'79	33
58	1'24	1'27	1'29	1'32	1'35	1'38	1'41	1'44	1'48	1'52	1'56	1'60	1'62	1'65	1'67	1'70	1'72	1'75	1'78	1'81	32
59	1'26	1'28	1'31	1'33	1'36	1'39	1'42	1'46	1'49	1'53	1'57	1'62	1'64	1'66	1'69	1'71	1'74	1'77	1'80	1'83	31
60	1'27	1'29	1'32	1'35	1'38	1'41	1'44	1'47	1'51	1'55	1'59	1'63	1'66	1'68	1'71	1'73	1'76	1'79	1'81	1'84	**30**
61	1'28	1'31	1'33	1'36	1'39	1'42	1'45	1'49	1'53	1'56	1'61	1'65	1'67	1'70	1'72	1'75	1'78	1'80	1'83	1'86	29
62	1'29	1'32	1'35	1'37	1'40	1'43	1'47	1'50	1'54	1'58	1'62	1'67	1'69	1'71	1'74	1'77	1'79	1'82	1'85	1'88	28
63	1'31	1'33	1'36	1'39	1'42	1'45	1'48	1'52	1'55	1'59	1'64	1'68	1'70	1'73	1'76	1'78	1'81	1'84	1'87	1'90	27
64	1'32	1'34	1'37	1'40	1'43	1'46	1'49	1'53	1'57	1'61	1'65	1'70	1'72	1'75	1'77	1'80	1'83	1'85	1'88	1'91	26
65	1'33	1'35	1'38	1'41	1'44	1'47	1'51	1'54	1'58	1'62	1'66	1'71	1'73	1'76	1'79	1'81	1'84	1'87	1'90	1'93	25
66	1'34	1'37	1'39	1'42	1'45	1'48	1'52	1'55	1'59	1'63	1'68	1'72	1'75	1'77	1'80	1'83	1'85	1'88	1'91	1'95	24
67	1'35	1'38	1'40	1'43	1'46	1'50	1'53	1'57	1'60	1'65	1'69	1'74	1'76	1'79	1'81	1'84	1'87	1'90	1'93	1'96	23
68	1'36	1'39	1'41	1'44	1'47	1'51	1'54	1'58	1'62	1'66	1'70	1'75	1'77	1'80	1'83	1'85	1'88	1'91	1'94	1'97	22
69	1'37	1.40	1'42	1'45	1'48	1'52	1'55	1'59	1'63	1'67	1'71	1'76	1'79	1'81	1'84	1'87	1'90	1'93	1'96	1'99	21
70	1'38	1'40	1'43	1'46	1'49	1'53	1'56	1'60	1'64	1'68	1'73	1'77	1'80	1'82	1'85	1'88	1'91	1'94	1'97	2'00	**20**
71	1'39	1'41	1'44	1'47	1'50	1'54	1'57	1'61	1'65	1'69	1'74	1'78	1'81	1'84	1'86	1'89	1'92	1'95	1'98	2'01	19
72	1'39	1'42	1.45	1'48	1'51	1'54	1'58	1'62	1'66	1'70	1'75	1'79	1'82	1'85	1'87	1'90	1'93	1'96	1'99	2'03	18
73	1'40	1'43	1'46	1'49	1'52	1'55	1'59	1'63	1'67	1'71	1'76	1'80	1'83	1'86	1'88	1'91	1'94	1'97	2'00	2'04	17
74	1'41	1'44	1'46	1'49	1'53	1'56	1'60	1'63	1'68	1'72	1'76	1'81	1'84	1'87	1'89	1'92	1'95	1'98	2'01	2'05	16
75	1'42	1'44	1'47	1'50	1'53	1'57	1'60	1'64	1'68	1'73	1'77	1'82	1'85	1'88	1'90	1'93	1'96	1'99	2'02	2'06	15
76	1'42	1'45	1'48	1'51	1'54	1'58	1'61	1'65	1'69	1'73	1'78	1'83	1'86	1'88	1'91	1'94	1'97	2'00	2'03	2'07	14
77	1'43	1'46	1'48	1'52	1'55	1'58	1'62	1'66	1'70	1'74	1'79	1'84	1'86	1'89	1'92	1'95	1'98	2'01	2'04	2'07	13
78	1'43	1'46	1'49	1'52	1'55	1'59	1'62	1'66	1'70	1'75	1'80	1'85	1'87	1'90	1'93	1'96	1'99	2'02	2'05	2'08	12
79	1'44	1'47	1'50	1'53	1'56	1'59	1'63	1'67	1'71	1 76	1'80	1'85	1'88	1'91	1'93	1'96	1'99	2'02	2'06	2'09	11
80	1'44	1'47	1'50	1'53	1'56	1'60	1'64	1'67	1'72	1'76	1'81	1'86	1'88	1'91	1'94	1'97	2'00	2'03	2'06	2'10	**10**
81	1'45	1'48	1'51	1'54	1'57	1'60	1'64	1'68	1'72	1'77	1'81	1'86	1'89	1'92	1'95	1'98	2'01	2'04	2'07	2'10	9
82	1'45	1'48	1'51	1'54	1'57	1'61	1'64	1'68	1'73	1'77	1'82	1'87	1'90	1'92	1'95	1'98	2'01	2'04	2'08	2'11	8
83	1'46	1'48	1'51	1'54	1'58	1'61	1'65	1'69	1'73	1'77	1'82	1'87	1'90	1'93	1'96	1'99	2'02	2'05	2'08	2'12	7
84	1'46	1'49	1'52	1'55	1'58	1'62	1'65	1'69	1'73	1'78	1'83	1'88	1'90	1'93	1'96	1'99	2'02	2'05	2'08	2'12	6
85	1 46	1'49	1'52	1'55	1'58	1'62	1'65	1'69	1'74	1'78	1'83	1'88	1'91	1'93	1'96	1'99	2'02	2'05	2'09	2'12	5
86	1'46	1'49	1'52	1'55	1'59	1'62	1'66	1'70	1'74	1'78	1'83	1'88	1'91	1'94	1'97	2'00	2'03	2'06	2'09	2'13	4
87	1'46	1'49	1'52	1'55	1'59	1'62	1'66	1'70	1'74	1'79	1'83	1'88	1'91	1'94	1'97	2'00	2'03	2'06	2'09	2'13	3
88	1'46	1'49	1'52	1'55	1'59	1'62	1'66	1'70	1'74	1'79	1'83	1'89	1'91	1'94	1'97	2'00	2'03	2'06	2'09	2'13	2
89	1'47	1'49	1'52	1'56	1'59	1'62	1'66	1'70	1'74	1'79	1'84	1'89	1'91	1'94	1'97	2'00	2'03	2'06	2'10	2'13	1
90	1'47	1'49	1'52	1'56	1'59	1'62	1'66	1'70	1'74	1'79	1'84	1'89	1'91	1'94	1'97	2'00	2'03	2'06	2'10	2'13	**0**

The bottom line on this page is the factor C.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT = STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	62½°	63°	63½°	64°	64½°	65°	65½°	66°	66½°	67°	67½°	68°	68½°	69°	69°10′	69°20′	69°30′	69°40′	69°50′	70°	ζ
°																					°
1	·04	·04	·04	·04	·04	·04	·04	·04	·04	·04	·05	·05	·05	·05	·05	·05	·05	·05	·05	·05	89
2	·08	·08	·08	·08	·08	·08	·08	·09	·09	·09	·09	·09	·10	·10	·10	·10	·10	·10	·10	·10	88
3	·11	·12	·12	·12	·12	·12	·13	·13	·13	·13	·14	·14	·14	·15	·15	·15	·15	·15	·15	·15	87
4	·15	·15	·16	·16	·16	·17	·17	·17	·18	·18	·18	·19	·19	·20	·20	·20	·20	·20	·20	·20	86
5	·19	·19	·19	·20	·20	·21	·21	·21	·22	·22	·23	·23	·24	·24	·24	·25	·25	·25	·25	·25	85
6	·23	·23	·23	·24	·24	·25	·25	·26	·26	·27	·27	·28	·28	·29	·29	·30	·30	·30	·30	·31	84
7	·26	·27	·27	·28	·28	·29	·29	·30	·31	·31	·32	·33	·33	·34	·34	·34	·35	·35	·35	·36	83
8	·30	·31	·31	·32	·32	·33	·34	·34	·35	·36	·36	·37	·38	·39	·39	·39	·40	·40	·40	·41	82
9	·34	·35	·35	·36	·36	·37	·38	·39	·39	·40	·41	·42	·43	·44	·44	·44	·45	·45	·45	·46	81
10	·38	·38	·39	·40	·40	·41	·42	·43	·43	·44	·45	·46	·47	·48	·49	·49	·50	·50	·50	·51	**80**
11	·41	·42	·43	·44	·44	·45	·46	·47	·48	·49	·50	·51	·52	·53	·54	·54	·54	·55	·55	·56	79
12	·45	·46	·47	·47	·48	·49	·50	·51	·52	·53	·54	·56	·57	·58	·58	·59	·59	·60	·60	·61	78
13	·49	·50	·50	·51	·52	·53	·54	·55	·56	·58	·59	·60	·61	·63	·63	·64	·64	·65	·65	·66	77
14	·52	·53	·54	·55	·56	·57	·58	·59	·61	·62	·63	·65	·66	·67	·68	·68	·69	·70	·70	·71	76
15	·56	·57	·58	·59	·60	·61	·62	·64	·65	·66	·68	·69	·71	·72	·73	·73	·74	·74	·75	·76	75
16	·60	·61	·62	·63	·64	·65	·66	·68	·69	·71	·72	·74	·75	·77	·78	·78	·79	·79	·80	·81	74
17	·63	·64	·66	·67	·68	·69	·70	·72	·73	·75	·76	·78	·80	·81	·82	·83	·83	·84	·85	·85	73
18	·67	·68	·69	·70	·72	·73	·74	·76	·77	·79	·81	·83	·84	·86	·87	·88	·88	·89	·90	·90	72
19	·70	·72	·73	·74	·76	·77	·78	·80	·82	·83	·85	·87	·89	·91	·92	·92	·93	·94	·94	·95	71
20	·74	·75	·77	·78	·79	·81	·82	·84	·86	·88	·89	·91	·93	·95	·96	·97	·98	·98	·99	1·00	**70**
21	·78	·79	·80	·82	·83	·85	·86	·88	·90	·92	·94	·96	·98	1·00	1·01	1·02	1.02	1·03	1·04	1·05	69
22	·81	·82	·84	·85	·87	·89	·90	·92	·94	·96	·98	1·00	1·02	1·05	1·05	1·06	1.07	1·08	1·09	1·09	68
23	·85	·86	·88	·89	·91	·92	·94	·96	·98	1·00	1·02	1·04	1·07	1·09	1·10	1·11	1.12	1·12	1·13	1·14	67
24	·88	·90	·91	·93	·94	·96	·98	1·00	1·02	1·04	1·06	1·09	1·11	1·14	1·14	1·15	1.16	1·17	1·18	1·19	66
25	·92	·93	·95	·96	·98	1·00	1·02	1·04	1·06	1·08	1·10	1·13	1·15	1·18	1·19	1·20	1.21	1·22	1·23	1·24	65
26	·95	·97	·98	1·00	1·02	1·04	1·06	1·08	1·10	1·12	1·15	1·17	1·20	1·22	1·23	1·24	1·25	1·26	1·27	1·28	64
27	·98	1·00	1·02	1·04	1·05	1·07	1·09	1·12	1·14	1·16	1·19	1·21	1·24	1·27	1·28	1·29	1·30	1·31	1·32	1·33	63
28	1·02	1·03	1·05	1·07	1·09	1·11	1·13	1·15	1·18	1·20	1·23	1·25	1·28	1·31	1·32	1·33	1·34	1·35	1·36	1·37	62
29	1·05	1·07	1·09	1·11	1·13	1·15	1·17	1·19	1·22	1·24	1·27	1·29	1·32	1·35	1·36	1·37	1·38	1·40	1·41	1·42	61
30	1·08	1·10	1·12	1·14	1·16	1·18	1·21	1·23	1·25	1·28	1·31	1·33	1·36	1·39	1·41	1·42	1·43	1·44	1·45	1·46	**60**
31	1·11	1·13	1·15	1·17	1·20	1·22	1·24	1·27	1·29	1·32	1·35	1·38	1·40	1·44	1·45	1·46	1·47	1·48	1·49	1·51	59
32	1·15	1·17	1·19	1·21	1·23	1·25	1·28	1·30	1·33	1·36	1·39	1·42	1·45	1·48	1·49	1·50	1·51	1·52	1·54	1·55	58
33	1·18	1·20	1·22	1·24	1·26	1·29	1·31	1·34	1·37	1·39	1·42	1·45	1·49	1·52	1·53	1·54	1·55	1·57	1·58	1·59	57
34	1·21	1·23	1·25	1·27	1·30	1·32	1·35	1·37	1·40	1·43	1·46	1·49	1·53	1·56	1·57	1·58	1·60	1·61	1·62	1·63	56
35	1·24	1·26	1·29	1·31	1·33	1·36	1·38	1·41	1·44	1·47	1·50	1·53	1·56	1·60	1·61	1·62	1·64	1·65	1·66	1·68	55
36	1·27	1·30	1·32	1·34	1·37	1·39	1·42	1·45	1·47	1·51	1·54	1·57	1·60	1·64	1·65	1·66	1·68	1·69	1·70	1·72	54
37	1·30	1·33	1·35	1·37	1·40	1·42	1·45	1·48	1·51	1·54	1·57	1·61	1·64	1·68	1·69	1·70	1·72	1·73	1·74	1·76	53
38	1·33	1·36	1·38	1·40	1·43	1·46	1·48	1·51	1·54	1·58	1·61	1·64	1·68	1·72	1·73	1·74	1·76	1·77	1·79	1·80	52
39	1·36	1·39	1·41	1·43	1·46	1·49	1·52	1·55	1·58	1·61	1·65	1·68	1·72	1·75	1·77	1·78	1·80	1·81	1·82	1·84	51
40	1·39	1·42	1·44	1·47	1·49	1·52	1·55	1·58	1·61	1·65	1·68	1·72	1·75	1·79	1·81	1·82	1·84	1·85	1·86	1·88	**50**
41	1·42	1·45	1·47	1·50	1·52	1·55	1·58	1·61	1·64	1·68	1·71	1·75	1·79	1·83	1·84	1·86	1·87	1·89	1·90	1·92	49
42	1·45	1·47	1·50	1·53	1·55	1·58	1·61	1·64	1·68	1·71	1·75	1·79	1·83	1·87	1·88	1·90	1·91	1·93	1·94	1·96	48
43	1·48	1·50	1·53	1·56	1·58	1·61	1·64	1·68	1·71	1·75	1·78	1·82	1·86	1·90	1·92	1·93	1·95	1·96	1·98	1·99	47
44	1·50	1·53	1·56	1·58	1·61	1·64	1·67	1·71	1·74	1·78	1·82	1·85	1·90	1·94	1·95	1·97	1·98	2·00	2·02	2·03	46
45	1·53	1·56	1·58	1·61	1·64	1·67	1·70	1·74	1·77	1·81	1·85	1·89	1·93	1·97	1·99	2·00	2·02	2·04	2·05	2·07	45

46	1·56	1·58	1·61	1·64	1·67	1·70	1·74	1·77	1·80	1·84	1·88	1·92	1·96	2·01	2·02	2·04	2·05	2·07	2·09	2·10	44
47	1·58	1·61	1·64	1·67	1·70	1·73	1·76	1·80	1·83	1·87	1·91	1·95	2·00	2·04	2·06	2·07	2·09	2·10	2·12	2·14	43
48	1·60	1·63	1·66	1·69	1·72	1·76	1·79	1·83	1·86	1·90	1·94	1·98	2·03	2·07	2·09	2·11	2·12	2·14	2·16	2·17	42
49	1·63	1·66	1·69	1·72	1·75	1·79	1·82	1·86	1·89	1·93	1·97	2·01	2·06	2·11	2·12	2·14	2·16	2·17	2·19	2·21	41
50	1·66	1·69	1·72	1·75	1·78	1·81	1·85	1·88	1·92	1·96	2·00	2·04	2·09	2·14	2·15	2·17	2·19	2·20	2·22	2·24	**40**
51	1·68	1·71	1·74	1·77	1·80	1·84	1·87	1·91	1·95	1·99	2·03	2·07	2·12	2·17	2·18	2·20	2·22	2·24	2·25	2·27	39
52	1·71	1·74	1·77	1·80	1·83	1·86	1·90	1·94	1·98	2·02	2·06	2·10	2·15	2·20	2·22	2·23	2·25	2·27	2·29	2·30	38
53	1·73	1·76	1·79	1·82	1·85	1·89	1·93	1·96	2·00	2·04	2·09	2·13	2·18	2·23	2·25	2·26	2·28	2·30	2·32	2·33	37
54	1·75	1·78	1·81	1·85	1·88	1·91	1·95	1·99	2·03	2·07	2·11	2·16	2·21	2·26	2·28	2·29	2·31	2·33	2·35	2·37	36
55	1·77	1·80	1·84	1·87	1·90	1·94	1·98	2·01	2·05	2·10	2·14	2·19	2·23	2·29	2·30	2·32	2·34	2·36	2·38	2·40	35
56	1·80	1·83	1·86	1·89	1·93	1·96	2·00	2·04	2·08	2·12	2·17	2·21	2·26	2·31	2·33	2·35	2·37	2·39	2·40	2·42	34
57	1·82	1·85	1·88	1·91	1·95	1·98	2·02	2·06	2·10	2·15	2·19	2·24	2·29	2·34	2·36	2·38	2·39	2·41	2·43	2·45	33
58	1·84	1·87	1·90	1·93	1·97	2·01	2·05	2·08	2·13	2·17	2·22	2·26	2·31	2·37	2·38	2·40	2·42	2·44	2·46	2·48	32
59	1·86	1·89	1·92	1·96	1·99	2·03	2·07	2·11	2·15	2·19	2·24	2·29	2·34	2·39	2·41	2·43	2·45	2·47	2·49	2·51	31
60	1·88	1·91	1·94	1·98	2·01	2·05	2·09	2·13	2·17	2·22	2·26	2·31	2·36	2·42	2·44	2·45	2·47	2·49	2·51	2·53	**30**
61	1·89	1·93	1·96	2·00	2·03	2·07	2·11	2·15	2·19	2·24	2·29	2·33	2·39	2·44	2·46	2·48	2·50	2·52	2·54	2·56	29
62	1·91	1·94	1·98	2·01	2·05	2·09	2·13	2·17	2·21	2·26	2·31	2·36	2·41	2·46	2·48	2·50	2·52	2·54	2·56	2·58	28
63	1·93	1·96	2·00	2·03	2·07	2·11	2·15	2·19	2·23	2·28	2·33	2·38	2·43	2·49	2·50	2·52	2·54	2·56	2·58	2·60	27
64	1·95	1·98	2·02	2·05	2·09	2·13	2·17	2·21	2·25	2·30	2·35	2·40	2·45	2·51	2·53	2·55	2·57	2·59	2·61	2·63	26
65	1·96	2·00	2·03	2·07	2·11	2·14	2·19	2·23	2·27	2·32	2·37	2·42	2·47	2·53	2·55	2·57	2·59	2·61	2·63	2·65	25
66	1·98	2·01	2·05	2·08	2·12	2·16	2·20	2·25	2·29	2·34	2·39	2·44	2·49	2·55	2·57	2·59	2·61	2·63	2·65	2·67	24
67	1·99	2·03	2·06	2·10	2·14	2·18	2·22	2·26	2·31	2·36	2·41	2·46	2·51	2·57	2·59	2·61	2·63	2·65	2·67	2·69	23
68	2·01	2·04	2·08	2·11	2·15	2·19	2·24	2·28	2·32	2·37	2·42	2·47	2·53	2·59	2·61	2·63	2·65	2·67	2·69	2·71	22
69	2·02	2·06	2·09	2·13	2·17	2·21	2·25	2·30	2·34	2·39	2·44	2·49	2·55	2·61	2·62	2·64	2·67	2·69	2·71	2·73	21
70	2·03	2·07	2·11	2·14	2·18	2·22	2·27	2·31	2·36	2·40	2·46	2·51	2·56	2·62	2·64	2·66	2·68	2·70	2·73	2·75	**20**
71	2·05	2·08	2·12	2·16	2·20	2·24	2·28	2·32	2·37	2·42	2·47	2·52	2·58	2·64	2·66	2·68	2·70	2·72	2·74	2·77	19
72	2·06	2·09	2·13	2·17	2·21	2·25	2·29	2·34	2·38	2·43	2·49	2·54	2·59	2·65	2·67	2·70	2·72	2·74	2·76	2·78	18
73	2·07	2·11	2·14	2·18	2·22	2·26	2·31	2·35	2·40	2·45	2·50	2·55	2·61	2·67	2·69	2·71	2·73	2·75	2·77	2·80	17
74	2·08	2·12	2·15	2·19	2·23	2·27	2·32	2·36	2·41	2·46	2·51	2·57	2·62	2·68	2·70	2·72	2·74	2·77	2·79	2·81	16
75	2·09	2·13	2·16	2·20	2·24	2·29	2·33	2·37	2·42	2·47	2·52	2·58	2·64	2·70	2·72	2·74	2·76	2·78	2·80	2·82	15
76	2·10	2·14	2·17	2·21	2·25	2·30	2·34	2·39	2·43	2·48	2·54	2·59	2·65	2·71	2·73	2·75	2·77	2·79	2·81	2·84	14
77	2·11	2·15	2·18	2·22	2·26	2·31	2·35	2·40	2·44	2·49	2·55	2·60	2·66	2·72	2·74	2·76	2·78	2·80	2·83	2·85	13
78	2·12	2·15	2·19	2·23	2·27	2·31	2·36	2·40	2·45	2·50	2·56	2·61	2·67	2·73	2·75	2·77	2·79	2·81	2·84	2·86	12
79	2·13	2·16	2·20	2·24	2·28	2·32	2·37	2·41	2·46	2·51	2·57	2·62	2·68	2·74	2·76	2·78	2·80	2·82	2·85	2·87	11
80	2·13	2·17	2·21	2·25	2·29	2·33	2·38	2·42	2·47	2·52	2·57	2·63	2·69	2·75	2·77	2·79	2·81	2·83	2·86	2·88	**10**
81	2·14	2·18	2·21	2·25	2·29	2·34	2·38	2·43	2·48	2·53	2·58	2·64	2·69	2·76	2·78	2·80	2·82	2·84	2·86	2·89	9
82	2·15	2·18	2·22	2·26	2·30	2·34	2·39	2·43	2·48	2·53	2·59	2·64	2·70	2·76	2·78	2·81	2·83	2·85	2·87	2·90	8
83	2·15	2·19	2·22	2·26	2·31	2·35	2·39	2·44	2·49	2·54	2·59	2·65	2·71	2·77	2·79	2·81	2·83	2·86	2·88	2·90	7
84	2·15	2·19	2·23	2·27	2·31	2·35	2·40	2·45	2·49	2·55	2·60	2·66	2·71	2·78	2·80	2·82	2·84	2·86	2·88	2·91	6
85	2·16	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	2·80	2·82	2·84	2·87	2·89	2·91	5
86	2·16	2·20	2·24	2·28	2·32	2·36	2·41	2·45	2·50	2·55	2·61	2·66	2·72	2·78	2·80	2·83	2·85	2·87	2·89	2·92	4
87	2·16	2·20	2·24	2·28	2·32	2·36	2·41	2·46	2·50	2·56	2·61	2·67	2·72	2·79	2·81	2·83	2·85	2·87	2·90	2·92	3
88	2·16	2·20	2·24	2·28	2·32	2·36	2·41	2·46	2·51	2·56	2·61	2·67	2·73	2·79	2·81	2·83	2·85	2·88	2·90	2·92	2
89	2·17	2·20	2·24	2·28	2·32	2·37	2·41	2·46	2·51	2·56	2·61	2·67	2·73	2·79	2·81	2·83	2·86	2·88	2·90	2·92	1
90	2·17	2·20	2·24	2·28	2·32	2·37	2·41	2·46	2·51	2·56	2·61	2·67	2·73	2·79	2·81	2·83	2·86	2·88	2·90	2·92	**0**

The bottom line on this page is the factor C.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT=STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	70° 10′	70° 20′	70° 30′	70° 40′	70° 50′	71°	71° 10′	71° 20′	71° 30′	71° 40′	71° 50′	72°	72° 10′	72° 20′	72° 30′	72° 40′	72° 50′	73°	73° 10′	73° 20′	ζ
°																					°
1	·05	·05	·05	·05	·05	·05	·05	·05	·05	·06	·06	·06	·06	·06	·06	·06	·06	·06	·06	·06	89
2	·10	·10	·10	·10	·11	·11	·11	·11	·11	·11	·11	·11	·11	·12	·12	·12	·12	·12	·12	·12	88
3	·15	·16	·16	·16	·16	·16	·16	·16	·16	·17	·17	·17	·17	·17	·17	·18	·18	·18	·18	·18	87
4	·20	·21	·21	·21	·21	·21	·22	·22	·22	·22	·22	·23	·23	·23	·23	·23	·24	·24	·24	·24	86
5	·26	·26	·26	·26	·26	·27	·27	·27	·27	·28	·28	·28	·28	·29	·29	·29	·30	·30	·30	·30	85
6	·31	·31	·31	·32	·32	·32	·32	·33	·33	·33	·34	·34	·34	·34	·35	·35	·35	·36	·36	·36	84
7	·36	·36	·37	·37	·37	·37	·38	·38	·38	·39	·39	·39	·40	·40	·41	·41	·41	·42	·42	·42	83
8	·41	·41	·42	·42	·42	·43	·43	·44	·44	·44	·45	·45	·45	·46	·46	·47	·47	·48	·48	·48	82
9	·46	·46	·47	·47	·48	·48	·48	·49	·49	·50	·50	·51	·51	·52	·52	·52	·53	·53	·54	·54	81
10	·51	·52	·52	·52	·53	·53	·54	·54	·55	·55	·56	·56	·57	·57	·58	·58	·59	·59	·60	·60	80
11	·56	·57	·57	·58	·58	·59	·59	·60	·60	·61	·61	·62	·62	·63	·63	·64	·65	·65	·66	·66	79
12	·61	·62	·62	·63	·63	·64	·64	·65	·66	·66	·67	·67	·68	·68	·69	·70	·70	·71	·72	·72	78
13	·66	·67	·67	·68	·68	·69	·70	·70	·71	·72	·72	·73	·74	·74	·75	·76	·76	·77	·78	·78	77
14	·71	·72	·72	·73	·74	·74	·75	·76	·76	·77	·78	·78	·79	·80	·80	·81	·82	·83	·84	·84	76
15	·76	·77	·78	·78	·79	·79	·80	·81	·81	·82	·83	·84	·84	·85	·86	·87	·88	·89	·89	·90	75
16	·81	·82	·83	·83	·84	·85	·85	·86	·87	·88	·88	·89	·90	·91	·92	·92	·93	·94	·95	·96	74
17	·86	·87	·88	·88	·89	·90	·90	·91	·92	·93	·94	·95	·96	·96	·97	·98	·99	1·00	1·01	1·02	73
18	·91	·92	·93	·93	·94	·95	·96	·96	·97	·98	·99	1·00	1·01	1·02	1·03	1·04	1·05	1·06	1·07	1·08	72
19	·96	·97	·98	·98	·99	1·00	1·01	1·02	1·03	1·04	1·04	1·05	1·06	1·07	1·08	1·09	1·10	1·11	1·12	1·14	71
20	1·01	1·02	1·02	1·03	1·04	1·05	1·06	1·07	1·08	1·09	1·10	1·11	1·12	1·13	1·14	1·15	1·16	1·17	1·18	1·19	70
21	1·06	1·06	1·07	1·08	1·09	1·10	1·11	1·12	1·13	1·14	1·15	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·24	1·25	69
22	1·10	1·11	1·12	1·13	1·14	1·15	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·24	1·25	1·26	1·27	1·28	1·29	1·31	68
23	1·15	1·16	1·17	1·18	1·19	1·20	1·21	1·22	1·23	1·24	1·25	1·26	1·28	1·29	1·30	1·31	1·32	1·34	1·35	1·36	67
24	1·20	1·21	1·22	1·23	1·24	1·25	1·26	1·27	1·28	1·29	1·30	1·32	1·33	1·34	1·35	1·36	1·38	1·39	1·40	1·42	66
25	1·25	1·26	1·27	1·28	1·29	1·30	1·31	1·32	1·33	1·34	1·36	1·37	1·38	1·39	1·41	1·42	1·43	1·45	1·46	1·47	65
26	1·29	1·30	1·31	1·32	1·34	1·35	1·36	1·37	1·38	1·39	1·41	1·42	1·43	1·44	1·46	1·47	1·48	1·50	1·51	1·53	64
27	1·34	1·35	1·36	1·37	1·38	1·39	1·41	1·42	1·43	1·44	1·46	1·47	1·48	1·50	1·51	1·52	1·54	1·55	1·57	1·58	63
28	1·38	1·40	1·41	1·42	1·43	1·44	1·45	1·47	1·48	1·49	1·51	1·52	1·53	1·55	1·56	1·58	1·59	1·60	1·62	1·64	62
29	1·43	1·44	1·45	1·46	1·48	1·49	1·50	1·52	1·53	1·54	1·56	1·57	1·58	1·60	1·61	1·63	1·64	1·66	1·67	1·69	61
30	1·47	1·49	1·50	1·51	1·52	1·54	1·55	1·56	1·58	1·59	1·60	1·62	1·63	1·65	1·66	1·68	1·69	1·71	1·73	1·74	60
31	1·52	1·53	1·54	1·56	1·57	1·58	1·60	1·61	1·62	1·64	1·65	1·67	1·68	1·70	1·71	1·73	1·74	1·76	1·78	1·80	59
32	1·56	1·57	1·59	1·60	1·61	1·63	1·64	1·66	1·67	1·68	1·70	1·71	1·73	1·75	1·76	1·78	1·80	1·81	1·83	1·85	58
33	1·60	1·62	1·63	1·64	1·66	1·67	1·69	1·70	1·72	1·73	1·75	1·76	1·78	1·80	1·81	1·83	1·85	1·86	1·88	1·90	57
34	1·65	1·66	1·68	1·69	1·70	1·72	1·73	1·75	1·76	1·78	1·79	1·81	1·83	1·84	1·86	1·88	1·89	1·91	1·93	1·95	56
35	1·69	1·70	1·72	1·73	1·75	1·76	1·78	1·79	1·81	1·82	1·84	1·86	1·87	1·89	1·91	1·92	1·94	1·96	1·98	2·00	55
36	1·73	1·75	1·76	1·78	1·79	1·80	1·82	1·84	1·85	1·87	1·88	1·90	1·92	1·94	1·95	1·97	1·99	2·01	2·03	2·05	54
37	1·77	1·79	1·80	1·82	1·83	1·85	1·86	1·88	1·90	1·91	1·93	1·95	1·96	1·98	2·00	2·02	2·04	2·06	2·08	2·10	53
38	1·82	1·83	1·84	1·86	1·88	1·89	1·91	1·92	1·94	1·96	1·98	1·99	2·01	2·03	2·05	2·07	2·09	2·11	2·13	2·15	52
39	1·86	1·87	1·89	1·90	1·92	1·93	1·95	1·97	1·98	2·00	2·02	2·04	2·06	2·07	2·09	2·11	2·13	2·15	2·17	2·19	51
40	1·89	1·91	1·93	1·94	1·96	1·97	1·99	2·01	2·03	2·04	2·06	2·08	2·10	2·12	2·14	2·16	2·18	2·20	2·22	2·24	50
41	1·93	1·95	1·96	1·98	2·00	2·01	2·03	2·05	2·07	2·09	2·10	2·12	2·14	2·16	2·18	2·20	2·22	2·24	2·26	2·29	49
42	1·97	1·99	2·00	2·02	2·04	2·05	2·07	2·09	2·11	2·13	2·15	2·16	2·18	2·20	2·22	2·25	2·27	2·29	2·31	2·33	48
43	2·01	2·03	2·04	2·06	2·08	2·09	2·11	2·13	2·15	2·17	2·19	2·21	2·23	2·25	2·27	2·29	2·31	2·33	2·36	2·38	47
44	2·05	2·06	2·08	2·10	2·12	2·13	2·15	2·17	2·19	2·21	2·23	2·25	2·27	2·29	2·31	2·33	2·35	2·38	2·40	2·42	46
45	2·08	2·10	2·12	2·14	2·15	2·17	2·19	2·21	2·23	2·25	2·27	2·29	2·31	2·33	2·35	2·37	2·40	2·42	2·44	2·46	45

46	2·12	2·14	2·15	2·17	2·19	2·21	2·23	2·25	2·27	2·29	2·31	2·33	2·35	2·37	2·39	2·41	2·44	2·46	2·48	2·51	44
47	2·16	2·17	2·19	2·21	2·23	2·25	2·27	2·28	2·30	2·32	2·35	2·37	2·39	2·41	2·43	2·45	2·48	2·50	2·52	2·55	43
48	2·19	2·21	2·22	2·24	2·26	2·28	2·30	2·32	2·34	2·36	2·38	2·40	2·43	2·45	2·47	2·49	2·52	2·54	2·57	2·59	42
49	2·22	2·24	2·26	2·28	2·30	2·32	2·34	2·36	2·38	2·40	2·42	2·44	2·46	2·49	2·51	2·53	2·56	2·58	2·61	2·63	41
50	2·26	2·28	2·29	2·31	2·33	2·35	2·37	2·39	2·41	2·44	2·46	2·48	2·50	2·52	2·55	2·57	2·60	2·62	2·64	2·67	40
51	2·29	2·31	2·33	2·35	2·37	2·39	2·41	2·43	2·45	2·47	2·49	2·51	2·54	2·56	2·58	2·61	2·63	2·66	2·68	2·71	39
52	2·32	2·34	2·36	2·38	2·40	2·42	2·44	2·46	2·48	2·50	2·53	2·55	2·57	2·60	2·62	2·64	2·67	2·69	2·72	2·75	38
53	2·35	2·37	2·39	2·41	2·43	2·45	2·47	2·50	2·52	2·54	2·56	2·58	2·61	2·63	2·66	2·68	2·71	2·73	2·76	2·78	37
54	2·38	2·40	2·42	2·44	2·46	2·48	2·51	2·53	2·55	2·57	2·60	2·62	2·64	2·67	2·69	2·72	2·74	2·77	2·79	2·82	36
55	2·41	2·43	2·45	2·47	2·50	2·52	2·54	2·56	2·58	2·60	2·63	2·65	2·68	2·70	2·72	2·75	2·78	2·80	2·83	2·86	35
56	2·44	2·46	2·48	2·50	2·52	2·55	2·57	2·59	2·61	2·64	2·66	2·68	2·71	2·73	2·76	2·78	2·81	2·84	2·86	2·89	34
57	2·47	2·49	2·51	2·53	2·55	2·58	2·60	2·62	2·64	2·67	2·69	2·71	2·74	2·76	2·79	2·82	2·84	2·87	2·90	2·92	33
58	2·50	2·52	2·54	2·56	2·58	2·61	2·63	2·65	2·67	2·70	2·72	2·74	2·77	2·79	2·82	2·85	2·87	2·90	2·93	2·96	32
59	2·53	2·55	2·57	2·59	2·61	2·63	2·66	2·68	2·70	2·72	2·75	2·77	2·80	2·82	2·85	2·88	2·90	2·93	2·96	2·99	31
60	2·55	2·57	2·59	2·62	2·64	2·66	2·68	2·71	2·73	2·75	2·78	2·80	2·83	2·85	2·88	2·91	2·93	2·96	2·99	3·02	30
61	2·58	2·60	2·62	2·64	2·66	2·69	2·71	2·73	2·76	2·78	2·80	2·83	2·86	2·88	2·91	2·94	2·96	2·99	3·02	3·05	29
62	2·60	2·62	2·64	2·67	2·69	2·71	2·74	2·76	2·78	2·81	2·83	2·86	2·88	2·91	2·94	2·96	2·99	3·02	3·05	3·08	28
63	2·63	2·65	2·67	2·69	2·71	2·74	2·76	2·78	2·81	2·83	2·86	2·88	2·91	2·94	2·96	2·99	3·02	3·05	3·08	3·11	27
64	2·65	2·67	2·69	2·72	2·74	2·76	2·78	2·81	2·83	2·86	2·88	2·91	2·94	2·96	2·99	3·02	3·04	3·07	3·10	3·13	26
65	2·67	2·69	2·71	2·74	2·76	2·78	2·81	2·83	2·86	2·88	2·91	2·93	2·96	2·99	3·01	3·04	3·07	3·10	3·13	3·16	25
66	2·69	2·71	2·74	2·76	2·78	2·81	2·83	2·85	2·88	2·90	2·93	2·96	2·98	3·01	3·04	3·07	3·10	3·13	3·16	3·18	24
67	2·71	2·74	2·76	2·78	2·80	2·83	2·85	2·88	2·90	2·93	2·95	2·98	3·01	3·03	3·06	3·09	3·12	3·15	3·18	3·21	23
68	2·73	2·76	2·78	2·80	2·82	2·85	2·87	2·90	2·92	2·95	2·97	3·00	3·03	3·06	3·08	3·11	3·14	3·17	3·20	3·23	22
69	2·75	2·77	2·80	2·82	2·84	2·87	2·89	2·92	2·94	2·97	2·99	3·02	3·05	3·08	3·10	3·13	3·16	3·19	3·22	3·26	21
70	2·77	2·79	2·81	2·84	2·86	2·89	2·91	2·94	2·96	2·99	3·01	3·04	3·07	3·10	3·12	3·15	3·18	3·21	3·24	3·28	20
71	2·79	2·81	2·83	2·86	2·88	2·90	2·93	2·95	2·98	3·01	3·03	3·06	3·09	3·12	3·14	3·17	3·20	3·23	3·26	3·30	19
72	2·80	2·83	2·85	2·87	2·90	2·92	2·95	2·97	3·00	3·02	3·05	3·08	3·10	3·13	3·16	3·19	3·22	3·25	3·28	3·32	18
73	2·82	2·84	2·86	2·89	2·91	2·94	2·96	2·99	3·01	3·04	3·07	3·09	3·12	3·15	3·18	3·21	3·24	3·27	3·30	3·33	17
74	2·83	2·86	2·88	2·90	2·93	2·95	2·98	3·00	3·03	3·06	3·08	3·11	3·14	3·17	3·20	3·23	3·26	3·29	3·32	3·35	16
75	2·85	2·87	2·89	2·92	2·94	2·97	2·99	3·02	3·04	3·07	3·10	3·13	3·15	3·18	3·21	3·24	3·27	3·30	3·34	3·37	15
76	2·86	2·88	2·91	2·93	2·96	2·98	3·01	3·03	3·06	3·08	3·11	3·14	3·17	3·20	3·23	3·26	3·29	3·32	3·35	3·38	14
77	2·87	2·90	2·92	2·94	2·97	2·99	3·02	3·04	3·07	3·10	3·12	3·15	3·18	3·21	3·24	3·27	3·30	3·33	3·36	3·40	13
78	2·88	2·91	2·93	2·95	2·98	3·00	3·03	3·06	3·08	3·11	3·14	3·16	3·19	3·22	3·25	3·28	3·31	3·34	3·38	3·41	12
79	2·89	2·92	2·94	2·96	2·99	3·02	3·04	3·07	3·09	3·12	3·15	3·18	3·20	3·23	3·26	3·29	3·33	3·36	3·39	3·42	11
80	2·90	2·93	2·95	2·97	3·00	3·02	3·05	3·08	3·10	3·13	3·16	3·19	3·22	3·24	3·27	3·31	3·34	3·37	3·40	3·43	10
81	2·91	2·94	2·96	2·98	3·01	3·03	3·06	3·09	3·11	3·14	3·17	3·20	3·23	3·25	3·28	3·32	3·35	3·38	3·41	3·44	9
82	2·92	2·94	2·97	2·99	3·02	3·04	3·07	3·09	3·12	3·15	3·18	3·20	3·23	3·26	3·29	3·32	3·36	3·39	3·42	3·45	8
83	2·92	2·95	2·97	3·00	3·02	3·05	3·08	3·10	3·13	3·16	3·18	3·21	3·24	3·27	3·30	3·33	3·36	3·40	3·43	3·46	7
84	2·93	2·96	2·98	3·00	3·03	3·06	3·08	3·11	3·13	3·16	3·19	3·22	3·25	3·28	3·31	3·34	3·37	3·40	3·43	3·47	6
85	2·94	2·96	2·98	3·01	3·03	3·06	3·09	3·11	3·14	3·17	3·20	3·22	3·25	3·28	3·31	3·34	3·38	3·41	3·44	3·47	5
86	2·94	2·96	2·99	3·01	3·04	3·06	3·09	3·12	3·14	3·17	3·20	3·23	3·26	3·29	3·32	3·35	3·38	3·41	3·44	3·48	4
87	2·94	2·97	2·99	3·02	3·04	3·07	3·09	3·12	3·15	3·18	3·20	3·23	3·26	3·29	3·32	3·35	3·38	3·42	3·45	3·48	3
88	2·95	2·97	2·99	3·02	3·04	3·07	3·10	3·12	3·15	3·18	3·20	3·23	3·26	3·29	3·32	3·35	3·39	3·42	3·45	3·48	2
89	2·95	2·97	3·00	3·02	3·04	3·07	3·10	3·12	3·15	3·18	3·21	3·24	3·27	3·30	3·33	3·36	3·39	3·42	3·45	3·49	1
90	2·95	2·97	3·00	3·02	3·05	3·07	3·10	3·12	3·15	3·18	3·21	3·24	3·27	3·30	3·33	3·36	3·39	8·42	•3·45	3·49	0

The bottom line on this page is the factor C.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT = STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	73° 30′	73° 40′	73° 50′	74°	74° 10′	74° 20′	74° 30′	74° 40′	74° 50′	75°	75° 10′	75° 20′	75° 30′	75° 40′	75° 50′	76°	76° 10′	76° 20′	76° 30′	76° 40′	ζ
°																					°
1	·06	·06	·06	·06	·06	·06	·06	·07	·07	·07	·07	·07	·07	·07	·07	·07	·07	·07	.07	·08	89
2	·12	·12	·12	·13	·13	·13	·13	·13	·13	·13	·14	·14	·14	·14	·14	·14	·15	·15	·15	·15	88
3	·18	·19	.19	·19	·19	·19	·20	·20	·20	·20	·20	·21	·21	·21	·21	·22	·22	·22	·22	·23	87
4	·24	·25	·25	·25	·26	·26	·26	·26	·27	·27	·27	·28	·28	·28	·28	·29	·29	·30	·30	·30	86
5	·31	·31	·31	·32	·32	·32	·33	·33	·33	·34	·34	·34	·35	·35	·36	·36	·36	·37	·37	·38	85
6	·37	·37	·38	·38	·38	·39	·39	.40	·40	·40	·41	.41	·42	·42	·43	·43	·44	·44	·45	·45	84
7	·43	·43	·44	·44	·45	·45	·46	·46	·47	·47	.48	·48	·49	·49	·50	·50	·51	.52	·52	·53	83
8	·49	.50	·50	·50	·51	·52	·52	·53	·53	·54	·54	·55	·56	·56	·57	·58	·58	·59	·60	·60	82
9	·55	·56	·56	·57	·57	·58	·58	·59	·60	·60	·61	·62	·62	·63	·64	·65	·65	·66	·67	·68	81
10	·61	·62	·62	.63	·64	·64	·65	·66	·66	·67	·68	·69	·69	·70	·71	·72	·73	.74	·74	·75	80
11	·67	·68	·68	·69	·70	·71	·71	·72	·73	·74	·74	·75	·76	·77	·78	·79	·80	·81	·82	·83	79
12	·73	·74	·75	·75	·76	.77	·78	·79	·79	·80	·81	·82	·83	·84	·85	·86	·87	·88	·89	·90	78
13	·79	·80	·81	·82	·82	·83	·84	·85	·86	·87	·88	·89	·90	·91	·92	·93	·94	·95	·96	·98	77
14	·85	·86	·87	·88	·89	·90	·91	·92	·93	·94	·95	·96	·97	·98	·99	1·00	1·01	1·02	1·04	1·05	76
15	·91	·92	·93	·94	·95	·96	·97	·98	·99	1·00	1·01	1·02	1·03	1·04	1·06	1·07	1·08	1·10	1·11	1·12	75
16	·97	·98	·99	1·00	1·01	1·02	1·03	1·04	1·05	1·06	1·08	1·09	1·10	1·11	1·13	1·14	1·15	1·17	1·18	1·20	74
17	1·03	1·04	1·05	1·06	1·07	1·08	1·09	1·11	1·12	1·13	1·14	1·16	1·17	1·18	1·20	1·21	1·22	1·24	1·25	1·27	73
18	1·09	1·10	1·11	1·12	1·13	1·14	1.16	1·17	1·18	1·19	1·21	1·22	1·23	1·25	1·26	1·28	1·29	1·31	1·32	1·34	72
19	1·15	1·16	1·17	1·18	1·19	1·21	1·22	1·23	1·24	1·26	1·27	1·29	1·30	1·32	1·33	1·35	1·36	1·38	1·39	1·41	71
20	1·20	1·22	1·23	1·24	1·25	1·27	1·28	1·29	1·31	1·32	1·34	1·35	1·37	1·38	1·40	1·41	1·43	1·45	1·47	1·48	70
21	1·26	1·27	1·29	1·30	1·31	1·33	1·34	1·36	1·37	1·38	1·40	1·42	1·43	1·45	1·46	1·48	1·50	1·52	1·54	1·55	69
22	1·32	1·33	1·34	1·36	1·37	1·39	1·40	1·42	1·43	1·45	1·46	1·48	1·50	1·51	1·53	1·55	1·57	1·58	1·60	1·62	68
23	1·38	1·39	1·40	1·42	1·43	1·45	1·46	1·48	1·49	1·51	1·53	1·54	1·56	1·58	1·60	1·62	1·63	1·65	1·67	1·69	67
24	1·43	1·45	1·46	1·48	1·49	1·51	1·52	1·54	1·55	1·57	1·59	1·61	1·63	1·64	1·66	1·68	1·70	1·72	1·74	1·76	66
25	1·49	1·50	1·52	1·53	1·55	1·56	1·58	1·60	1·62	1·63	1·65	1·67	1·69	1·71	1·73	1·75	1·77	1·79	1·81	1·83	65
26	1·54	1·56	1·58	1·59	1·61	1·62	1·64	1·66	1·68	1·69	1·71	1·73	1·75	1·77	1·79	1·81	1·83	1·86	1·88	1·90	64
27	1·60	1·61	1·63	1·65	1·66	1·68	1·70	1·72	1·74	1·75	1·77	1·79	1·81	1·83	1·86	1·88	1·90	1·92	1·95	1·97	63
28	1·65	1·67	1·69	1·70	1·72	1·74	1·76	1·78	1·79	1·81	1·83	1·85	1·87	1·90	1·92	1·94	1·96	1·99	2·01	2·04	62
29	1·71	1·72	1·74	1·76	1·78	1·80	1·81	1·83	1·85	1·87	1·89	1·92	1·94	1·96	1·98	2·00	2·03	2·05	2·08	2·10	61
30	1·76	1·78	1·80	1·81	1·83	1·85	1·87	1·89	1·91	1·93	1·95	1·98	2·00	2·02	2·04	2·07	2·09	2·12	2·14	2·17	60
31	1·81	1·83	1·85	1·87	1·89	1·91	1·93	1·95	1·97	1·99	2·01	2·03	2·06	2·08	2·10	2·13	2·15	2·18	2·21	2·23	59
32	1·87	1·88	1·90	1·92	1·94	1·96	1·98	2·00	2·02	2·05	2·07	2·09	2·12	2·14	2·16	2·19	2·22	2·24	2·27	2·30	58
33	1·92	1·94	1·96	1·98	2·00	2·02	2·04	2·06	2·08	2·10	2·13	2·15	2·18	2·20	2·22	2·25	2·28	2·30	2·33	2·36	57
34	1·97	1·99	2·01	2·03	2·05	2·07	2·09	2·12	2·14	2·16	2·18	2·21	2·23	2·26	2·28	2·31	2·34	2·37	2·40	2·42	56
35	2·02	2·04	2·06	2·08	2·10	2·12	2·15	2·17	2·19	2·22	2·24	2·26	2·29	2·32	2·34	2·37	2·40	2·43	2·46	2·49	55
36	2·07	2·09	2·11	2·13	2·15	2·18	2·20	2·22	2·25	2·27	2·30	2·32	2·35	2·37	2·40	2·43	2·46	2·49	2·52	2·55	54
37	2·12	2·14	2·16	2·18	2·21	2·23	2·25	2·28	2·30	2·33	2·35	2·38	2·40	2·43	2·46	2·49	2·52	2·55	2·58	2·61	53
38	2·17	2·19	2·21	2·23	2·26	2·28	2·30	2·33	2·35	2·38	2·40	2·43	2·46	2·49	2·52	2·55	2·58	2·61	2·64	2·67	52
39	2·22	2·24	2·26	2·28	2·31	2·33	2·35	2·38	2·40	2·43	2·46	2·49	2·51	2·54	2·57	2·60	2·63	2·66	2·70	2·73	51
40	2·26	2·29	2·31	2·33	2·36	2·38	2·40	2·43	2·46	2·48	2·51	2·54	2·57	2·60	2·63	2·66	2·69	2·72	2·75	2·79	50
41	2·31	2·33	2·36	2·38	2·40	2·43	2·45	2·48	2·51	2·53	2·56	2·59	2·62	2·65	2·68	2·71	2·74	2·78	2·81	2·84	49
42	2·36	2·38	2·40	2·43	2·45	2·48	2·50	2·53	2·56	2·58	2·61	2·64	2·67	2·70	2·73	2·77	2·80	2·83	2·87	2·90	48
43	2·40	2·42	2·45	2·47	2·50	2·53	2·55	2·58	2·61	2·63	2·66	2·69	2·72	2·76	2·79	2 82	2·85	2·89	2·92	2·96	47
44	2·45	2·47	2·50	2·52	2·55	2·57	2·60	2·63	2·66	2·68	2·71	2·74	2·77	2·81	2·84	2·87	2·90	2·94	2·98	3·01	46
45	2·49	2·51	2·54	2·56	2·59	2·62	2·65	2·67	2·70	2·73	2·76	2·79	2·82	2·86	2·89	2·92	2·96	2·99	3·03	3·07	45

46	2·53	2·56	2·58	2·61	2·64	2·66	2·69	2·72	2·75	2·78	2·81	2·84	2·87	2·91	2·94	2·97	3·01	3·04	3·08	3·12	44
47	2·57	2·60	2·63	2·65	2·68	2·71	2·74	2·77	2·80	2·83	2·86	2·89	2·92	2·95	2·99	3·02	3·06	3·10	3·13	3·17	43
48	2·62	2·64	2·67	2·70	2·72	2·75	2·78	2·81	2·84	2·87	2·90	2·94	2·97	3·00	3·04	3·07	3·11	3·15	3·18	3·22	42
49	2·66	2·68	2·71	2·74	2·77	2·80	2·82	2·85	2·88	2·92	2·95	2·98	3·01	3·05	3·08	3·12	3·16	3·19	3·23	3·27	41
50	2·70	2·72	2·75	2·78	2·81	2·84	2·87	2·90	2·93	2·96	2·99	3·02	3·06	3·09	3·13	3·17	3·20	3·24	3·28	3·32	40
51	2·74	2·76	2·79	2·82	2·85	2·88	2·91	2·94	2·97	3·00	3·04	3·07	3·10	3·14	3·18	3·21	3·25	3·29	3·33	3·37	39
52	2·77	2·80	2·83	2·86	2·89	2·92	2·95	2·98	3·01	3·04	3·08	3·11	3·15	3·18	3·22	3·26	3·30	3·34	3·38	3·42	38
53	2·81	2·84	2·87	2·90	2·93	2·96	2·99	3·02	3·05	3·09	3·12	3·15	3·19	3·23	3·26	3·30	3·34	3·38	3·42	3·46	37
54	2·85	2·88	2·91	2·94	2·97	3·00	3·03	3·06	3·09	3·13	3·16	3·20	3·23	3·27	3·31	3·34	3·38	3·42	3·47	3·51	36
55	2·88	2·91	2·94	2·97	3·00	3·03	3·07	3·10	3·13	3·16	3·20	3·24	3·27	3·31	3·35	3·39	3·43	3·47	3·51	3·55	35
56	2·92	2·95	2·98	3·01	3·04	3·07	3·10	3·14	3·17	3·20	3·24	3·27	3·31	3·35	3·39	3·43	3·47	3·51	3·55	3·60	34
57	2·95	2·98	3·01	3·04	3·07	3·11	3·14	3·17	3·21	3·24	3·28	3·31	3·35	3·39	3·43	3·47	3·51	3·55	3·59	3·64	33
58	2·99	3·02	3·05	3·08	3·11	3·14	3·17	3·21	3·24	3·28	3·31	3·35	3·39	3·43	3·47	3·51	3·55	3·59	3·63	3·68	32
59	3·02	3·05	3·08	3·11	3·14	3·17	3·21	3·24	3·28	3·31	3·35	3·38	3·42	3·46	3·50	3·54	3·58	3·63	3·67	3·72	31
60	3·05	3·08	3·11	3·14	3·17	3·21	3·24	3·28	3·31	3·35	3·38	3·42	3·46	3·50	3·54	3·58	3·62	3·66	3·71	3·76	30
61	3·08	3·11	3·14	3·17	3·21	3·24	3·27	3·31	3·34	3·38	3·42	3·45	3·49	3·53	3·57	3·62	3·66	3·70	3·75	3·79	29
62	3·11	3·14	3·17	3·20	3·24	3·27	3·30	3·34	3·38	3·41	3·45	3·49	3·53	3·57	3·61	3·65	3·69	3·74	3·78	3·83	28
63	3·14	3·17	3·20	3·23	3·27	3·30	3·33	3·37	3·41	3·44	3·48	3·52	3·56	3·60	3·64	3·68	3·73	3·77	3·82	3·86	27
64	3·16	3·20	3·23	3·26	3·29	3·33	3·36	3·40	3·44	3·47	3·51	3·55	3·59	3·63	3·67	3·72	3·76	3·80	3·85	3·90	26
65	3·19	3·22	3·26	3·29	3·32	3·36	3·39	3·43	3·46	3·50	3·54	3·58	3·62	3·66	3·70	3·75	3·79	3·84	3·88	3·93	25
66	3·22	3·25	3·28	3·31	3·35	3·38	3·42	3·46	3·49	3·53	3·57	3·61	3·65	3·69	3·73	3·78	3·82	3·87	3·91	3·96	24
67	3·24	3·27	3·31	3·34	3·37	3·41	3·44	3·48	3·52	3·56	3·60	3·64	3·68	3·72	3·76	3·81	3·85	3·90	3·94	3·99	23
68	3·26	3·30	3·33	3·36	3·40	3·43	3·47	3·51	3·54	3·58	3·62	3·66	3·70	3·74	3·79	3·83	3·88	3·92	3·97	4·02	22
69	3·29	3·32	3·35	3·39	3·42	3·46	3·49	3·53	3·57	3·61	3·65	3·69	3·73	3·77	3·82	3·86	3·90	3·95	4·00	4·05	21
70	3·31	3·34	3·38	3·41	3·44	3·48	3·52	3·55	3·59	3·63	3·67	3·71	3·75	3·80	3·84	3·89	3·93	3·98	4·03	4·08	20
71	3·33	3·36	3·40	3·43	3·47	3·50	3·54	3·58	3·61	3·65	3·69	3·73	3·78	3·82	3·86	3·91	3·96	4·00	4·05	4·10	19
72	3·35	3·38	3·42	3·45	3·49	3·52	3·56	3·60	3·63	3·67	3·72	3·76	3·80	3·84	3·89	3·93	3·98	4·02	4·07	4·12	18
73	3·37	3·40	3·44	3·47	3·50	3·54	3·58	3·62	3·65	3·69	3·74	3·78	3·82	3·86	3·91	3·95	4·00	4·05	4·10	4·15	17
74	3·38	3·42	3·45	3·49	3·52	3·56	3·60	3·64	3·67	3·71	3·76	3·80	3·84	3·88	3·93	3·97	4·02	4·07	4·12	4·17	16
75	3·40	3·44	3·47	3·50	3·54	3·58	3·61	3·65	3·69	3·73	3·77	3·82	3·86	3·90	3·95	3·99	4·04	4·09	4·14	4·19	15
76	3·42	3·45	3·48	3·52	3·56	3·59	3·63	3·67	3·71	3·75	3·79	3·83	3·88	3·92	3·96	4·01	4·06	4·11	4·16	4·21	14
77	3·43	3·46	3·50	3·54	3·57	3·61	3·65	3·68	3·72	3·76	3·81	3·85	3·89	3·94	3·98	4·03	4·08	4·12	4·17	4·22	13
78	3·44	3·48	3·51	3·55	3·58	3·62	3·66	3·70	3·74	3·78	3·82	3·86	3·91	3·95	4·00	4·04	4·09	4·14	4·19	4·24	12
79	3·46	3·49	3·53	3·56	3·60	3·64	3·67	3·71	3·75	3·79	3·83	3·88	3·92	3·96	4·01	4·06	4·11	4·16	4·21	4·26	11
80	3·47	3·50	3·54	3·57	3·61	3·65	3·68	3·72	3·76	3·81	3·85	3·89	3·93	3·98	4·02	4·07	4·12	4·17	4·22	4·27	10
81	3·48	3·51	3·55	3·58	3·62	3·66	3·70	3·74	3·78	3·82	3·86	3·90	3·94	3·99	4·04	4·08	4·13	4·18	4·23	4·28	9
82	3·49	3·52	3·56	3·59	3·63	3·67	3·71	3·75	3·79	3·83	3·87	3·91	3·96	4·00	4·05	4·09	4·14	4·19	4·24	4·29	8
83	3·49	3·53	3·56	3·60	3·64	3·68	3·72	3·75	3·79	3·84	3·88	3·92	3·96	4·01	4·06	4·10	4·15	4·20	4·25	4·30	7
84	3·50	3·54	3·57	3·61	3·64	3·68	3·72	3·76	3·80	3·84	3·88	3·93	3·97	4·02	4·06	4·11	4·16	4·21	4·26	4·31	6
85	3·51	3·54	3·58	3·61	3·65	3·69	3·73	3·77	3·81	3·85	3·89	3·93	3·98	4·02	4·07	4·12	4·17	4·22	4·27	4·32	5
86	3·51	3·55	3·58	3·62	3·66	3·69	3·73	3·77	3·81	3·85	3·90	3·94	3·98	4·03	4·08	4·12	4·17	4·22	4·27	4·33	4
87	3·52	3·55	3·59	3·62	3·66	3·70	3·74	3·78	3·82	3·86	3·90	3·94	3·99	4·03	4·08	4·13	4·18	4·23	4·28	4·33	3
88	3·52	3·55	3·59	3·62	3·66	3·70	3·74	3·78	3·82	3·86	3·90	3·95	3·99	4·04	4·08	4·13	4·18	4·23	4·28	4·33	2
89	3·52	3·56	3·59	3·63	3·66	3·70	3·74	3·78	3·82	3·86	3·91	3·95	3·99	4·04	4·08	4·13	4·18	4·23	4·28	4·34	1
90	3·52	3·56	3·59	3·63	3·66	3·70	3·74	3·78	3·82	3·86	3·91	3·95	3·99	4·04	4·09	4·13	4·18	4·23	4·28	4·34	0

The bottom line on this page is the factor C.

Table of factors for reduction of transit observations.

For factor A use left-hand argument. TOP ARGUMENT=STAR'S DECLINATION (δ). For factor B use right-hand argument.

ζ	76° 50′	77°	77° 10′	77° 20′	77° 30′	77° 40′	77° 50′	78°	78° 10′	78° 20′	78° 30′	78° 40′	78° 50′	79°	79° 10′	79° 20′	79° 30′	79° 40′	79° 50′	80°	ζ
°																					°
1	.08	.08	.08	.08	.08	.08	.08	.08	.08	.09	.09	.09	.09	.09	.09	.09	.10	.10	.10	.10	89
2	.15	.16	.16	.16	.16	.16	.17	.17	.17	.17	.18	.18	.18	.18	.19	.19	.19	.20	.20	.20	88
3	.23	.23	.24	.24	.24	.24	.25	.25	.26	.26	.26	.27	.27	.27	.28	.28	.29	.29	.30	.30	87
4	.31	.31	.31	.32	.32	.33	.33	.34	.34	.34	.35	.36	.36	.37	.37	.38	.38	.39	.40	.40	86
5	.38	.39	.39	.40	.40	.41	.41	.42	.42	.43	.44	.44	.45	.46	.46	.47	.48	.49	.49	.50	85
6	.46	.46	.47	.48	.48	.49	.50	.51	.51	.52	.52	.53	.54	.55	.56	.56	.57	.58	.59	.60	84
7	.54	.54	.55	.56	.56	.57	.58	.59	.59	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70	83
8	.61	.62	.63	.64	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75	.76	.78	.79	.80	82
9	.69	.70	.70	.71	.72	.73	.74	.75	.76	.77	.78	.80	.81	.82	.83	.84	.86	.87	.89	.90	81
10	.76	.77	.78	.79	.80	.81	.82	.84	.85	.86	.87	.88	.90	.91	.92	.94	.95	.97	.98	1.00	80
11	.84	.85	.86	.87	.88	.89	.90	.92	.93	.94	.96	.97	.98	1.00	1.02	1.03	1.05	1.06	1.08	1.10	79
12	.91	.92	.94	.95	.96	.97	.99	1.00	1.01	1.03	1.04	1.06	1.07	1.09	1.11	1.12	1.14	1.16	1.18	1.20	78
13	.99	1.00	1.01	1.03	1.04	1.05	1.07	1.08	1.10	1.11	1.13	1.14	1.16	1.18	1.20	1.22	1.23	1.25	1.27	1.30	77
14	1.06	1.08	1.09	1.10	1.12	1.13	1.15	1.16	1.18	1.20	1.21	1.23	1.25	1.27	1.29	1.31	1.33	1.35	1.37	1.39	76
15	1.14	1.15	1.16	1.18	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	1.47	1.49	75
16	1.21	1.23	1.24	1.26	1.28	1.29	1.31	1.33	1.34	1.36	1.38	1.40	1.42	1.44	1.47	1.49	1.51	1.54	1.56	1.59	74
17	1.28	1.30	1.32	1.33	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.56	1.58	1.60	1.63	1.66	1.68	73
18	1.36	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.57	1.60	1.62	1.64	1.67	1.70	1.72	1.75	1.78	72
19	1.43	1.45	1.47	1.48	1.50	1.52	1.54	1.57	1.59	1.61	1.63	1.66	1.68	1.71	1.73	1.76	1.79	1.82	1.84	1.87	71
20	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.67	1.69	1.72	1.74	1.77	1.79	1.82	1.85	1.88	1.91	1.94	1.97	70
21	1.57	1.59	1.61	1.63	1.65	1.68	1.70	1.72	1.75	1.77	1.80	1.82	1.85	1.88	1.91	1.94	1.97	2.00	2.03	2.06	69
22	1.64	1.66	1.69	1.71	1.73	1.75	1.78	1.80	1.83	1.85	1.88	1.91	1.93	1.96	1.99	2.02	2.06	2.09	2.12	2.16	68
23	1.72	1.74	1.76	1.78	1.81	1.83	1.85	1.88	1.90	1.93	1.96	1.99	2.02	2.05	2.08	2.11	2.14	2.18	2.21	2.25	67
24	1.79	1.81	1.83	1.86	1.88	1.90	1.93	1.96	1.98	2.01	2.04	2.07	2.10	2.13	2.16	2.20	2.23	2.27	2.30	2.34	66
25	1.86	1.88	1.90	1.93	1.95	1.98	2.00	2.03	2.06	2.09	2.12	2.15	2.18	2.22	2.25	2.28	2.32	2.36	2.39	2.43	65
26	1.92	1.95	1.97	2.00	2.02	2.05	2.08	2.11	2.14	2.17	2.20	2.23	2.26	2.30	2.33	2.37	2.41	2.44	2.48	2.52	64
27	1.99	2.02	2.04	2.07	2.10	2.12	2.15	2.18	2.21	2.24	2.28	2.31	2.34	2.38	2.42	2.45	2.49	2.53	2.57	2.61	63
28	2.06	2.09	2.11	2.14	2.17	2.20	2.23	2.26	2.29	2.32	2.36	2.39	2.42	2.46	2.50	2.54	2.58	2.62	2.66	2.70	62
29	2.13	2.15	2.18	2.21	2.24	2.27	2.30	2.33	2.36	2.40	2.43	2.47	2.50	2.54	2.58	2.62	2.66	2.70	2.75	2.79	61
30	2.20	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	2.79	2.83	2.88	60
31	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	2.83	2.87	2.92	2.97	59
32	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	2.91	2.95	3.00	3.05	58
33	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	2.99	3.04	3.09	3.14	57
34	2.46	2.49	2.52	2.55	2.58	2.62	2.65	2.69	2.73	2.76	2.80	2.84	2.89	2.93	2.98	3.02	3.07	3.12	3.17	3.22	56
35	2.52	2.55	2.58	2.62	2.65	2.68	2.72	2.76	2.80	2.84	2.88	2.92	2.96	3.01	3.05	3.10	3.15	3.20	3.25	3.30	55
36	2.58	2.61	2.65	2.68	2.72	2.75	2.79	2.83	2.87	2.91	2.95	2.99	3.04	3.08	3.13	3.18	3.23	3.28	3.33	3.38	54
37	2.64	2.67	2.71	2.74	2.78	2.82	2.86	2.90	2.94	2.98	3.02	3.06	3.11	3.15	3.20	3.25	3.30	3.36	3.41	3.47	53
38	2.70	2.74	2.77	2.81	2.85	2.88	2.92	2.96	3.00	3.04	3.09	3.13	3.18	3.23	3.28	3.33	3.38	3.43	3.49	3.55	52
39	2.76	2.80	2.83	2.87	2.91	2.95	2.99	3.03	3.07	3.11	3.16	3.20	3.25	3.30	3.35	3.40	3.45	3.51	3.56	3.62	51
40	2.82	2.86	2.89	2.93	2.97	3.01	3.05	3.09	3.14	3.18	3.22	3.27	3.32	3.37	3.42	3.47	3.53	3.58	3.64	3.70	50
41	2.88	2.92	2.95	2.99	3.03	3.07	3.11	3.16	3.20	3.24	3.29	3.34	3.39	3.44	3.49	3.54	3.60	3.66	3.72	3.78	49
42	2.94	2.97	3.01	3.05	3.09	3.13	3.18	3.22	3.26	3.31	3.36	3.41	3.46	3.51	3.56	3.61	3.67	3.73	3.79	3.85	48
43	2.99	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	3.74	3.80	3.86	3.93	47
44	3.05	3.09	3.13	3.17	3.21	3.25	3.30	3.34	3.39	3.43	3.48	3.54	3.59	3.64	3.70	3.75	3.81	3.87	3.94	4.00	46
45	3.10	3.14	3.18	3.22	3.27	3.31	3.36	3.40	3.45	3.50	3.55	3.60	3.65	3.71	3.76	3.82	3.88	3.94	4.01	4.07	45

46	3·16	3·20	3·24	3·28	3·32	3·37	3·41	3·46	3·51	3·56	3·61	3·66	3·71	3·77	3·83	3·89	3·95	4·01	4·08	4·14	44
47	3·21	3·25	3·29	3·34	3·38	3·42	3·47	3·52	3·57	3·62	3·67	3·72	3·78	3·83	3·89	3·95	4·01	4·08	4·14	4·21	43
48	3·26	3·30	3·35	3·39	3·43	3·48	3·53	3·57	3·62	3·68	3·73	3·78	3·84	3·89	3·95	4·02	4·08	4·14	4·21	4·28	42
49	3·31	3·36	3·40	3·44	3·49	3·53	3·58	3·63	3·68	3·73	3·79	3·84	3·90	3·96	4·02	4·08	4·14	4·21	4·28	4·35	41
50	3·36	3·41	3·45	3·49	3·54	3·59	3·63	3·68	3·74	3·79	3·84	3·90	3·96	4·02	4·08	4·14	4·20	4·27	4·34	4·41	**40**
51	3·41	3·45	3·50	3·54	3·59	3·64	3·69	3·74	3·79	3·84	3·90	3·96	4·01	4·07	4·14	4·20	4·26	4·33	4·40	4·48	39
52	3·46	3·50	3·55	3·59	3·64	3·69	3·74	3·79	3·84	3·90	3·95	4·01	4·07	4·13	4·19	4·26	4·32	4·39	4·46	4·54	38
53	3·51	3·55	3·60	3·64	3·69	3·74	3·79	3·84	3·89	3·95	4·01	4·06	4·12	4·19	4·25	4·32	4·38	4·45	4·52	4·60	37
54	3·55	3·60	3·64	3·69	3·74	3·79	3·84	3·89	3·94	4·00	4·06	4·12	4·18	4·24	4·30	4·37	4·44	4·51	4·58	4·66	36
55	3·60	3·64	3·69	3·74	3·78	3·83	3·89	3·94	3·99	4·05	4·11	4·17	4·23	4·29	4·36	4·43	4·50	4·57	4·64	4·72	35
56	3·64	3·68	3·73	3·78	3·83	3·88	3·93	3·99	4·04	4·10	4·16	4·22	4·28	4·34	4·41	4·48	4·55	4·62	4·70	4·77	34
57	3·68	3·73	3·78	3·83	3·88	3·93	3·98	4·04	4·09	4·15	4·21	4·27	4·33	4·39	4·46	4·53	4·60	4·68	4·75	4·83	33
58	3·72	3·77	3·82	3·87	3·92	3·97	4·02	4·08	4·14	4·19	4·25	4·32	4·38	4·44	4·51	4·58	4·65	4·73	4·80	4·88	32
59	3·76	3·81	3·86	3·91	3·96	4·01	4·07	4·12	4·18	4·24	4·30	4·36	4·43	4·49	4·56	4·63	4·70	4·78	4·86	4·94	31
60	3·80	3·85	3·90	3·95	4·00	4·05	4·11	4·17	4·22	4·28	4·34	4·41	4·47	4·54	4·61	4·68	4·75	4·83	4·91	4·99	**30**
61	3·84	3·89	3·94	3·99	4·04	4·09	4·15	4·21	4·26	4·32	4·39	4·45	4·52	4·58	4·65	4·72	4·80	4·88	4·96	5·04	29
62	3·88	3·93	3·98	4·03	4·08	4·13	4·19	4·25	4·31	4·37	4·43	4·49	4·56	4·63	4·70	4·77	4·85	4·92	5·00	5·08	28
63	3·91	3·96	4·01	4·06	4·12	4·17	4·23	4·29	4·35	4·41	4·47	4·53	4·60	4·67	4·74	4·81	4·89	4·97	5·05	5·13	27
64	3·95	4·00	4·05	4·10	4·15	4·21	4·26	4·32	4·38	4·44	4·51	4·57	4·64	4·71	4·78	4·86	4·93	5·01	5·09	5·18	26
65	3·98	4·03	4·08	4·13	4·19	4·24	4·30	4·36	4·42	4·48	4·55	4·61	4·68	4·75	4·82	4·90	4·97	5·05	5·14	5·22	25
66	4·01	4·06	4·11	4·17	4·22	4·28	4·34	4·40	4·46	4·52	4·58	4·65	4·72	4·79	4·86	4·94	5·01	5·09	5·18	5·26	24
67	4·04	4·09	4·14	4·20	4·25	4·31	4·37	4·43	4·49	4·55	4·62	4·68	4·75	4·82	4·90	4·97	5·05	5·13	5·22	5·30	23
68	4·07	4·12	4·17	4·23	4·28	4·34	4·40	4·46	4·52	4·58	4·65	4·72	4·79	4·86	4·93	5·01	5·09	5·17	5·25	5·34	22
69	4·10	4·15	4·20	4·26	4·31	4·37	4·43	4·49	4·55	4·62	4·68	4·75	4·82	4·89	4·97	5·04	5·12	5·20	5·29	5·38	21
70	4·12	4·18	4·23	4·28	4·34	4·40	4·46	4·52	4·58	4·65	4·71	4·78	4·85	4·93	5·00	5·08	5·16	5·24	5·32	5·41	**20**
71	4·15	4·20	4·26	4·31	4·37	4·43	4·49	4·55	4·61	4·68	4·74	4·81	4·88	4·96	5·03	5·11	5·19	5·27	5·36	5·45	19
72	4·18	4·23	4·28	4·34	4·39	4·45	4·51	4·57	4·64	4·70	4·77	4·84	4·91	4·98	5·06	5·14	5·22	5·30	5·39	5·48	18
73	4·20	4·25	4·30	4·36	4·42	4·48	4·54	4·60	4·66	4·73	4·80	4·87	4·94	5·01	5·09	5·17	5·25	5·33	5·42	5·51	17
74	4·22	4·27	4·33	4·38	4·44	4·50	4·56	4·62	4·69	4·75	4·82	4·89	4·96	5·04	5·11	5·19	5·27	5·36	5·45	5·53	16
75	4·24	4·29	4·35	4·40	4·46	4·52	4·58	4·65	4·71	4·78	4·85	4·92	4·99	5·06	5·14	5·22	5·30	5·38	5·47	5·56	15
76	4·26	4·31	4·37	4·42	4·48	4·54	4·60	4·67	4·73	4·80	4·87	4·94	5·01	5·09	5·16	5·24	5·32	5·41	5·50	5·59	14
77	4·28	4·33	4·39	4·44	4·50	4·56	4·62	4·68	4·75	4·82	4·89	4·96	5·03	5·11	5·18	5·26	5·35	5·43	5·52	5·61	13
78	4·29	4·35	4·40	4·46	4·52	4·58	4·64	4·70	4·77	4·84	4·91	4·98	5·05	5·13	5·20	5·28	5·37	5·45	5·54	5·63	12
79	4·31	4·36	4·42	4·48	4·54	4·60	4·66	4·72	4·79	4·85	4·92	5·00	5·07	5·14	5·22	5·30	5·39	5·47	5·56	5·65	11
80	4·32	4·38	4·43	4·49	4·55	4·61	4·67	4·74	4·80	4·87	4·94	5·01	5·08	5·16	5·24	5·32	5·40	5·49	5·58	5·67	**10**
81	4·34	4·39	4·45	4·50	4·56	4·62	4·69	4·75	4·82	4·88	4·95	5·03	5·10	5·18	5·26	5·34	5·42	5·51	5·60	5·69	9
82	4·35	4·40	4·46	4·52	4·58	4·64	4·70	4·76	4·83	4·90	4·97	5·04	5·11	5·19	5·27	5·35	5·43	5·52	5·61	5·70	8
83	4·36	4·41	4·47	4·53	4·59	4·65	4·71	4·78	4·84	4·91	4·98	5·05	5·13	5·20	5·28	5·36	5·45	5·53	5·62	5·72	7
84	4·37	4·42	4·48	4·54	4·60	4·66	4·72	4·79	4·85	4·92	4·99	5·06	5·14	5·21	5·29	5·37	5·46	5·54	5·63	5·73	6
85	4·37	4·43	4·48	4·54	4·60	4·66	4·73	4·79	4·86	4·93	5·00	5·07	5·14	5·22	5·30	5·38	5·47	5·55	5·64	5·74	5
86	4·38	4·43	4·49	4·55	4·61	4·67	4·73	4·80	4·86	4·93	5·00	5·08	5·15	5·23	5·31	5·39	5·47	5·56	5·65	5·74	4
87	4·38	4·44	4·50	4·55	4·61	4·68	4·74	4·81	4·87	4·94	5·01	5·08	5·16	5·23	5·31	5·40	5·48	5·57	5·66	5·75	3
88	4·39	4·44	4·50	4·56	4·62	4·68	4·74	4·81	4·87	4·94	5·01	5·09	5·16	5·24	5·32	5·40	5·48	5·57	5·66	5·75	2
89	4·39	4·44	4·50	4·56	4·62	4·68	4·74	4·81	4·88	4·94	5·01	5·09	5·16	5·24	5·32	5·40	5·49	5·57	5·66	5·76	1
90	4·39	4·44	4·50	4·56	4·62	4·68	4·74	4·81	4·88	4·94	5·02	5·09	5·16	5·24	5·32	5·40	5·49	5·58	5·67	5·76	**0**

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PART II.

THE DETERMINATION OF THE DIFFERENCE OF LONGITUDE OF TWO STATIONS.

INTRODUCTORY.

29. The meridian at Greenwich having been adopted as the initial one to which all longitudes in the United States are to be referred, the determination of the longitude of a new station consists simply of the determination of the difference of longitude of the new station and of Greenwich, or some station of which the longitude reckoned from Greenwich is known. The determination of a difference of astronomic longitude is nothing more nor less than the determination of the difference of the local times of the stations.*

There are three general methods of determining longitude now in use, viz, the telegraphic, the chronometric, and the lunar.

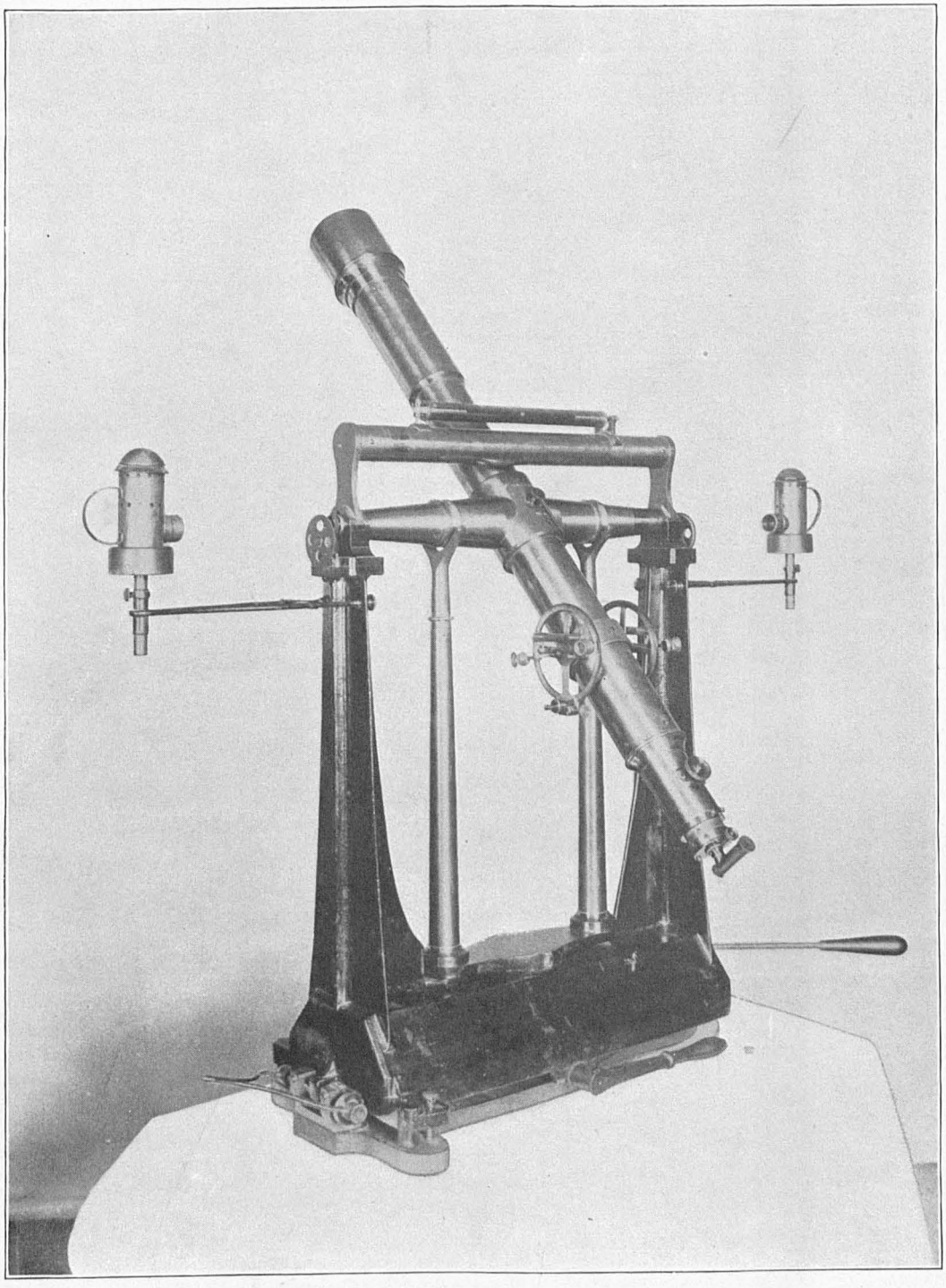
In the telegraphic method the error of the local chronometer on local sidereal time is determined at each of the two stations by the methods stated in Part I of this Appendix, and the two chronometer times are then compared by telegraphic signals sent between the stations.

In the chronometric method certain chronometers which are transported back and forth between the stations take the place of the telegraphic signals and thus serve merely to compare the station chronometers.

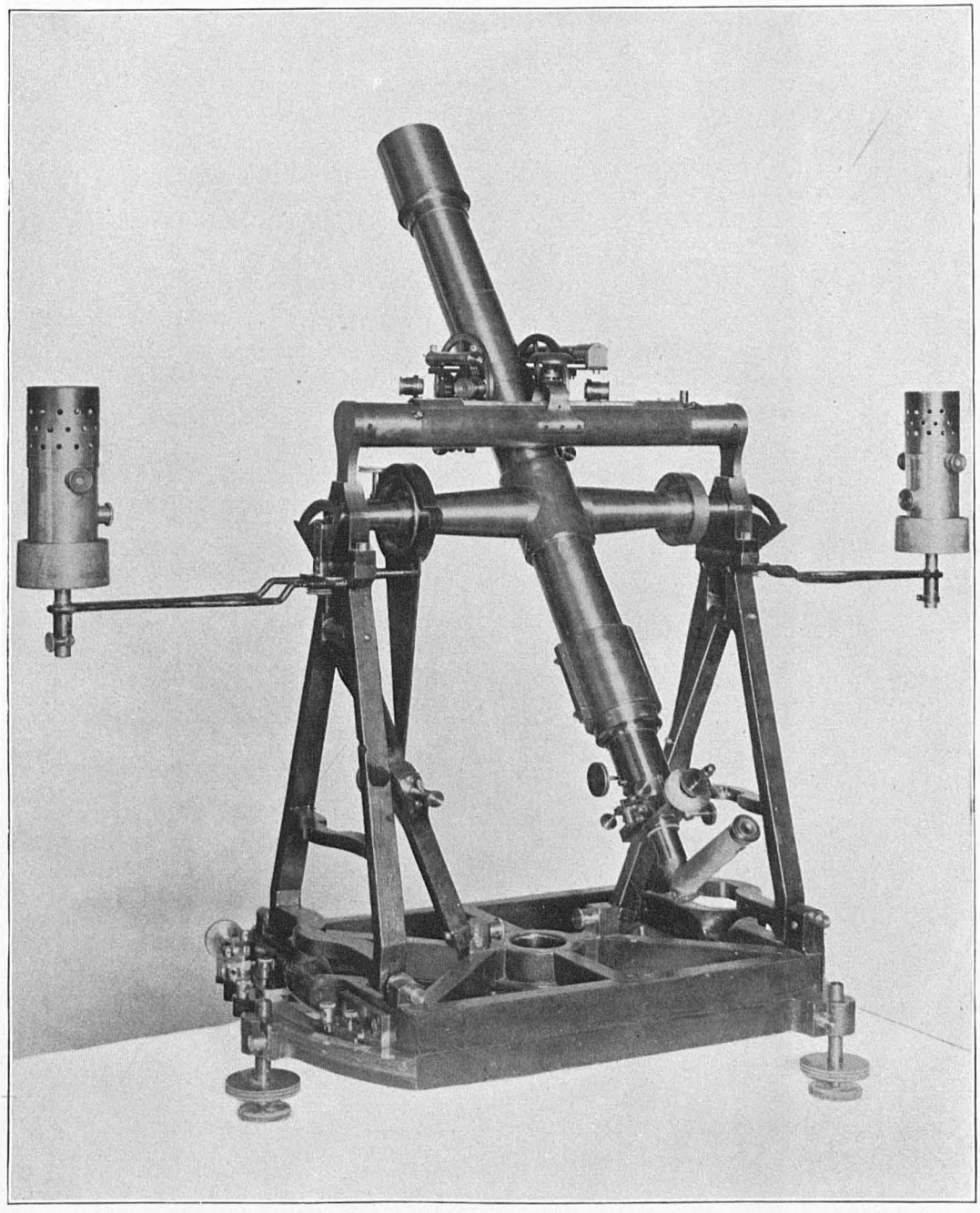
In each of the lunar methods the observer at a station of which the longitude is required observes the position of the moon, or at least one coordinate of that position, and notes the *local* time at which his observation was made. He may then consult the Ephemeris and find at what instant of Greenwich time the moon was actually in the position in which he observed it. The difference between this time and the local time of his observation is his longitude reckoned from Greenwich. One coordinate fixing the position of the moon may be determined to serve as a means of deriving a longitude by measuring the right ascension of the moon at a transit across the meridian; by measuring the angular distance between the moon and the sun or one of the four larger planets, or between the moon and one of the brighter stars;† or by observing the times

*The times may be either sidereal or mean solar. Usually the sidereal times are compared because the time observations are usually made upon stars.

†The lunar distances of these objects are given for stated Greenwich times in the Ephemeris. Data in regard to the occultations referred to in the next phrase are also given in the Ephemeris.



LARGE PORTABLE TRANSIT.



MERIDIAN TELESCOPE.

of disappearance and reappearance (immersion and emersion) of a known star behind the moon—the lunar distance of the star at those instants being the angle subtended by the moon's radius. In each case the Greenwich time at which the moon occupied the position in which it was observed is obtained either from the Ephemeris, from observations at Greenwich at about the time in question, or from similar observations at some station of known longitude.

The telegraphic method* is the most accurate known method of determining differences of longitude. It is always used on this Survey for all longitude determinations in regions penetrated by telegraph lines, and is therefore set forth fully in this Appendix.

The next method in order of accuracy† (save the exception stated in the footnote), and therefore the best for use in regions not reached by the telegraph, is the chronometric method. As this has been extensively used at coast stations in Alaska during the past ten years, and will probably continue to be so used during some years to come, it is also here treated in full.

To use the chronometric method one must be able to travel back and forth carrying chronometers between the two stations. The cost of such a longitude determination increases with increased cost of travel between stations, and its accuracy decreases as the time required to make a round trip increases. These facts cause the chronometric method to give way to lunar methods in certain comparatively rare situations. The points at which the boundary between Alaska and British America (one hundred and forty-first meridian) crosses the Yukon and Porcupine rivers were determined by lunar methods. Comparatively few such cases have occurred in late years on this Survey in which it was desirable to resort to observations upon the moon to determine important longitudes.‡ To determine these longitudes by transportation of chronometers would have been exceedingly difficult and costly, and would have given results of a low order of accuracy, for there are more than a thousand miles of slow river navigation between the mouth of the Yukon and either station.

As the lunar methods will probably be used less and less with the lapse of time and the increase of traveling facilities, it does not seem desirable to incorporate details in regard to them in this Appendix, especially as such details would greatly increase its size. The computations involved are long, complex, and difficult. Those who wish to study the lunar methods are referred for details to Doolittle's Practical Astronomy, to

*The telegraphic method of determining differences of longitude was originated by the Coast Survey in 1846, two years after the first transmission of telegraphic messages over wires. During the half century since that time the method has gradually been brought to its present high state of perfection. For a historical note on this subject see Appendix No. 2, Report for 1897, pp. 202–203.

†In certain cases in which the telegraph line is wanting, the same principles may be used with the substitution of a flash of light between stations in the place of the electric wave. For example, one might so determine the longitudes of the Aleutian Islands of Alaska, the successive islands being in general intervisible. This method has not, however, been used on this Survey. The cost of determining longitudes by this method will in general be so much greater than by the chronometric method (because of the many intermediate stations which will be required between distant stations), as to more than offset its greater accuracy.

‡A statement of the results of these determinations, which is especially interesting as showing what errors may be expected in such observations, is given in Appendix No. 3, of the Report for 1895.

Chauvenet's Astronomy, Vol. I, and in the American Ephemeris (aside from the tables), especially to the pages in the back of each volume headed "Use of tables."

PROGRAMME AND APPARATUS OF THE TELEGRAPHIC METHOD.

30. During the fifty years of its use by the Coast and Geodetic Survey this method has been gradually modified, and the apparatus and programme as at present used will be here described.

The nightly programme at each station is to observe two independent sets of ten stars each with a transit of the type shown in Illustration No. 1 at the end of Part 1. By previous arrangement the same stars are observed at the two stations. Each set of ten stars is selected as described in § 21 and gives a complete determination of the chronometer connection at the epoch of that set, and the two sets of stars observed furnish, therefore, the rate of the chronometer for the interval between the two epochs. It is customary to reverse the transit at least twice—that is, in the middle of each set. As near the middle time of all the observations as can be conveniently arranged * telegraphic signals are exchanged between the two stations to compare the two chronometers, and therefore to compare the local times which have been determined from the star observations. For this purpose the two observatories must be connected by telegraph wire, which is usually effected by running a wire from each to the nearest telegraph office. The convenience of this connection may have some weight in locating the observing station. An arrangement is made with the telegraph company for a direct connection at the required time on the nights of observation, this connection, if possible, to be a continuous circuit without repeaters. The general arrangement of the electrical apparatus at each station during the time that the star observations are being made and the general arrangement while signals are being exchanged is shown in the diagrams of Illustration No. 5. Illustration No. 4 shows the actual switch board and instruments used in these operations. This board carries an ordinary telegrapher's key, sounder relay, and signal relay, all of which are included in the main telegraph circuit, and a sounder which is worked by the sounder relay through a separate battery. The board is provided with binding posts for making the necessary battery and circuit connections, and with plug switches for the required arrangements of circuits. During the star observations the local observatory circuit is entirely independent of the telegraph line and includes the break-circuit chronometer † (or clock), battery, chronograph, and the break-circuit observing key. (See illustration No. 5.) All the time observations, together with chronometer record, are thus recorded on the chronograph sheet.

A few minutes before the time for exchange of signals the telegraph operator secures a clear line between stations, ascertains whether the observations at the other station are proceeding successfully, and telegraphs the exact epoch at which signals will

* As the same stars are observed at both stations, the exchange of signals will come before the middle time at the western station, and after it at the eastern station, by one-half the difference of longitude. It must also be timed so as to come at a convenient interval between star observations at both stations (preferably about a five-minute interval), and the exchange may be slightly displaced for this purpose. The necessity of having such convenient intervals should be kept in mind when selecting the stars to be observed.

† Or the chronometer may be placed in a separate local circuit, breaking this one through a relay.

be exchanged. When that epoch (usually arranged not to interfere with star observations) arrives, by the removal of a switch plug the points of the signal relay at each station are placed in the local circuit. (See lower half of illustration No. 5.). Any break in the main line circuit will now cause corresponding breaks in the two local circuits, so that a signal made with the telegraph key* will be recorded on both chronographs. The observer at the western station customarily sends the signals first, by releasing the telegraph key for an instant, at average intervals of two seconds, between the breaks of his chronometer. He times these signals so that they will not interfere with his own chronometer record, and he must also be prepared to change the part of the second used if they are conflicting with the record of the chronometer of the other observer, of which notice is given by the latter by breaking into the circuit and making a quick succession of breaks with the key. After thirty signals have been sent from the western station, thirty more are sent in the same manner by the eastern observer. Thirty signals cover an interval of one minute. This number is chosen with a view to eliminating the effect of errors in the contact wheel of the chronometer. A signal sent from either station will be recorded on the chronograph at that station slightly before it is on the distant chronograph, and this difference in time of record is generally called the transmission time, but it, in fact, depends both on the retardation of the signal in the telegraph line between the stations and the difference in the quickness of action of the signal relays† at the two stations. Signals sent from west to east will make the difference in longitude appear too large, and signals from east to west make it too small, by the amount of this transmission time. By taking the mean of differences as given by signals in both directions this source of error is eliminated, providing the transmission time is the same in both directions.‡ In receiving signals the chronographs are run at double speed, so that the signals may be read to hundredths of seconds. The advantage in sending signals by making arbitrary breaks of the circuit § is that they will come at varying fractions of the second, thus tending to eliminate personal equation in reading parts of a second. The following extract from one night's record shows the form in which the signals are written as read from the chronograph sheet, and the taking out of the differences and means. Should portions of the record be missed, the corresponding signals at the two stations may readily be identified by comparing the successive differences between signals.

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*It is to be noted that these signals are made by breaking the circuit, which is opposite to the ordinary correspondence use of the key.

†The latter is probably a small quantity. Some measurements of the armature time of one of the quick-acting relays used in these longitude determinations showed it to vary from 0·005 to 0·015 second with extreme changes in adjustments and current.

‡There is always some uncertainty on this score when repeaters are used in the main telegraph line, because of the distinct mechanical arrangements for repeating the signals in the two directions. Repeaters are therefore to be avoided as far as practicable.

§Chronometer signals were formerly used—that is, the chronometers were alternately made to send their breaks through the main line circuit, recording on both chronographs.

Record of exchange of signals, and computation of difference of chronometers.

Station, Atlanta, Ga. Observer, G. R. P.
Date, March 7, 1896. Recorder, G. R. P.

ARBITRARY SIGNALS.

From Atlanta to Key West.			From Key West to Atlanta.		
Key West record.	Atlanta record.	Difference of chronometers.	Key West record.	Atlanta record.	Difference of chronometers.
h. m. s.	*h. m. s.*	*m. s.*	*h. m. s.*	*h. m. s.*	*m. s.*
7 35 59·97	7 25 42·39	10 17·58	7 37 08·76	7 26 51·51	10 17·25
36 01·90	44·30	·60	10·82	53·60	·22
04·03	46·47	·56	12·78	55·52	·26
05·96	48·39	·57	15·28	58·04	·24
*	*	*	*	*	*
*	*	*	*	*	*
56·90	26 39·30	·60	38 38·48	28 21·21	·27
58·91	41·34	·57	40·60	23·33	·27
h. m.	*h. m.*	*m. s.*	*h. m.*	*h. m.*	*m. s.*
Means 7 36·5	7 26·2	10 17·570	7 37·9	7 27·6	10 17·249

COMPUTATION OF DIFFERENCE OF LONGITUDE.

31. For convenience in computing, the results of the time observations on the different nights are collected in the form shown below, and the rates per minute are obtained for each evening by comparing the two time determinations, dividing the difference in chronometer corrections by the number of minutes in the difference in epochs. The instrumental constants are collected in this form simply to allow of convenient inspection and comparison.

Summary of results of time determinations at Atlanta.

Date.	Epoch (by face of chronometer).	Chronometer correction ΔT_W.	Rate per minute.	Collimation.	Azimuth.	
					West.	East.
1896.	*h. m.*	*s.*	*s.*	*s.*	*s.*	*s.*
March 7	6 56·4	−13·546	+·00261	+·03	−·154	+·035
" 7	8 12·6	−13·347		−·01	−·036	−·070
" 8	6 56·3	− 7·742	+·00310	−·01	+·115	+·089
" 8	8 12·5	− 7·506		−·06	+·190	+·313
*	*	*	*	*	*	*
*	*	*	*	*	*	*
" 27	8 12·6	−12·660	+·00043	−·18	+·183	+·155
" 27	9 22·4	−12·630		−·22	+·378	+·167

Summary of results of time determinations at Key West.

Date.	Epoch (by face of chronometer).	Chronometer correction ΔT_c.	Rate per minute.	Collimation.	Azimuth.	
					West.	East.
1896.	*h. m.*	*s.*	*s.*	*s.*	*s.*	*s.*
March 7	6 56·4	−11·157	−·00232	−·05	−1·108	−1·236
" 7	8 12·6	−11·334		−·03	−1·220	−1·108
" 8	6 56·4	−13·994	−·00227	−·06	−1·649	−1·447
" 8	8 12·6	−14·167		−·03	−1·644	−1·580
*	*	*	*	*	*	*
*	*	*	*	*	*	*
" 27	8 12·4	− 4·992	−·00223	−·06	−0·181	−0·256
" 27	9 21·8	− 5·147		−·00	−0·121	−0·144

The next step is the computation of the difference in the longitude separately from the signals sent in each direction, as shown in the forms below. The epoch of signals and difference of chronometers are taken from the record of signals for each night, and the chronometer corrections at these epochs are computed for each station and night, using the rates per minute in the preceding forms. To the difference in chronometers is then applied the difference, eastern chronometer correction minus western chronometer correction, giving the difference of longitude uncorrected for transmission time and personal equation. The chronometer correction ΔT at the time of exchange T and its probable error r are expressed by

$$\Delta T = \Delta T_1 + \frac{\Delta T_2 - \Delta T_1}{T_2 - T_1}(T - T_1) \text{ and } r = \frac{[(T_2 - T)^2 r_1^2 + (T - T_1)^2 r_2^2]^{1/2}}{T_2 - T_1}$$

where ΔT_1 and $\pm r_1$ are the chronometer correction and its probable error derived from the first set time of observations at epoch T_1, and ΔT_2 and $\pm r_2$ are the same quantities, respectively, for the second set at epoch T_2.

$\Delta\lambda$ from western or Atlanta signals.

[Uncorrected for transmission time and personal equation.]

Date.	Epoch of signals.*		Difference of chronometers.	Chronometer corrections.			$\Delta\lambda_W$ (from western signals.)
	Key West T_c	Atlanta T_W		Key West ΔT_c	Atlanta ΔT_W	Difference $\Delta T_c - \Delta T_W$	
1896.	*h. m.*	*h. m.*	*m. s.*	*s.*	*s.*	*s.*	*m. s.*
March 7	7 36·5	7 26·2	10 17·570	−11·250	−13·468	+2·218	10 19·788
" 8	7 36·6	7 26·2	10 26·199	−14·085	− 7·649	−6·436	19·763
*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*
" 27	8 51·3	8 41·1	10 12·507	− 5·079	−12·648	+7·569	20·076

* By face of chronometer.

Δ λ from eastern or Key West signals.

[Uncorrected for transmission time and personal equation.]

Date.	Epoch of signals.*		Difference of chronometers.	Chronometer corrections.			Δ λe (from eastern signals.)
	Key West T_e	Atlanta T_w		Key West Δ T_e	Atlanta Δ T_w	Difference Δ T_e − Δ T_w	
1896.	*h. m.*	*h. m.*	*m. s.*	*s.*	*s.*	*s.*	*m. s.*
March 7	7 37·9	7 27·6	10 17·249	−11·253	−13·464	+2·211	10 19·460
" 8	7 37·6	7 27·2	10 25·881	−14·087	− 7·646	−6·441	·440
*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*
" 27	8 53·3	8 43·1	10 12·136	− 5·083	−12·647	+7·564	·700

* By face of chronometer.

COMBINATION OF LONGITUDE RESULTS.

32. The table below gives the collection of the results for the different nights and their combination to develop and eliminate the transmission time and personal equation. The mean of the differences of longitude as derived from the western and eastern signals will be free from the transmission time, and their difference is double the transmission time. The relative weights for the resulting differences of longitude for different nights are derived from the expression $p=\frac{p_1 p_2}{p_1+p_2}$, where p_1 and p_2 are the weights of the determinations of the chronometer corrections at the epoch of exchange of signals at the two stations, respectively, or $p_1=\frac{1}{r_1^2}$ and $p_2=\frac{1}{r_2^2}$ in which r_1 and r_2 are the probable errors of the chronometer corrections. To obtain the personal equation the weighted means are taken for each position of the observers, and half their difference is the personal equation to be applied with opposite signs to the two groups. This gives the corrected result for difference of longitude for each night, and the weighted mean of all the nights is the final difference of longitude. The probable error of the latter is $0{\cdot}674\sqrt{\frac{\Sigma pv^2}{(n-2)\Sigma p}}$ where n is the number of nights of observation and 2 is the number of unknowns (longitude and personal equation). In the table the means in the seventh and ninth columns are weighted means.

The personal equation is one-half the difference in the weighted results for the two positions of the observers, or

$$S-P=\frac{19{\cdot}884-19{\cdot}645}{2}=+{\cdot}120,$$

the sign indicating that S observes later than P. The probable error* of the personal equation may be taken as identical with that of the resulting difference of longitude.

The transmission time, as stated, is one-half the difference between the results from western and eastern signals, or in this example, $=\frac{{\cdot}338}{2}={}^{s}{\cdot}169$, an unusually large value, due to the marine cable between Key West and the mainland.

* Practically the same result is obtained by deriving separate values for the personal equation by comparing each result in the first position of the observers with the corresponding result in the second position and computing the probable error from the variations in these separate values.

Table of resulting difference of longitude between Atlanta, Ga., and Key West, Fla.

Date.	Observer at—		From western or Atlanta signals. $\Delta\lambda_w$	From eastern or Key West signals. $\Delta\lambda_e$	Double transmission time. $\Delta\lambda_w - \Delta\lambda_e$	Mean of W. and E. signals.	Personal equation.	Difference of longitude.	Combination weight. p.	Residuals. v.
	A.	K. W.								
1896.			*m. s.*	*m. s.*	*s.*	*m. s.*	*s.*	*m. s.*		*s.*
Mar. 7	P.	S.	10 19·788	10 19·460	0·328	10 19·624	+0·120	10 19·744	8	− ·021
8	P.	S.	·763	·440	·323	·602		·722	11	− ·043
9	P.	S.	·754	·445	·309	·600		·720	4	− ·045
13	P.	S.	·802	·495	·307	·648		·768	13	+ ·003
14	P.	S.	·842	·522	·320	·682		·802	21	+ ·037
				Mean..	·317	10 19·645				
Mar. 20	S.	P.	10 20·018	10 19·686	·332	10 19·852	−0·120	·732	9	− ·033
21	S.	P.	·075	·705	·370	·890		·770	5	+ ·005
25	S.	P.	·102	·737	·365	·919		·799	4	+ ·034
26	S.	P.	·074	·721	·353	·897		·777	8	+ ·012
27	S.	P.	·076	·700	·376	·888		·768	6	+ ·003
				Mean..	0·359	10 19·884		10 19·765	±0·07	

The above formulae and forms are used in the office computation. The field computation differs from that made in the office in that the time computation is made by the approximate field method shown in § 16 instead of the least square method of § 19, and that in the field no probable errors or weights are computed and indiscriminate means are taken instead of weighted means. In the past some of the forms used in the field have been slightly different from those shown above. The office computation will be facilitated by making the field computation as here indicated.

PERSONAL EQUATION.

33. The absolute personal equation in time observations is the interval from the actual instant of transit of a star image across a line to the instant to which the transit is assigned by the observer. When the time is observed with a chronograph by the method recommended in § 8 this interval seems to be simply that required for the nerves and portions of the brain concerned in an observation to perform their functions. On the other hand an observation of time by eye and ear involves a rather complex mental process and the personal equation apparently depends upon a much more complicated set of physical and psychological conditions than when the observations are made with a chronograph. Although the personal equation has been studied by many persons and for many years little more can be confidently said in regard to the laws which govern its magnitude than that it is a function of the observer's personality, that probably whatever affects the observer's physical and mental conditions affects its value, that it tends to become constant with experience, that it is probably different for extremely slow-moving stars than for ordinary stars, and that it is different for very faint stars which the observer sees with difficulty than for stars seen easily.

The relative personal equation of two observers is the difference of their absolute personal equations.

As the accuracy of the telegraphic determinations of longitude depends upon the constancy of the relative personal equation of the two observers concerned it is in order to inquire into the evidence as to this constancy. The following table (from Appendix No. 2, Report of 1897, with slight modifications) showing the values of the relative

personal equation of the two observers as derived from telegraphic longitude observations, indicates to what extent it may be expected to vary from month to month and year to year, if observations are made with the chronograph. The plus sign indicates that the observer first named observes later (slower) than the other.

Relative personal equation (not reduced to equator).

C. H. Sinclair—E. Smith. [14 years.]			C. H. Sinclair—R. A. Marr. [4 years].			C. H. Sinclair—G. R. Putnam. [5 years.]		
	s.	s.		s.	s.		s.	s.
1881 Aug. and Sept.	−0·123	±0·008	1886 Sept. and Oct.	+0·288	±0·008	1891 May and June	+0·184	±0·011
1881 Nov. and Dec.	− ·085	06	1888 Sept.	+ ·210	09	1891 June and July	+ ·140	08
1885 Apr. and May	− ·047	08	1888 Oct. and Nov.	+ ·144	11	1891 July	+ ·172	06
1885 May and June	− ·131	03	1888–9 Dec. and Jan.	+ ·214	10	1891 Aug.	+ ·161	10
1885 July and Aug.	− ·110	10	1889 Jan.	+ ·233	05	1891 Aug. and Sept.	+ ·176	11
1886 May and June	− ·062	08	1889 Jan. and Feb.	+ ·225	07	1892 Feb. and Mar.	+ ·160	06
1886 June and July	+ ·010	06	1889 Feb. and Mar.	+ ·267	07	1892 Mar.	+ ·192	04
1886 July and Aug.	− ·023	12	1889 Mar. and Apr.	+ ·278	12	1892 Mar. and Apr.	+ ·140	02
1886 Aug. and Sept.	+ ·056	04	1889 Apr. and May	+ ·217	12	1892 Apr.	+ ·150	05
1887 May and June	+ .038	10	1889 May and June	+ ·282	18	1892 Apr. and May	+ ·126	04
1887 June, July, and Aug.	+ ·109	13	1889 June and July	+ ·246	07	1892 June and July	+ ·109	10
			1889 July	+ ·275	08	1893 Feb. and Mar.	+ ·082	10
1887 Sept.	+ ·111	13	1889 July	+ ·265	05	1896 Feb. and Mar.	+ ·155	03
1887 Sept. and Oct.	+ ·160	09	1889 July and Aug.	+ ·228	15	1896 Mar.	+ ·129	07
1895 Feb. and Mar.	+ ·093	11	1889 Aug.	+ ·284	08	1896 Apr.	+ ·122	05
1895 Mar.	+ ·075	11	1889 Aug. and Sept.	+ ·226	06	1896 Apr. and May	+ ·181	05
1895 Apr.	+0·086	±0·005	1889 Sept.	+ ·258	07	1896 May and June	+ ·142	13
			1890 May and June	+ ·166	14	1896 June and July	+0·124	±0·008
The relative personal equation of these two observers seems to be a function of the time and a mean of the above values would therefore have but little meaning.			1890 July	+ ·238	10			
			1890 July and Aug.	+ ·237	14	Mean S. − P. =	+0·147	
			1890 Aug.	+0·278	±0·006	Prob. error* of a single value		±0·020
			Mean S. − M. =	+0·241		This value may be taken as a measure of variability of the personal equation.		
			Prob. error* of a single value		±0·026			

* This value may be taken as a measure of the variability of the personal equation.

Each value in the table depends upon eight to ten nights of observation, four or five nights each before and after the exchange of observers, and may therefore be considered to be a mean value covering a period of from two weeks to a month or more. It is improbable that the variation of the relative personal equation from night to night is as small as would be inferred directly from the above table. The error due to personal equation, remaining in the deduced longitude, is one-half the difference between the mean relative personal equation before and after exchange of observers.

If in making a longitude determination circumstances, or the question of cost, prevent the interchange of observers, the effect of the relative personal equation upon the computed longitude may still be eliminated, in part, at least, by a special determination of the equation by joint observations at a common station.

The two observers may place their instruments side by side in the same observatory, observe the same stars, and record their observations upon the same chronograph.* The difference of the two chronometer corrections computed by them, corrected for the

* This method, as well as that given in the next paragraph, is equally applicable when observations are taken by eye and ear.

minute longitude difference corresponding to the measured distance between their instruments, is then their relative personal equation. The differences between the errors of inclination, collimation, and azimuth of the two instruments will in general, especially if the equatorial intervals are not the same for the two instruments, prevent frequent overlapping of the records on the chronograph. If necessary, each instrument may be purposely thrown slightly out of adjustment in collimation for this purpose. It may be necessary for identification for one observer to make longer breaks than the other.

The relative personal equation may be observed with a single transit as follows: On the first star A observes the transits over the lines of the first half of the reticle, and then quickly gives place to B, who observes the transits across the remaining lines (the middle line being omitted altogether if necessary). On the second star B observes on the first half of the reticle and A follows. After observing a series of stars thus, each leading alternately, each observer computes for each star, from the known equatorial intervals of the lines and from his own observations, the time of transit of the star across the mean line of the reticle. The difference of the two deduced times of transit across the mean line is the relative personal equation. If each has led the same number of times in observing, the mean result is independent of any error in the assumed equatorial intervals of the lines. No readings of the striding level need be taken, and the result is less affected by the instability of the instrument than in the other method.

DISCUSSION OF ERRORS.

34. Let it be supposed that the regular programme of observation, five nights each before and after exchange of observers, as indicated in §32, has been carried out. The computed result, the difference of astronomic longitudes of the two stations, is subject to the following errors:

First. An accidental error arising from the accidental errors of observations of 200 stars at each station. If the accidental error of observation of a single star be estimated at $\pm 0^{s}10$, and this is surely a sufficiently large estimate to cover both the observer's errors and those instrumental errors which belong to the accidental class, the probable error of the final result arising from this cause would be $\pm 0^{s}10 \div \sqrt{100} = \pm 0^{s}010$.

Second. An accidental error arising from the accidental errors in the adopted right ascensions of such stars as are observed at one station on a given night but not at the other. It is in such cases only that the errors of right ascensions have any effect upon the computed result. If entirely different stars were observed at the two stations, twenty at each station, and if the estimate of $\pm 0^{s}03$ for the probable error of a right ascension as stated in §26 be accepted, the probable error of the final result arising from this source would be $\pm 0^{s}03 \div \sqrt{10} = \pm 0^{s}009$. In the ordinary case, in which less than 10 per cent of the stars observed are not common to both stations, this accidental error is reduced to $\pm 0^{s}001$ or less.

Third. Errors due to errors in the assumption that the rate of the chronometer is constant during and between the two time sets of a night. As the interval between the mean epochs of the sets is ordinarily only about an hour, these errors are probably exceedingly small. It is for the purpose of making these errors inappreciable that longitude observers should use chronometers known to show but small variations of rate, and should protect them as thoroughly as is feasible while in use against jars and sudden changes of temper-

ature. The errors from this source will be of about the same value whether the exchange of signals between stations is made at about the mean epoch of the two sets of time observations or is made at *any* other epoch *within* the interval covered by the two sets. The effect of making the exchange much earlier, or much later, than the mean epoch of the two time sets is to put more of the burden of determining the chronometer correction at exchange upon one time set than upon the other (see formula for computing the chronometer correction at exchange, page 325), and so to decrease the accuracy of the final result.

Fourth. Errors arising from the variation of the relative personal equation from night to night. These are probably among the largest errors involved in longitude determinations. A constant error, not eliminated by the exchange of observers, may possibly arise from this source if the temperature, altitude, moisture conditions, etc., are very different at the two stations. Other than this, the errors arising from this source belong to the accidental class when considered with reference to the computed difference of longitude and are exhibited in the residuals corresponding to the separate nights of observation.

Fifth. Errors arising from lateral refraction. The probable minuteness of these errors in time observations has already been commented upon (§ 26). It is not impossible, however, that small constant errors may arise from this source at stations established in the busy portions of great cities.

Sixth. Errors arising from variation of transmission time. By transmission time is meant the interval that elapses from the instant at which the signal relay breaks the local circuit at the sending station to that at which the signal relay breaks the local circuit at the receiving station. This interval is made up of armature time, induction time, and the true transmission time of the electric wave passing along the wire. It is only the variation in transmission time occurring between the two halves of the exchange of signals on each night that introduces error into the computed result. As this interval is only about a minute the error is probably insensible if there is a continuous wire connection between stations. If the line between stations passes through a "repeater" the transmission time in one direction through the repeater will be different from that in the other direction unless the two magnets of the repeater are adjusted exactly alike, and half this difference will enter into the computed result as an error. The repeaters used in ordinary telegraph service are not specially designed for quick action, as are the signal relays on the Coast and Geodetic Survey switch board, nor is their adjustment in the control of the longitude observers. Hence the desirability of a continuous wire connection.

Any change in transmission time within the local circuit occurring within the minute elapsing between the two halves of the exchange of signals will produce an error in the computed longitude, but such changes are probably insensible. A change at any other time in the local circuit will appear in the observations as a change in the chronometer correction and will probably have no appreciable effect on the final result for the night.

Seventh. The difference of the transmission time through the two signal relays enters as an error in the final result, as may be seen by inspection of illustration No. 5. This error is made very small in the present longitude work of the Survey by using signal relays which are as nearly alike as possible and which are specially designed to

act very quickly. This error might possibly be eliminated still more completely if each observer carried his own switch board with him when they exchanged places.

If the difference of longitude which is being measured is large, more than 30^m, say, it becomes desirable to abandon the practice of observing the same stars at both stations to such an extent as is necessary to make the exchange of arbitrary signals come nearly in the middle of the night's observation at each end. The errors of right ascension as thus introduced (see second heading above) will be more than offset by the accuracy gained by the proper placing of the exchange (see third heading above).

Are there appreciable errors which are constant for the night in the time determinations or in the other operations involved in the determination of a longitude difference by the telegraphic method; and if so, what is the average magnitude of such errors? The excess of the probable error of a longitude difference computed as indicated in § 32 over its value as derived from the computed probable errors of the chronometer corrections at exchange is due to errors which are constant for and peculiar to each night. Using this principle* the error peculiar to a night has been computed from fifteen longitude determinations made since 1890. It was found that the error peculiar to each night, and therefore not capable of elimination by increasing the number of observations per night, was, expressed as a probable error, $= \pm 0^s.022$, while the probable error in the result for a night arising from accidental errors of observation, and therefore capable of further elimination by increased observation, was $\pm 0^s.013$. It should be noted that the errors discussed under all but the first heading above are each capable of contributing to the error peculiar to a night. It is likely that variation in the personal equation is the most potent cause of such errors. It is evident from the probable errors given above that very little is lost in ultimate accuracy if clouds interfere so as to cut off a part, say one-fourth, of the regular programme of time observations (two sets of ten stars each), and that almost no gain in accuracy would result from lengthening the programme.

It is advisable, in view of the above considerations, to reverse the instrument at the end of *every* half set. *Any* two consecutive half sets will then form a time set from which the collimation correction can be effectively determined and the chronometer correction computed. If the fourth half set of a night is missed, the first and second, and the second and third half sets may be considered to form two time sets, which are only partially independent, but from which the longitude difference may, nevertheless, be computed with only slightly less accuracy than from two complete independent time sets.

Are there appreciable errors in a telegraphic determination of a difference of longitude which are constant for the interval of several days over which the determination extends; and, if so, what is the average magnitude of such errors? We may obtain an answer to this question by comparing the probable errors of longitude difference computed as in § 32 with the same probable errors as computed from the residuals developed in adjusting such a longitude net as that given in Appendix No. 2 of the Report for 1897. The excess of the last-named probable errors over the first-named is due to errors which are constant for the station during the time of occupation. From the published adjustment of the great longitude net referred to above (see pp. 246, 247, 255, of Report for 1897), after omitting the first eleven determinations (all made not later than 1872,

* For the formulæ used in applying a similar principle to latitude observations see § 52.

and several involving transatlantic cables) and the fifty-eighth determination (publication incomplete), it follows that the constant error peculiar to each longitude determination and not capable of elimination by increasing the number of nights per station is, expressed as a probable error, $= \pm 0^s.022$, while the accidental error of the deduced difference of longitude, which is capable of further reduction by increasing the number of nights per station (beyond the standard number, ten), is $\pm 0^s.011$. It follows that a reduction of the number of nights per station to six, or even four, would result in but a slight decrease in accuracy—about ten per cent. Three sources of errors peculiar to a station in the order of their probable magnitude are those mentioned under the fourth, sixth, seventh, and fifth headings above, namely: Variation in personal equation, variation in transmission time (especially when a repeater interrupts a circuit), the difference of the two signal relay times, and possibly lateral refraction in some cases.

LONGITUDE BY THE CHRONOMETRIC METHOD.

35. The equipment, programme of observations, and methods of computation pertaining to a determination of a difference of longitude by the chronometric method, in which chronometers transported back and forth between stations take the place of the telegraphic signals, may be most conveniently explained by giving a concrete example.

The longitude of a station at Anchorage Point, Chilkat Inlet, Alaska, was determined in 1894 by transporting chronometers between that station and Sitka, of which the longitude had previously been determined. At Anchorage Point observations were taken on every possible night from May 15 to August 12, namely on fifty-three nights, by the eye and ear method, using a meridian telescope. The hack or observing chronometer kept sidereal time, and there were also four other chronometers at the station, two keeping mean time and two sidereal. These four chronometers were never removed during the season from the padded double-walled box in which they were kept for protection against sudden changes of temperature and in which the hack chronometer was also kept when not in use. The instrumental equipment and procedure at Sitka was similar to that just described. A sidereal chronometer was the hack, and two other chronometers, one sidereal and one mean time, were used in addition. Nine chronometers, eight keeping mean time and one sidereal, were carried back and forth between the stations on the steamer *Hassler*.

Aside from the time observations, the programme of operations was as follows: Just before beginning the time observations at Anchorage Point, and again as soon as they were finished on each night, the hack chronometer was compared with the two mean time chronometers by the method of coincidence of beats (described in § 37). These two were then compared with each of the two remaining (sidereal) chronometers at the station. These comparisons, together with the transit time observations, served to determine the correction of each chronometer to local time at the epoch of the transit observations. Whenever the steamer first arrived at the station, and again when it was about to leave, the hack chronometer was compared with the other station chronometers, as indicated above, was carried on board the steamer and compared with the nine traveling chronometers, and then immediately returned to the station and compared with the other four station chronometers. On board the steamer the hack was compared by coincidence of beats with each of the eight mean time chronometers, and the remaining (sidereal) chronometer was then compared with some of the eight. The comparisons on shore before and after the trip to the steamer served to determine the correction of

the hack at the epoch of the steamer comparisons. The steamer comparisons* determined the corrections of each of the traveling chronometers to Anchorage Point time. Similar operations at Sitka determined the corrections of the nine traveling chronometers to Sitka time as soon as they arrived and again just before they departed from Sitka. During the season the steamer made seven and a half round trips between the stations.

CARE OF CHRONOMETERS.

36. To secure the greatest possible uniformity of rate a chronometer should be kept running continuously, both when in use and when out of use between seasons of work. When it is allowed to remain stopped for a considerable time, the oil in the bearings tends to become gummy. When started again, the chronometer will tend to have a varying rate for some time until the effects of the stoppage have been worn off.

If a chronometer is to be shipped (by express, for example), and therefore is to be subjected presumably to comparatively violent handling and jarring, it should always be stopped and the balance wheel locked by gently inserting small wedge-shaped pieces of clean cork under it.

A running chronometer should always be protected as carefully as possible against jars, and especially against such sharp quick jars as result from setting it down upon a hard surface. Either the surface upon which it is set should be padded or a cushion should be carried with the chronometer. When it becomes necessary to carry a chronometer in the hand—as, for example, when a hack chronometer is carried back and forth between an observatory and a steamer in connection with chronometric longitudes—the gimbals should be locked to prevent the chronometer from swinging. It is important that the locking should be done in such a way that there will be no looseness and the corresponding tendency to a chucking motion. While the chronometer is being carried swinging of the arm should be avoided as much as possible. Any swinging of the chronometer in azimuth is especially objectionable, as it tends to make it skip seconds and to damage it. Chronometers have been known to skip seconds, probably from this cause, even in the hands of an experienced and careful officer. On shipboard chronometers should be left free to swing in their gimbals, which should be so adjusted that the face of the chronometer will be approximately horizontal. Any change in this adjustment is apt to produce a change of rate.

COMPARISON OF CHRONOMETERS BY COINCIDENCE OF BEATS.

37. The process of comparing a sidereal and a mean time chronometer is analogous to that of reading a vernier. The sidereal chronometer gains gradually on the mean time chronometer, and once in about three minutes the two chronometers tick exactly together (one beat=0^s.5). As one looks along a vernier to find a coincidence, so one listens to this audible vernier and waits for a coincidence. As in reading a vernier one should look at lines on each side of the supposed coincidence to check, and perhaps correct, the reading by observing the symmetry of adjacent lines, so here one listens for the approaching coincidence, hears the ticks nearly together, apparently hears them exactly together for a few seconds, and then hears them begin to separate, and notes the real coincidence as being at the instant of symmetry. The time of coincidence is

*In addition to the chronometer comparisons referred to in this paragraph the steamer chronometers and the station chronometers were each intercompared daily. This was done merely as a check upon their performance.

noted by the face of one of the chronometers. Just before or just after the observation of the coincidence the difference of the seconds readings of the two chronometers is noted to the nearest half second (either mentally or on paper). This difference serves to give the seconds reading of the second chronometer at the instant of coincidence. The hours and minutes of both chronometers are observed directly. When a number of chronometers are to be intercompared, the experienced observer is able to pick out from among them two that are about to coincide. He compares those; selects two more that are about to coincide and compares them, and so on; and thus to a certain extent avoids the waits, of a minute and a half on an average, which would otherwise be necessary to secure an observation on a pair of chronometers selected arbitrarily.

At Sitka on July 13, 1894, it was observed that $18^h\ 30^m\ 08^s{\cdot}00$ on chronometer No. 194 (sidereal) $= 11^h\ 52^m\ 30^s{\cdot}00$ on chronometer No. 208 (mean time); and that $11^h\ 15^m\ 35^s{\cdot}50$ on chronometer No. 1510 (mean time) $= 14^h\ 48^m\ 10^s{\cdot}00$ on chronometer No. 387 (sidereal). It was known that at the epoch of the comparisons the correction of No. 194 to Sitka sidereal time was $-1^m\ 54^s{\cdot}01$, and of No. 1510 to Sitka mean time was $-6^m\ 26^s{\cdot}34$. The required corrections to No. 208 and No. 387 were computed as follows:

	h.	*m.*	*s.*		*h.*	*m.*	*s.*
Time by 194	=18	30	08·00	Time by 1510	= 11	15	35·50
Correction to 194	=	−01	54·01	Correction to 1510	=	+ 6	26·34
Sidereal time	=18	28	13·99	Mean time	= 11	09	09·16
Sidereal time of mean noon	= 7	26	53·66	Correcting mean to sidereal	=	+01	49·93
Sidereal interval	=11	01	20·33	Sidereal interval	= 11	10	59·09
Correction, sidereal to mean	=	−01	48·34	Sidereal time of mean noon	= 7	26	53·66
Mean time	=10	59	31·99	Sidereal time	= 18	37	52·75
Time by 208	=11	52	30·00	Time by 387	= 14	48	10·00
Correction to 208	=	−52	28·01	Correction to 387	=+3	49	42·75

The correction to reduce a sidereal to a mean time interval, or *vice versa*, may be taken from the tables in the back part of the American Ephemeris. The sidereal time of mean noon may be taken from that part of the Ephemeris headed "Solar ephemeris," and it should not be overlooked that it is the sidereal time of *local* mean noon that is required, and that therefore the longitude (approximate) of the station must be taken into account. The correction to be applied to Washington sidereal time of mean noon to obtain that for the station is the same as the correction to reduce a mean time interval equal to the longitude of the station from Washington to a sidereal interval.

COMPUTATION OF LONGITUDE FROM A SINGLE ROUND TRIP.

38. From the operations at Anchorage Point the correction of each station chronometer at the epoch of each set of time observations became known. The intercomparisons on shore before leaving for the steamer and after returning, together with the assumption that each station chronometer runs at a uniform rate between time sets, gave five separate determinations of the correction to the hack at the epoch of the steamer comparisons.

Thus, on June 18, 1894, at $3^h{\cdot}45$ by its own face, the middle epoch of the steamer comparisons, the correction to the hack (No. 380) was

	m.	s.	
By its own rate	−2	38·16	(weight ½).
By No. 4969 rated		38·30	
By No. 2490 rated		38·26	
By No. 207 rated		38·16	
By No. 2637 rated		38·62	(weight ¼).
Mean	= −2	38·30	
Weighted mean	= −2	38·25	

The comparisons of No. 380 with No. 4969 at the station on this date, computed upon the supposition that No. 4969 ran at a uniform rate between preceding and following time observations, showed that the correction to No. 380 at $2^h{\cdot}64$ by its face was $-2^m\ 38^s{\cdot}34$, and at $4^h{\cdot}36$ was $-2^m\ 38^s{\cdot}25$. Assuming it to run uniformly between these epochs, its correction was $-2^m\ 38^s{\cdot}30$ at $3^h{\cdot}45$, as shown above.

An examination of the daily rates of the five chronometers showed that No. 2637 ran very irregularly, and that No. 380 did not run as regularly as the other three. Hence these chronometers were assigned less weight than the others, as indicated above.*

Using the weighted mean value for the correction to No. 380 at the epoch of the steamer comparisons these comparisons give the correction of each traveling chronometer on Anchorage Point time.

Similar operations at Sitka gave the correction to each traveling chronometer on Sitka time on each arrival at and departure from Sitka.

Computation of difference of longitude of Sitka and Anchorage Point.

FIRST TRIP STARTING FROM ANCHORAGE POINT.

Chronometers.	Anchorage Point, May 15.		Sitka, May 17.		Sitka, May 20.		Anchorage Point, May 23.	
	Chr. epoch.	Correction.	Chr. epoch.	Correction.	Chr. epoch.	Correction.	Chr. epoch.	Correction.
	h.	*h. m. s.*	*h.*	*h. m. s.*	*h.*	*h. m. s.*	*h.*	*h. m. s.*
M. T. 231	11·83	−0 03 31·39	7·54	−0 03 02·93	7·55	−0 03 02·14	7·65	−0 03 29·46
" 1 507	11·84	−0 01 03·88	7·81	−0 00 34·93	7·67	−0 00 33·73	7·65	−0 01 01·34
" 1 510	12·15	−0 03 42·50	7·75	−0 03 19·43	7·52	−0 03 28·22	7·75	−0 04 05·90
" 196	9·49	+2 26 28·51	5·20	+2 26 53·00	5·19	+2 26 46·08	5·29	+2 26 10·72
" 1 542	11·92	−0 02 55·84	7·53	−0 02 29·37	7·72	−0 02 31·83	7·81	−0 03 02·63
" 1 728	9·38	+2 34 40·23	5·08	+2 34 59·90	4·91	+2 34 46·00	5·23	+2 34 02·46
" 208	12·71	−0 42 08·24	8·17	−0 42 01·19	8·48	−0 42 35·76	8·56	−0 43 38·37
" 2 167	8·73	+3 18 39·99	4·39	+3 19 09·98	4·15	+3 19 12·69	4·59	+3 18 47·44
Sid. 387	11·97	+3 46 50·04	7·65	+3 47 22·97	7·78	+3 47 29·67	8·29	+3 47 09·31

Chronometers.	Total.		At Sitka.		Traveling.		Daily rate.	From Anchorage Point to Sitka.		Correction at Sitka on Anchorage Point time.	Difference of longitude.
	Time.	Rate.	Time.	Rate.	Time.	Rate.		Time.	Rate.		
	d. h.	*s.*	*d. h.*	*s.*	*d. h.*	*s.*	*s.*	*d. h.*	*s.*	*h. m. s.*	*m. s.*
231	7 19·82	+ 1·93	2 24·01	+ 0·79	4 19·81	+ 1·14	+ 0·24	1 19·71	+ 0·43	−0 03 30·96	0 28·03
1 507	·81	+ 2·54	23·86	+ 1·20	19·95	+ 1·34	+ 0·28	19·97	+ 0·51	−0 01 03·37	28·44
1 510	·60	−23·40	23·77	− 8·79	19·83	−14·61	− 3·03	19·60	− 5·50	−0 03 48·00	28·57
196	·80	−17·79	23·99	− 6·92	19·81	−10·87	− 2·25	19·71	− 4·10	+2 26 24·41	28·59
1 542	·89	− 6·79	24·19	− 2·46	19·70	− 4·33	− 0·90	19·61	− 1·64	−0 02 57·48	28·11
1 728	·85	−37·77	23·83	−13·90	20·02	−23·87	− 4·94	19·70	− 8·99	+2 34 31·24	28·66
208	·85	−90·13	24·31	−34·57	19·54	−55·56	−11·54	19·46	−20·90	−0 42 29·14	27·95
2 167	·86	+ 7·45	23·76	+ 2·71	20·10	+ 4·74	+ 0·98	19·66	+ 1·78	+3 18 41·77	28·21
387	20·32	+19·27	24·13	+ 6·70	20·19	+12·57	+ 2·60	19·68	+ 4·73	+3 46 54·77	28·20

* If considered desirable the relative weights to be assigned to the station chronometers may be determined more accurately by the method outlined in the footnote to § 40.

In the above form the column headed "Chr. epoch" gives the face reading of the chronometer, expressed in hours and hundredths (rather than minutes and seconds) for convenience in computation. The corrections at Anchorage Point are to the local time of that station, and at Sitka to Sitka local time.

In the second part of the form, the second and third columns give the elapsed chronometer time and the accumulated rate between the Anchorage Point steamer comparisons, and the fourth and fifth columns give the same quantities between the Sitka steamer comparisons. The second minus the fourth, and the third minus the fifth columns are the traveling time (both ways) and the accumulated rate while traveling, from which the daily traveling rate as given in the eighth column becomes known. The ninth column gives the traveling time between steamer comparisons from Anchorage Point to Sitka, and the tenth column gives the accumulated rate during this interval computed by the use of the eighth column. This accumulated rate being applied as a correction to the chronometer correction on Anchorage Point time at the beginning of the trip gives the correction on Anchorage Point time on arrival at Sitka. This difference subtracted from the directly observed correction on Sitka time at that epoch, shown in the upper form, gives the required difference of longitude.

It should be noted that in this computation the traveling rate is supposed to be a constant during the round trip, but is not assumed to be the same as the rate while in port.

The longitude difference if computed from the return half of the trip, from Sitka to Anchorage Point, would necessarily by this process of computation be identical with that shown above.

If the steamer had stopped so short a time at Sitka that only one set of steamer comparisons had been made while there, as was frequently the case, the above computation would have been simplified in an obvious manner.

COMBINATION OF RESULTS.

39. The difference of longitude was thus computed from each traveling chronometer for each round trip, starting from Anchorage Point, the last half trip (7½ round trips being made) from Anchorage Point to Sitka, being omitted. A similar computation was also made for each round trip, starting from Sitka, the first half trip, Anchorage Point to Sitka, now being omitted.* Each of these computations would be subject to a constant error if the traveling chronometers had uniformly accelerated or uniformly retarded rates, but their mean is free from this error. One half of the computation also serves as a check on the other half.

*If the steamer had returned again to Anchorage Point, so as to complete eight round trips, all of the eight would have been used in the first computation; and in the second computation (round trips, starting from Sitka) the *last* trip from Sitka to Anchorage Point, combined with the *first* trip in the opposite direction, would have been used as the eighth round trip. This principle of computing the difference of longitude from the round trips starting from each station in turn, and combining the two results was used for the first time by Assistant C. A. Schott in 1857 in deriving the difference of longitude of Savannah, Ga., and Fernandina, Fla. (See Coast Survey Report for 1857, pp. 314-324.)

The method of combining these separate results is shown in the following form:

Difference of longitude between Sitka and Anchorage Point, Chilkat Inlet, Alaska.

SUMMARY OF RESULTS FROM SEVEN ROUND TRIPS, STARTING FROM ANCHORAGE POINT.

Chronometers, M. T. or Sid.		1st	2d	3d	4th	5th	6th	7th	Means. $\Delta\lambda$	Weights.
		m. *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	
M. T.	231	0 28·03	0 26·36	0 28·36	0 28·19	0 28·45	0 28·19	0 28·18	0 27·97	3
	1507	28·44	29·06	29·18	28·26	28·27	28·20	28·54	28·56	4
	1510	28·57	29·25	29·00	28·52	28·63	28·06	28·58	28·66	7
	196	28·59	29·09	29·54	28·59	28·43	28·51	28·92	28·81	3
	1542	28·11	28·11	28·66	28·23	28·47	28·38	28·37	28·33	22
	1728	28·66	28·94	29·16	28·63	28·58	28·43	28·59	28·71	6
	208	27·95	27·40	28·21	28·19	28·42	28·42	28·09	28·10	6
	2167	28·21	28·56	28·90	28·55	28·68	28·27	28·64	28·54	17
Sid.	387	28·20	28·44	28·91	27·93	28·41	27·93	28·59	28·34	6
Mean		0 28·31	0 28·36	0 28·88	0 28·34	0 28·48	0 28·27	0 28·50	0 28·45	
Weighted mean		28·25	28·38	28·82	28·35	28·52	28·28	28·49	28·44	
Weight		3	1	2	2	2	1	2		

Weighted mean $0^h\ 0^m\ 28^s{\cdot}44 \pm 0^s{\cdot}05$

SUMMARY OF RESULTS FROM SEVEN ROUND TRIPS, STARTING FROM SITKA.

Chronometers, M. T. or Sid.		1st	2d	3d	4th	5th	6th	7th	Means. $\Delta\lambda$	Weights.
		m. *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	*m.* *s.*	
M. T.	231	0 28.87	0 28.78	0 28·74	0 28·39	0 28·37	0 28·71	0 28·11	0 28·57	3
	1507	27·69	29·08	29·11	27·76	28·78	27·93	28·64	28·43	4
	1510	28·37	28·88	28·82	27·91	28·83	28·10	28·58	28·50	7
	196	28·59	29·07	28·95	27·66	28·03	29·56	29·20	28·72	3
	1542	28·93	28·57	28·59	28·22	28·50	28·50	28·32	28·52	22
	1728	27·59	28·90	28·75	27·99	29·01	28·09	28·75	28·44	6
	208	27·71	28·03	28·52	28·58	27·88	28·76	27·65	28·16	6
	2167	28·24	28·71	28·80	28·27	28·77	28·31	28·49	28·51	17
Sid.	387	28·68	28·80	28·43	27·69	28·97	27·98	28·73	28·47	6
Mean		0 28·30	0 28·76	0 28·75	0 28·05	0 28·57	0 28·44	0 28·50	0 28·48	
Weighted mean		28·41	28·69	28·70	28·13	28·61	28·38	28·44	28·48	
Weight		1	2	2	2	2	2	2		

Weighted mean $0^h\ 0^m\ 28^s{\cdot}48 \pm 0^s{\cdot}05$

Final mean $\Delta\lambda$ $= +0^h\ 0^m\ 28^s{\cdot}46 \pm 0^s{\cdot}05$

Let N be the number of days during which the chronometers are depended upon to carry the time during each round trip, reckoned by adding to the "traveling time," as given in the sixth column of the form on page 335, the interval between each comparison of the hack chronometer with the traveling chronometers and the nearest (either before or after) time observation made at that station. The weight assigned to each trip is proportional to the reciprocal of N. This weighting depends upon the assumptions that errors in the computed longitude arising from the time determinations and from the

chronometer comparisons are small as compared with those arising from variations in chronometer rates; that the time is carried by the combined station chronometers over the intervals during which they are depended upon with about the same degree of accuracy (due regard being paid to the length of the interval) as the combined traveling chronometers carry the time during the trip, and, finally, that the errors arising from the variations in the chronometer rates belong to the accidental class and are proportional to the square root of the length of the interval over which the time is carried.

WEIGHTS ASSIGNED TO SEPARATE CHRONOMETERS.

40. Even a cursory examination of such a table as that given in the preceding section shows that some chronometers run much more uniformly than others, and therefore furnish determinations of the longitude difference which are entitled to greater weight. Let $l_1, l_2, l_3, \ldots l_n$ be the derived values of the difference of longitude as given by one chronometer on the different trips, and let l be their mean. Let n be the number of trips. Then, by the ordinary laws of least squares, assigning equal weights to the separate trips, the probable error of any one of these ls is

$$\pm\sqrt{\frac{(0.455)\,[(l-l_1)^2+(l-l_2)^2+\ldots(l-l_n)^2]}{n-1}}$$

The weight p, inversely proportional to the square of this probable error to be assigned to a chronometer, is proportional to

$$\frac{n-1}{[(l-l_1)^2+(l-l_2)^2+\ldots(l-l_n)^2]}$$

The computation of weights may be put in the following convenient tabular form:

COMPUTATION OF WEIGHTS.

From the seven round trips starting from Anchorage Point.

Chronometer l	231 27s·97	1507 28s·56	1510 28s·66	196 28s·81	1542 28s·33	1728 28s·71	208 28s·10	2167 28s·54	387 28s·34
$l-l_1$	− ·06	+ ·12	+ ·09	+ ·22	+ ·22	+ ·05	+ ·15	+ ·33	+ ·14
$l-l_2$	+1·61	− ·50	− ·59	− ·28	+ ·22	− ·23	+ ·70	− ·02	− ·10
$l-l_3$	− ·39	− ·62	− ·34	− ·73	− ·33	− ·45	− ·11	− ·36	− ·57
$l-l_4$	− ·22	+ ·30	+ ·14	+ ·22	+ ·10	+ ·08	− ·09	− ·01	+ ·41
$l-l_5$	− ·48	+ ·29	+ ·03	+ ·38	− ·14	+ ·13	− ·32	− ·14	− ·07
$l-l_6$	− ·22	+ ·36	+ ·60	+ ·30	− ·05	+ ·28	− ·32	+ ·27	+ ·41
$l-l_7$	− ·21	+ ·02	+ ·08	− ·11	− ·04	+ ·12	+ ·01	− ·10	− ·25
$(l-l_1)^2$	·00	·01	·01	·05	·05	·00	·02	·11	·02
$(l-l_2)^2$	2·59	·25	·35	·08	·05	·05	·49	·00	·01
$(l-l_3)^2$	·15	·38	·12	·53	·11	·20	·01	·13	·32
$(l-l_4)^2$	·05	·09	·02	·05	·01	·01	·01	·00	·17
$(l-l_5)^2$	·23	·08	·00	·14	·02	·02	·10	·02	·00
$(l-l_6)^2$	·05	·13	·36	·09	·00	·08	·10	·07	·17
$(l-l_7)^2$	·04	·00	·01	·01	·00	·01	·00	·01	·06
$\Sigma(l-l_n)^2$	3·11	·94	·87	·95	·24	·37	·73	·34	·75
By 2d comb.*	·47	2·30	·89	2·73	·30	1·78	1·22	·36	1·32
Mean of 2	1·79	1·62	0·88	1·84	0·27	1·08	0·98	0·35	1·04
n−1	6	6	6	6	6	6	6	6	6
$\frac{n-1}{\Sigma(l-l_n)^2}$	3·3	3·7	6·8	3·3	22·2	5·6	6·1	17·0	5·8

*From similar results from seven round trips starting from Sitka.

A similar computation was made using the seven round trips starting from Sitka, the results of which are shown in the line marked "by 2d combination," and the weights were derived from the mean results of the two computations.*

DISCUSSION OF ERRORS.

41. The error in a difference of longitude observed and computed as indicated in the preceding sections depends upon the errors in the transit time observations, errors in the comparison of chronometers, errors arising from variations in the rates of chronometers, and finally the relative personal equation of the two observers concerned.

The errors in the time observations will in general be very small in comparison with the other errors affecting the result. For the probable magnitude of the time errors see the first part of this appendix. In Appendix No. 3 of the Report for 1894 and in No. 3 of 1895 may be found detailed statements of the results of several determinations of longitude by the chronometric method which will serve to give a concrete idea of the magnitude of the errors involved in such determinations. The relative magnitude of the errors arising from the time determinations increases as the time, N (see § 39), required for a round trip decreases.

The errors made in comparing chronometers by the method of coincidences are neglible in their effect upon the final result. The checks obtained during the intercomparisons of chronometers indicated in § 35 show that the probable error in a single comparison is about $\pm 0^s.01$, corresponding to a probable error of about $\pm 4^s$ in estimating the time of coincidence of ticks.

The errors arising from variations in the rates of chronometers are by far the most serious class of errors involved in chronometric determinations of longitude. The table of results given on page 337 gives a fair indication of the magnitude of the errors to be expected from this source.

The various traveling chronometers are subjected to variations of temperature, humidity, and barometric pressure, and to disturbances arising from the motion of the ship, which are *common to them all.* Do these common conditions produce variations in rate which are common to all the chronometers, and therefore introduce a common error into the various values of the longitude difference resulting from any one trip? An examination of the results of six chronometric determinations of longitude in Alaska, printed in the 1894 and 1895 Reports, indicates that such errors in the deduced longitudes, common to all the chronometers on a given trip, are exceedingly small upon an average, so small that they are concealed by the accidental errors.

Chronometers are compensated for temperature as well as possible by the maker, but such compensation is necessarily somewhat imperfect. In general, however, this compensation is so nearly perfect that little or nothing is gained in accuracy by deriving

* The relative weights to be assigned to the station chronometers when they are used to determine the correction of the hack at the epoch of the steamer comparisons might be computed by an analogous process. Let O be the correction to a chronometer at the epoch of transit time observations as determined from those observations. Let I be its correction at that same epoch interpolated between its observed corrections at the last preceding and first following transit time observations on the assumption that its rate during that interval is constant. For a group of chronometers whose corrections are all determined a number of times in succession by the same transit observations, the relative weights are evidently proportional to $\frac{1}{\Sigma (I-O)^2}$.

and using temperature coefficients connecting the temperature and the rate. There are occasional exceptions; for example, the Hutton chronometer No. 194 (see pp. 77–78 of the Report for 1894) shows a very large variation in rate due to change of temperature.

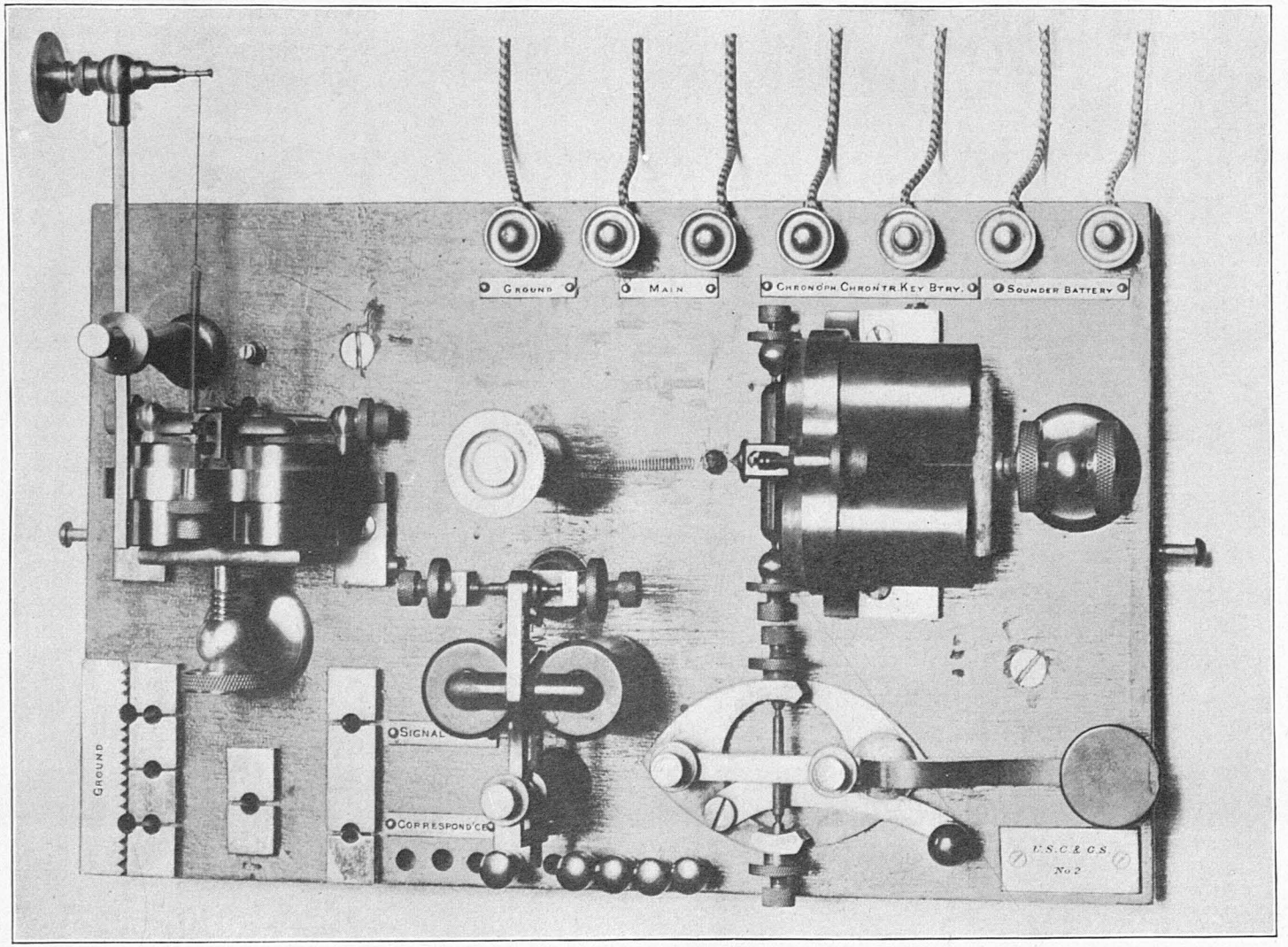
In considering the errors due to variations in chronometer rates it should not be overlooked that the station chronometers are depended upon to carry the time over the interval from the nearest time observations to the steamer comparisons in precisely the same manner in which the traveling chronometers are depended upon during the trip. It is because of this fact that it may be desirable during periods of very bad weather to supplement the transit observations upon stars by transit observations upon the sun, as indicated on page 307, or in low latitudes by theodolite observations for time, or even by sextant observations for time.

Unless the relative personal equation is eliminated from the computed longitude it is apt to be one of the largest errors affecting the mean result, except when the round trips are very long or very few chronometers are carried. It may be eliminated by any of the methods suggested in § 33.

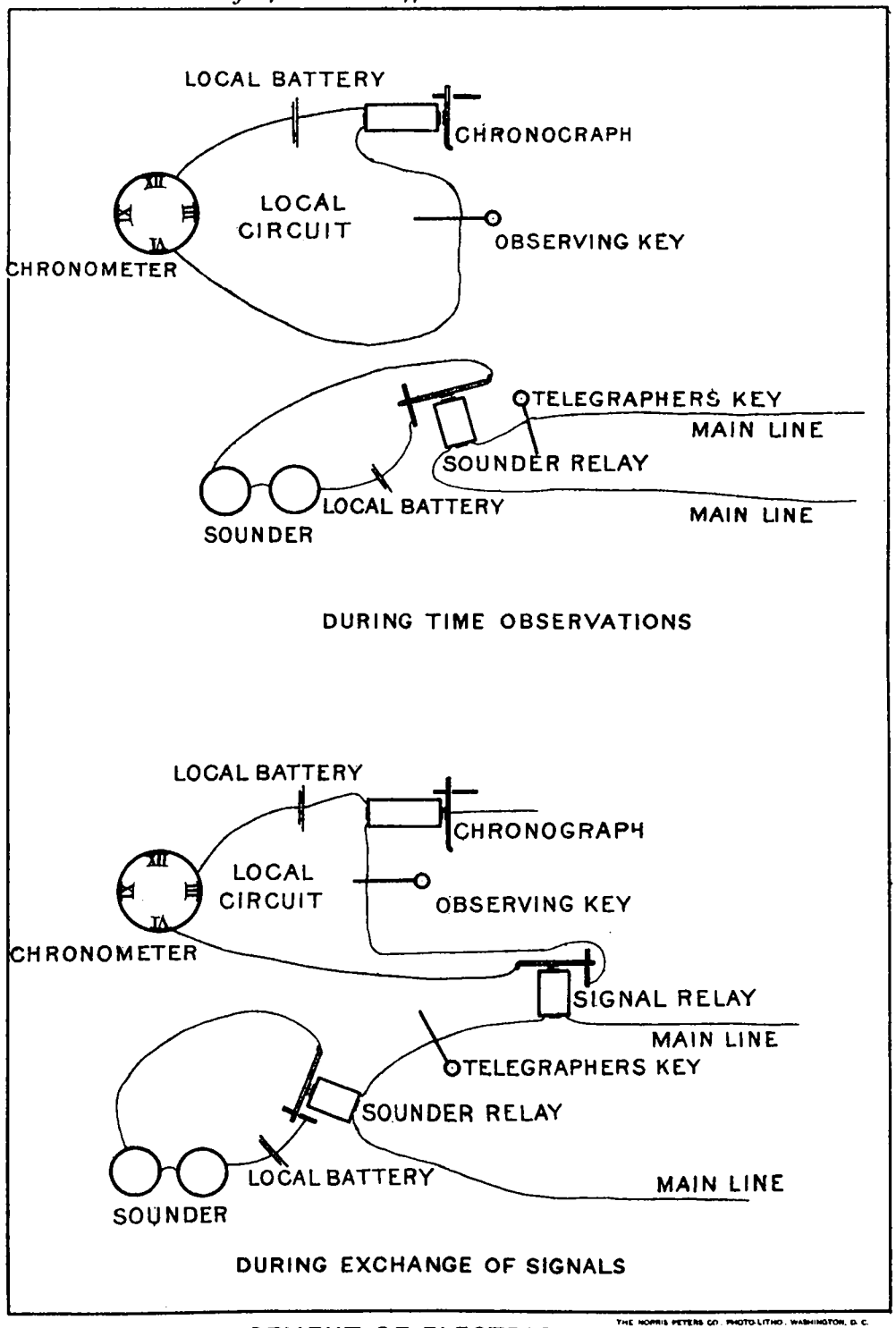
Assuming that the relative personal equation is eliminated by direct determination or otherwise, the error of the mean result of a chronometric longitude determination will be nearly inversely proportional to the square root of the number of chronometers carried (provided the stations are supplied with a sufficient number of good chronometers to make the shore errors small), to the square root of the number of round trips, and the square root of the average value of N (the interval over which the time is carried by the chronometers). It will depend very intimately upon the quality of the chronometers and upon the care with which they are protected from temperature changes and jars. It will be affected very little by an increase in the errors of the time observations proper, resulting from very fragmentary observations on cloudy nights or from substituting some more approximate method for transit observations upon stars.

From the above principles and the numerical values given in Appendix No. 3 of the 1894 Report and in No. 3 of the 1895 Report, one may make an estimate of the errors to be expected if the above elaborate plan of operations can be carried out only in part, as, for example, when an observer determines the longitude of a new station by making a single trip to it, carrying a few chronometers only and making all time observations at both ends of the trip himself.

In connection with any plan of operations which involves long intervals between the arrival at and the departure from a given station, it should be kept in mind that the computation usually involves the assumption that the rates of the traveling chronometers are the same on the trip to the station as on the return trip, and therefore a long stay at the station is apt to increase the error of the final result by giving the chronometers a long time to acquire new rates. Under extreme conditions it may sometimes be well to avoid this assumption and to use a separate traveling rate for each half trip derived from observations just preceding or following that half trip.



SWITCH BOARD.



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ARRANGEMENT OF ELECTRICAL APPARATUS

PART III.

THE DETERMINATION OF LATITUDE BY MEANS OF THE ZENITH TELESCOPE.

INTRODUCTORY.

42. A measurement of the meridional zenith distance of a known star, or other celestial object, furnishes a determination of the latitude of the station of observation. In the zenith telescope, or Horrebow-Talcott, method of determining the latitude, there is substituted for the measurement of the absolute zenith distance of a star the measurement of the small difference of meridional zenith distances of two stars culminating at about the same time, and on opposite sides of the zenith. The effect of this substitution is the attainment of a much higher degree of precision, arising from the increased accuracy of a differential measurement, in general, over the corresponding absolute measurement; from the elimination of the use of a graduated circle from the essential part of the measurement; and from the fact that the computed result is affected, not by the error in estimating the absolute value of the astronomical refraction, but simply by the error in estimating the very small difference of refraction of two stars at nearly the same altitude.

Because of its great accuracy, combined with convenience and rapidity, the Horrebow-Talcott method has become the only standard method on this Survey. For other methods of determining the latitude, involving in most cases absolute measurements of zenith distance or altitude, the reader is referred to treatises on astronomy.

The method of determining the latitude by observing the time of transit of a star across the prime vertical, is one which is capable of a very high degree of accuracy and is well adapted to field use, as the effects of instrumental errors may be readily eliminated. To determine the latitude of a station by this method, the times of transit of various stars (of positive declination less than the latitude) across the plane of a transit placed approximately in the prime vertical are observed. The inclination of the transverse axis is determined accurately with a striding level. The effects of error of collimation and pivot inequality are eliminated by reversal of the axis. The effects of azimuth error (deviation of the instrument from the prime vertical) and of constant errors in the observed times (personal equation) are eliminated by observing some stars to the eastward of the zenith and others to the westward. The declinations of the stars observed must be accurately known, as the declination errors enter directly into the latitude at about their full value, but the right ascensions need be known but approximately.

This method has been little used upon this Survey, perhaps because more time is required to prepare an extended observing list than in the zenith telescope method, but

it may be found useful in the future. If the only instrument available is a theodolite having a good striding level, but not equipped for observations by the zenith telescope method, observations in the prime vertical will give the best possible determination of the latitude. For details in regard to this method see Chauvenet's Astronomy, Vol. II, pp. 238–271, and Doolittle's Practical Astronomy, pp. 348–377. For an interesting early test of the method (1827) by Bessel, with a very small portable instrument, see *Astronomische Nachrichten*, Vol. 9, pp. 413–436.

DESCRIPTION OF INSTRUMENT.

43. Illustration No. 6 shows one of the best zenith telescopes now in use on this Survey. This instrument, Zenith Telescope No. 4, was originally made by Troughton & Simms, of London, in 1849, and was remodeled at the Coast and Geodetic Survey Office in 1891. It carries a telescope with a clear aperture of about 76^{mm} (3 inches), and a focal length of about $116{\cdot}6^{cm}$ (46 inches). The magnifying power with the eyepiece ordinarily used is 100. Two latitude levels are used instead of one, to secure increased accuracy. Each of these levels carries a graduation which is numbered continuously from one end to the other (instead of each way from the middle), the numbering of the upper one running from 0 to 50 and of the lower from 60 to 110. A 2^{mm} division on the upper level has a value of about $1''{\cdot}6$ and on the lower about $1''{\cdot}4$. The vertical axis of the instrument is in the vertical plane in which the telescope swings. The clamp arm, perforated for the sake of lightness, gives the telescope a marked degree of stability in so far as changes of inclination are concerned. The eyepiece micrometer, arranged to measure zenith distance, has a value of about 45″ per turn, and the micrometer head is graduated to hundreths of a turn.

The better known type of zenith telescope, in which the telescope is mounted eccentrically on one side of the vertical axis instead of in front of it, is also in use on the Survey. The meridian telescopes described in § 3 are extensively used for latitude determinations, as well as for time.

ADJUSTMENTS.

44. When setting up the instrument place two of the foot screws in an east and west line. The level correction may then be kept small during the progress of the observations by using one foot screw only.

The vertical axis may be made approximately vertical by use of the plate level, if there is one on the instrument, and the final adjustment made by using the latitude level. The position of the horizontal axis may now be tested by readings of the striding level. If the horizontal axis is found to be inclined, it must be made horizontal by using the screws which change the angle between the horizontal and vertical axes, if the instrument is of the old form. With the new form of instrument (Illustration No. 6), or with a meridian telescope, the two axes will always remain so nearly at right angles that no means for making this adjustment is needed. With these instruments the vertical axis may be made vertical by using both the striding level and the latitude level at the same time.

The eyepiece and objective should be carefully focused as indicated on pages 271–272. It is important that the focus of the objective should not be changed during the stay at a station, since the angular value of one turn of the eyepiece micrometer is depended upon to remain constant for the station. It is well, therefore, to clamp the draw tube of the telescope in position as soon as a satisfactory focus has been obtained.

The movable micrometer thread with which all pointings are to be made must be truly horizontal. This adjustment may be made, at least approximately, in daylight after the other adjustments. Point, with movable thread, upon a distant well-defined object, with the image of that object near the apparent right-hand side of the field of the eyepiece, and with the telescope clamped in zenith distance. Shift the image to the apparent left-hand side of the field by turning the instrument about its vertical axis. If the bisection is not still perfect, half the correction should be made with the micrometer and half with the slow-motion screws which rotate the whole eyepiece and reticle about the axis of figure of the telescope. Repeat, if necessary. The adjustment should be carefully tested at night after setting the stops, by taking a series of pointings upon a slow-moving star as it crosses the field with the telescope in the meridian. If the adjustment is perfect, the mean reading of the micrometer before the star reaches the middle of the field should agree with the mean reading after passing the middle, except for the accidental errors of pointing. It is especially important to make this adjustment carefully, for the tendency of any inclination is to introduce a *constant* error into the computed values of the latitude.

The line of collimation as defined by the middle vertical line of the reticle must be perpendicular to the horizontal axis. If the instrument is a meridian telescope, or of the form shown in Illustration No. 6, this adjustment may be made as for a transit (p. 272) by reversing the horizontal axis in the wyes. If the instrument is of the form in which the telescope is to one side of the vertical axis, the method of making the test must be modified accordingly. It may be made by using two collimating telescopes which are pointed upon one another in such positions that the zenith telescope may be pointed first upon one and then upon the other with no intermediate motion except a rotation of 180° about the horizontal axis. It may be made as for an engineer's transit, but using two fore and two back points, the distance apart of each pair of points being made double the distance between the vertical axis and the line of collimation of the telescope. A single pair of points at that distance apart may be used and the horizontal circle trusted to determine when the instrument has been turned 180° in azimuth. Or a single point at an approximately known distance may be used and the horizontal circle trusted as before, and a computed allowance made on the horizontal circle for the parallax of the point when the telescope is changed from one of its positions to the other. Thus, let d = the distance of the vertical axis from the line of collimation of the telescope, D = the distance to the point, and p = the parallax for which correction is to be made; then, in seconds of arc:

$$p = \frac{2d}{D \sin 1''}$$

If one considers the allowable limit of error in this adjustment (see pages 372, 373) it is evident that refined tests are not necessary, and that a telegraph pole or small tree, if *sufficiently distant* from the instrument, may be assumed to be of radius = d, and the adjustment made accordingly.

The stops on the horizontal circle must be set so that when the abutting piece is in contact with either of them the line of collimation is in the meridian. For this purpose, and throughout the observations, the chronometer correction must be known roughly—within one second, say. Set the telescope for an Ephemeris star which culminates well to the northward of the zenith, and look up the apparent right ascension for the date.

Follow the star with the middle vertical line of the reticle, at first with the azimuth motion free and afterwards using the tangent screw on the horizontal circle, until the chronometer, corrected for its error, indicates that the star is on the meridian. Then clamp a stop in place against the abutting piece. Repeat for the other stop, using a star which culminates far to the southward of the zenith. It is well, if time permits, to test the setting of each stop by an observation of another star before commencing latitude observations.

The finder circle must be adjusted to read zenith distances (see p. 273).

THE OBSERVING LIST.

45. Before commencing observations at a station an observing list similar to that shown below should be prepared.

At present the best list to be used in selecting pairs is the Greenwich Ten-Year Catalogue for 1880,* and the mean places there given may be used in making the field computation. To find *all* available pairs in a given list one may, for each star in succession within the zone of observation, 45° each way from the zenith, subtract the declination from twice the latitude, and then compare this difference with the declination of each star of the list within the *following* 20^m of right ascension. Any star whose declination† is within 20′ of the above difference will combine with the star under consideration to make a pair, provided the other conditions stated below are fulfilled. By proceeding thus, every available pair will be found. ‡

Observing list.

Mount Desert, Me. Aug.–Sept., 1856. Zenith Telescope No. 5. Approximate $\phi = 44° 21'.1$.

Star No. B. A. C.	Mag.	Right Ascension.	Declination.	Zenith Distance.	N. or S.	Setting.	Turns.
		h m. s.	° ′	° ′		° ′	
6062	5½	17 47 24	40 01	4 20	S.		30
6068	5½	48 36	40 02	4 19	S.	4 13	29
6129	5	59 23	48 28	4 07	N.		11
6255	5	18 17 52	49 03	4 42	N.		11
6268	5½	19 29	39 26	4 55	S.	4 48	30
6357	6	33 21	39 33	4 48	S.		20
6395	5	39 50	55 24	11 03	N.		16
6429	3	44 47	33 12	11 09	S.	11 06	24
6522	6	57 53	55 27	11 06	N.		20
6553	6	19 01 59	32 17	12 04	S.		11
6583	5	08 57	56 37	12 16	N.	12 10	29
6629	6½	15 28	62 57	18 36	N.		30
6637	6	16 58	25 59	18 22	S.	18 29	10
etc.							

* The Greenwich Ten-Year Catalogue for 1890 will soon be available and will supersede the 1880 catalogue for the purpose under consideration. As soon as the proposed new Coast and Geodetic Survey Catalogue is available it should be used in preference to any other.

† Or $180° - \delta$ for subpolars.

‡ At stations in Alaska there are but few stars in the zone extending 45° northward from the zenith as compared with the corresponding zone to the southward of the zenith, and the above process may be improved by comparing each star in the northern zone with stars in *both the preceding and the following* 20^m.

For the purposes of the observing list the mean right ascensions to within one second, and the declinations and derived quantities to the nearest minute of arc, are sufficiently accurate. To obtain the zenith distances within this limit the latitude of the station must be known to the nearest minute. If not already known from geodetic connections or from a map, it may be determined by observing the meridional zenith distance of a star with the finder circle of the zenith telescope. The setting of the finder circle, as given in the observing list, is the mean of the zenith distances of the stars of the pair or of the extreme stars of a triplet. The approximate reading of the turns is given to facilitate identification of stars and to enable the observer to put the micrometer line approximately in position before the star enters the field of view. The reading of the middle of the micrometer comb is called 20 to avoid negative readings. The reading of the turns from the comb will then be, approximately, for each star, 20 turns + (Zenith Distance — Setting, expressed in turns). The value of one turn of the micrometer of Zenith Telescope No. 5 was about 40″.

Among the requisites for a pair of stars for this list are, that their right ascensions shall not differ by more than 20^m, to avoid too great errors arising from instability in the relative positions of different parts of the instrument; nor by less than 1^m, that interval being required to take the readings upon the first star and prepare for the second star of a pair; that their difference of zenith distances shall not exceed the half length of the micrometer comb, 20′ for many instruments; that each star shall be bright enough to be seen distinctly, not fainter than the seventh magnitude for the larger instruments; and that no zenith distance shall exceed 45°, to guard against too great an uncertainty in the refraction. The third of the above conditions may be used more conveniently in this form; the sum of two declinations must not differ from twice the latitude by more than 20′. The total range of the list in right ascension is governed by the hours of darkness on the proposed dates of observation, and by the convenience of the observer.

In the list of pairs resulting directly from the search there will be many pairs which overlap in time. A feasible observing list may be formed by omitting such pairs that among the remainder the shortest interval between the last star of one pair and the first star of the next is not less than 2^m. In that interval a rapid observer can finish the readings upon one pair, and set for the next, under favorable circumstances. The omitted pairs may be included in a list prepared for the second or third night of observation. It will frequently be found that the same star occurs in two or more different pairs. Such pairs may be treated like those which overlap in time, or the three or more stars forming what might be called a compound pair may all be observed at one setting of the telescope, and then treated in the computation as two or more separate, but not independent pairs.*

The pairs actually observed should be such that the algebraic sum of all the differences of zenith distance at a station shall be nearly zero, so that the computed mean latitude may be nearly free from any effect of error in the mean value of the micrometer screw.

* Past records furnish abundant evidence that observations made by pointing twice upon a circumzenith star, once in each position of the instrument, give results of a low order of accuracy, probably because of the hurry with which the observations must be made, and of the fact that one or both of the observations must be made out of the meridian. It is therefore not advisable to make such observations.

DIRECTIONS FOR OBSERVING.

46. All adjustments having previously been made, set for the first star and await it with the bubble of the latitude level nearly in the middle of the tube, and with the micrometer line at that part of the comb at which the star is expected, as shown by the observing list. Watch the chronometer so as to know when to expect the star. When the star enters the field, place the micrometer line approximately upon it, and center the eyepiece over the line. As soon as the star comes within the safe observing limits of the field bisect it carefully. As the star moves along watch the bisection and correct it if any error is detected. Because of momentary changes in the refraction, the star will usually be seen to move along the line with an irregular motion, now partly above it, and now partly below. The mean position of the star is to be covered by the line.* It is possible, but not advisable, to make several bisections of the star while it is passing across the field. As soon as the star reaches the middle vertical line of the diaphragm read off promptly from the comb the whole turns of the micrometer, read the level, and then the fraction of a micrometer turn, in divisions, from the micrometer head. Set promptly for the next star, even though it is not expected soon. In setting for the second star of a pair all that is necessary is to reverse the instrument in azimuth and set the micrometer line to a new position.

Especial care should be taken in handling the micrometer screw, as any longitudinal force applied to it produces a flexure of the telescope, which tends to enter the result directly as an error. The last motion of the micrometer head in making a bisection should always be in one direction (preferably that in which the screw acts positively against its opposing spring), to insure that any lost motion is always taken up in one direction. The bubble should be read promptly, so as to give it as little time as possible to change its position after the bisection. The desired reading is that at which it stood at the instant of bisection. Avoid carefully any heating of the level by putting the reading lamp, warm breath, or face any nearer to it than necessary. During the observation of a pair the tangent screw of the setting circle must not be touched, for the angle between the telescope and the level must be kept constant. If it is necessary to relevel, to keep the bubble within reading limits, use the tangent screw which changes the inclination of the telescope. Even this may introduce an error, due to a change in the flexure of the telescope, and should be avoided if possible. It is desirable to relevel the instrument from time to time between pairs, so as to keep the level correction small, less than one division of the level if possible.

Occasionally the approximate time at which the star being observed transits across the middle vertical line of the diaphragm should be noted, so as to make sure that the adjustment of the stops in azimuth is still sufficiently exact. For first-class observing it is desirable to have a recorder. He may count seconds aloud from the face of the chronometer in such a way as to indicate when the star is to culminate. Such counting aloud serves a double purpose. It is a warning to be ready and indicates where to look for the star if it is faint and difficult to find. It also gives for each star a rough check upon the position of the azimuth stops. It is only a rough check, because the observing list gives mean right ascensions instead of apparent right ascensions for the

*This wording must be modified to correspond if, in accordance with the considerations stated on page 380, two close parallel lines are used instead of a single line.

date, but it is sufficiently accurate (see § 51). The observer, or recorder, can easily make allowance for the fact that all stars (except circumpolars) will appear to be too early or too late, according to the observing list, by about the same interval, 0^s to 5^s, the difference between the mean and the apparent right ascension. If a star can not be observed upon the middle line, on account of temporary interference by clouds or tardiness in preparing for the observation, observe it anywhere within the safe limits of the field (often indicated by vertical lines on the diaphragm) and record the chronometer time of observation.

It is desirable to make all settings with such accuracy that the mean of the two micrometer readings on a pair shall not differ from twenty turns by more than one turn. It is not infrequently true that the value of a micrometer screw increases slightly but steadily from one end to the other. In such cases the correction to each observed value of the latitude, due to this irregularity of the screw, will be insensible if the settings are made with the indicated accuracy, but not otherwise.

47. EXAMPLE OF RECORD AND COMPUTATION.

Zenith telescope record for latitude.

Station, Marysville, Cal. Date, June 1, 1898. Chronometer, Hutton 194. Observer, C. H. S.

No. of pair.	Star number. B. A. C. Cat.	N. or S.	Micrometer. Turns.	Micrometer. Div's.	Level. North.	Level. South.	Chronometer time of culmination.	Chronometer time of observation.	Mer'n. dist.	Remarks.
					d.	*d.*	*h. m. s.*	*h. m. s.*	*s.*	
10	4615	S.								Chronometer fast 30^s.
	1167 C. S.	N.	Clouds.							
11	4696	N.	23	96·0	40·7	7·3	14 02 07			
	4751	S.	20	69·0	6·8	40·0	14 50			
12	4758	N.	14	73·5	38·0	4·4	16 06			
	4812	S.	28	95·0	4·8	38·2	28 27			Fog.
13	1208 C. S.	N.	21	63·0	44·0	10·7	29 49	14 29 59	10	Faint, clouds, poor.
	1214 C. S.	S.	22	58·0	11·0	44·8	36 15			
14	4870	N.	29	56·0	41·1	7·3	40 17			
	4906	S.	13	03·5	8·0	41·7	46 59			

Latitude

Station: Marysville. State: California.

Date.	Catalogue.		Micrometer.		Level.			Meridian distance.	Declination.
	Star No.	N. or S.	Reading.	Diff., Z. D.	N.	S.	Diff., N-S.		
1898.			*t.* *d.*	*t.* *d.*	*d.*	*d.*	*d.*	*s.*	° ′ ″
May 28	4696	N	23 43·5		42·6	8·5			64 51 44·41
	4751	S	20 17·5	— 3 26·0	8·4	42.8	—0·1		13 28 15·63
May 29	"	"	23 96·0		43·0	8·2			
			20 74·0	— 3 22·0	8·2	43·0	0·0		
" 30	"	"	23 08·0		42·2	9·0			44·95
			19 85·0	— 3 23·0	9·4	42·6	—0·8		15·97
June 1	"	"	23 96·0		40·7	7·3			
			20 69·0	— 3 27·0	6·8	40·0	+1·2		
" 2	"	"	24 29·0		41·0	8·5			45·71
			20 99·5	— 3 29·5	8·5	41·0	0·0		16·45
May 29	4758	N	14 02.0		40·2	5·2			39 15 36·83
	4812	S	28 27·0	+ 14 25·0	5·2	40·2	0·0		38 45 07·28

computation.

Observer: C. H. S. Instrument: Meridian Telescope No. 1.

Sum and half sum.	Corrections.				Latitude.	Remarks.
	Microm.	Level.	Refr.	Merid.		
° ′ ″	′ ″	″	″	″	° ′ ″	
78 20 00·04						
39 10 00·02	—1 47·78	—·05	—·04		39 08 12·16	
+0·01						
00·48						
00·24	—1 46·46	·00	—·04		13·75	
+0·01						
00.92						
00.46	—1 46·79	—·38	—·04		13·25	
0·00						
01·75						
00·88	—1 48·11	+·57	—·04		13·30	
0·00						
02·16						
01·08	—1 48·94	·00	—·04		12·10	
0·00						
78 00 44·11						
39 00 22·06	+7 51·14	·00	+·13		39 08 13·34	
+0·01						

d = one division of level = 1″ ·901. R = one turn of micrometer = 66″ ·125.

EXPLANATION OF COMPUTATION.

48. Let ζ and ζ' equal the true meridional zenith distance of the southern and northern star, and δ and δ' the apparent 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; d the value of one division of level; r and r' the refraction correction, and m and m' the reduction of the measured zenith distance to the meridian for the south and the north star, respectively, then

$$\varphi = \tfrac{1}{2}(\delta + \delta') + \tfrac{1}{2}(z - z') + \frac{d}{4}\left\{(n + n') - (s + s')\right\}^{*} + \tfrac{1}{2}(r - r') + \tfrac{1}{2}(m - m')$$

and if M and M' be the micrometer readings of the south and the north star, increased micrometer readings corresponding to increased zenith distances, and R the value of one division, then

$$\tfrac{1}{2}(z - z') = (M - M')\frac{R}{2}$$

The details of the computation of the second and third terms in the above formula are sufficiently indicated in the computation shown above. The first, fourth, and fifth terms are explained more fully in the following sections (49–51).

The chronometer times of observation were recorded only for those stars which were observed off the meridian.

Tenths of divisions of the micrometer head are usually estimated. At this station the nearest half-division only was read. As a change of half a division in a micrometer reading changes the computed latitude by nearly 0″·17, greater accuracy would have been obtained by reading to tenths.

COMPUTATION OF APPARENT PLACES.

49. The data given in the office list of mean places in regard to a star, and from which its apparent place at the time of observation is to be computed, are the mean right ascension and north polar distance, α_m and p_m, at the beginning of some fictitious year, t_m; the annual variation† in right ascension, $\frac{d\alpha_m}{dt}$; the annual precession and proper

*The correction for inclination as here given is for a level of which the graduation is numbered in both directions from the middle. If the graduation is numbered continuously from one end to the other with numbers increasing *toward the objective* the level correction is

$$\frac{d}{4}\left\{(n' - n) + (s' - s)\right\}$$

(Compare this with the similar formula for a striding level on page 280.) If the numbering on the level graduation increases *toward the eyepiece* this formula becomes

$$\frac{d}{4}\left\{(n - n') + (s - s')\right\}$$

†Including both the proper motion and the annual precession.

motion, μ', in north polar distance, which together constitute $\frac{dp_m}{dt}$; the secular variation of the precession in north polar distance, usually given for 100 years, which, by moving the decimal point, becomes $\frac{d^2p_m}{dt^2}$. The date of maximum weight (t_{max}) of the north polar distance is also given, together with the probable error at that date and the probable error of the proper motion, $e_{\mu'}$.

The reduction to the apparent place at observation is made in two steps; first, the given mean place is reduced to the mean place at the beginning of the year of observation, and upon that as a basis the apparent place computation is then made.

Let the mean right ascension and north polar distance at the beginning of the year of observation be called α_o and p_o.

Then

$$\alpha_o = \alpha_m + (t_o - t_m)\frac{d\alpha_m}{dt}$$

$$p_o = p_m + (t_o - t_m)\frac{dp_m}{dt} + \tfrac{1}{2}(t_o - t_m)^2\frac{d^2p_m}{dt^2}$$

Also the square of the probable error of p_o is e_*^2 = (square of probable error at t_{max}) + $(t_o - t_{max})^2(e_{\mu'})^2$.

The office list of mean places shows that for the star B. A. C. 8370 $\alpha_m = \alpha_{90} =$ $0^h\ 00^m\ 03^s$, with an annual variation $= \frac{d\alpha_m}{dt} = +3^s{\cdot}07$. Also $p_m = p_{90} = 77^\circ\ 12'\ 57''{\cdot}71$. Precession$_{90} = -20''{\cdot}053$; proper motion $= \mu' = +0''{\cdot}009$, $\frac{d^2p_m}{dt^2} = +0{\cdot}00007$. The date of maximum weight = 1869·2, and the corresponding probable error $= \sqrt{0{\cdot}010}$. $e_{\mu'}$ = the probable error of the proper motion $= \sqrt{0{\cdot}000015}$.

Let it be supposed that this star was observed for latitude on November 6 and 10, 1899, at a station $3^h\ 14^m$ west of Washington.

$\alpha_o = \alpha_{99} = 0^h\ 00^m\ 03^s + (9)\ (3^s{\cdot}07) = 0^h\ 00^m\ 31^s$, with sufficient accuracy for use in connection with latitude observations.

$$\begin{aligned} p_o = p_{99} &= 77^\circ\ 12'\ 57''{\cdot}71 + (9)\ (-20''{\cdot}053 + 0''{\cdot}009) + \tfrac{1}{2}\ (9)^2\ (0''{\cdot}00007) \\ &= 77^\circ\ 12'\ 57''{\cdot}71 - 3'\ 00''{\cdot}40 + 0''{\cdot}00 = 77^\circ\ 09'\ 57''{\cdot}31 \\ \delta_o &= 90^\circ - p_o = 12^\circ\ 50'\ 02''{\cdot}69 \\ e_*^2 &= 0{\cdot}010 + (99 - 69)^2\ (0{\cdot}000015) = 0{\cdot}010 + 0{\cdot}014 = 0{\cdot}02 \end{aligned}$$

e_* may be considered to be the probable error of the declination at the time of observation.

The apparent declination, δ, at the instant of observation may now be computed by the formula given on page 280 of the American Ephemeris, namely,

$$\delta = \delta_o + \tau\mu' + g\cos(G + \alpha_o) + h\cos(H + \alpha_o)\sin\delta_o + i\cos\delta_o$$

in which g, G, h, H, and i are quantities called independent star-numbers which are functions of the time only and are given in the Ephemeris (pp. 285–292) for every Washington mean midnight during the year. τ is the elapsed decimal fraction of the fictitious year and is given in the Ephemeris with the independent star-numbers.

The actual arrangement of the computation on the forms now in use is shown below:

STATION *X*.

$\lambda = 3^h\ 14^m$ *W. of W.*

Star B. A. C. 8370

Year. 1899.	*h.* *m.* *s.*	$\delta_o = 12°\ 50'{\cdot}0$	$\mu' = -0''{\cdot}009$
$\alpha_o =$	0 00 31	$\sin \delta_o$	$\cos \delta_o$
	0° 08′	9·3466	9·9890
$\delta - \delta_o$	g cos (G + α_o)	h cos (H + α_o)	i cos δ_o
			$\tau\mu'$
Date:			
	3° 15′	43° 05′	
Nov. 6	9·9993	9·8635	
	1·3677	0·5025	0·7521
32″·14	+ 23·32	+ 3·18	5·65
			− 0·01
Date:			
	3 11	39 06	
Nov. 10	9·9993	9·8899	
	1·3733	0·5315	0·7197
32″·25	+ 23·62	+ 3·40	+ 5·24
			− 0·01

In this computation G, log$g$, H, log$h$, are used but are not shown on the form The $\delta - \delta_o$ as shown in the form just under the date, being applied as a correction to δ_o, gives the required apparent declination* at the time of observation.

The formula and computation have been put in a more convenient form, conducive to more rapid computation and adapted to the use of natural numbers and Crelle's multiplication tables, in an Appendix to the Cape Meridian Observations, 1890–91, entitled Star-Correction Tables, by W. H. Finlay, M. A.

The formula is transformed so that it reads

$$\delta = \delta_o + P'\ (1+x) + Q'\ (1+y) + I + \tau\mu'$$

in which I, P', and Q', are tabulated in the tables referred to.

$P' = g_o \cos\ (G + \alpha_o)$ and is tabulated with respect to the argument $G + \alpha_o$

$Q' = h_o \cos\ (H + \alpha_o) \sin \delta_o$ and is tabulated with respect to the arguments $(H + \alpha_o)$ and δ_o

$I = i \cos \delta_o$ and is tabulated with respect to the arguments i and δ_o

g_o and h_o are arbitrary constants, namely, 20″.0521 and 18″.500, respectively, from which g and h never differ greatly. The tables are so arranged that P', Q', and I for a given star and date are obtained from a single opening of the table, and all interpolations involve such small tabular differences that they may be made mentally.

$$x = \frac{g - g_o}{g_o} \text{ and } y = \frac{h - h_o}{h_o}$$

x and y are functions of the time only, and may usually, with sufficient accuracy, be considered constant for a night.

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*In the comparatively rare cases in which it is necessary to compute the apparent right ascension of a star, as, for example, that cited in §13, it may be done by use of the formula

$$\alpha = \alpha_o + f + \tau\mu + \tfrac{1}{15} g \sin\ (G + \alpha_o) \tan \delta_o + \tfrac{1}{15} h \sin\ (H + \alpha_o) \sec \delta_o$$

or by use of Finlay's Star-Correction Tables referred to below.

When computing many star places by this method it is convenient first to tabulate and compute those quantities which are functions of the time only, thus:

	Nov. 6.	Nov. 10.
	h. *m.*	*h.* *m.*
$G.$	0 12·5	0 12·2
$H.$	2 51·8	2 35·9
$i.$	+ 5·79	+ 5·37
$\log g$	1·3684	1·3740
$g.$	23·356	23·659
$g-g_0$	+ 3·304	+ 3·607
x	+ 0·165	+ 0·180
$\log h$	1·2924	1·2950
h	19·606	19·724
$h-h_0$	+ 1·106	+ 1·224
y	+ 0·060	+ 0·066
τ	0·85	0·86

If the period over which the observations extend on any evening is not more than four hours long, the quantities shown in the table may be taken from the Ephemeris for the middle of the period and assumed to be constant for the evening. The errors resulting from this assumption will be small and of both algebraic signs.

With this table, Crelle's multiplication tables, and Finlay's star-correction tables all open before him, the computer may rapidly make the computation for each star and date as indicated on the following form:

Star—B. A. C. 8370—Year 1899.

$\alpha_0 = 0^h\ 00^m{\cdot}5 \qquad \delta_0 = 12°{\cdot}8 \qquad \mu' = -0''{\cdot}009$

$G+\alpha_0$, $H+\alpha_0$	$0^h\ 13^m{\cdot}0$	$2^h\ 52^m{\cdot}3$	I	Date.
P' , Q'	+20·02	+2·99	$\tau\mu'$	$\delta-\delta_0$
$P'x$, $Q'x$	+ 3·30	+0·18	+5·64	Nov. 6
$P'(1+x)$, $Q'(1+x)$	+23·32	+3·17	−0·01	+32·12
$G+\alpha_0$, $H+\alpha_0$	$0^h\ 12^m{\cdot}7$	$2^h\ 36^m{\cdot}4$	I	Date.
P' , Q'	+20·02	+3·18	$\tau\mu'$	$\delta-\delta_0$
$P'x$ $Q'x$	+ 3·60	+0·21	+5·23	Nov. 10
$P'(1+x)$, $Q'(1+x)$	+23·62	+3·39	−0·01	+32·23

In the particular case here computed the observations were supposed to be made nearly at Washington mean midnight and no interpolations were necessary in taking out the star numbers (α of star + longitude of station $= 0^h\ 00^m + 3^h\ 14^m$ = Washington sidereal time of observation, whereas local sidereal time of mean midnight at Washington on November $6 = 3^h\ 05^m$, and on November $10 = 3^h\ 20^m$). When the time of observa-

tion differs much from Washington mean midnight two courses are usually open—when the computation of mean places is being made either by the ordinary methods or by the use of Finlay's tables. One may follow the suggestion of the preceding page and interpolate the independent star-numbers from the Ephemeris for the middle of the period of observation of each night (provided that period does not exceed about four hours) and then assume them constant for the night. Or one may compute the apparent places for Washington mean midnight and enter them on the latitude computation form as shown on page 349. After the "half sum" of the declinations have been computed and the rate of change of this "half sum" becomes evident the interpolation from Washington mean midnight to the actual time of observation may be made as shown by the small figures written just below the "half sum." This method is not available if each pair is observed but once.

When a given pair is observed on several nights in quick succession it is not necessary to compute the apparent places for every night of observation. The apparent places may be computed for certain nights at intervals of not more than three days and then the interpolation for intermediate dates made between the values of the sums of the two declinations of a pair on those nights, as shown in the computation on pages 348, 349.

Still another way of abridging the work of making apparent place computations has been devised by Assistant E. D. Preston, and is stated in full in Appendix No. 13 of the Report for 1888.

CORRECTION FOR DIFFERENTIAL REFRACTION.

50. The difference of refraction for any pair of stars is so small that we may neglect the variation in the state of the atmosphere at the time of the observation from that mean state supposed in the refraction tables, except for stations at high altitudes. 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 one-half difference of zenith distance as shown in the second column of the right-hand page of the computation at the side, and the argument zenith distance at the top.

If the station is so far above sea level that the mean barometric pressure at the station is less than 90 per cent of the mean barometric pressure at sea level (760^{mm}) it may be desirable to take this fact into account by diminishing the values given in the following table (computed for sea level) to correspond to the reduced pressure. That is, if the mean pressure is 10 per cent less than at sea level diminish each value taken from the table by 10 per cent of itself, if 20 per cent less diminish tabular values by 20 per cent, and so on. This need only be done roughly, since the tabular values are small.

Correction to latitude for differential refraction $= \frac{1}{2}(r - r')$.

[The sign of the correction is the same as that of the micrometer difference.]

½ diff. of zenith distance.	Zenith distance.							
	0°	10°	20°	25°	30°	35°	40°	45°
′	″	″	″	″	″	″	″	″
0	·00	·00	·00	·00	·00	·00	·00	·00
0·5	·01	·01	·01	·01	·01	·01	·01	·02
1	·02	·02	·02	·02	·02	·02	·03	·03
1·5	·03	·03	·03	·03	·03	·03	·04	·05
2	·03	·03	·04	·04	·04	·05	·06	·07
2·5	·04	·04	·05	·05	·05	·06	·07	·08
3	·05	·05	·06	·06	·07	·08	·09	·10
3·5	·06	·06	·07	·07	·08	·09	·10	·12
4	·07	·07	·08	·08	·09	·10	·11	·13
4·5	·08	·08	·09	·09	·10	·11	·13	·15
5	·08	·09	·10	·10	·11	·13	·14	·17
5·5	·09	·10	·10	·11	·12	·14	·16	·18
6	·10	·10	·11	·12	·13	·15	·17	·20
6.5	·11	·11	·12	·13	·14	·16	·19	·22
7	·12	·12	·13	·14	·15	·18	·20	·24
7·5	·13	·13	·14	·15	·16	·19	·21	·25
8	·13	·14	·15	·16	·18	·21	·23	·27
8·5	·14	·15	·16	·17	·19	·22	·24	·29
9	·15	·16	·17	·18	·20	·23	·26	·30
9·5	·16	·17	·18	·20	·21	·24	·27	·32
10	·17	·18	·19	·21	·23	·26	·29	·34
10·5	·18	·19	·20	·22	·24	·27	·30	·35
11	·18	·19	·21	·23	·25	·28	·31	·37
11·5	·19	·20	·22	·24	·26	·30	·33	·39
12	·20	·21	·23	·25	·27	·31	·34	·40
12·5	·21	·21	·24	·26	·28	·32	·36	·42

REDUCTION TO THE MERIDIAN.

51. If a star is observed off the meridian while the line of collimation of the telescope remains in the meridian, the measured zenith distance is in error on account of the curvature of the apparent path of the star. Let m be the correction to reduce the measured zenith distance to what it would have been if the star had been observed upon the meridian.

Then, save the algebraic sign,

$$m = \frac{\sin^2 \frac{1}{2}\tau}{\sin 1''} \sin 2\delta$$

in which τ is the hour-angle of the star. The signs are such that the *correction to the latitude* $(= \frac{m}{2})$ is always plus for the stars of positive declination and minus for stars of negative declination (below the equator), *regardless of whether the star is to the northward or to the southward of the zenith.* The following table gives the corrections to the latitude computed from the above formula. If both stars of a pair are observed off the meridian, two such corrections must be applied to the computed latitude.

Correction to latitude for reduction to meridian.

[Star off the meridian but instrument in the meridian. The sign of the correction to the latitude is positive except for stars south of the equator.]

δ	10s	15s	20s	22s	24s	26s	28s	30s	32s	34s	36s	38s	40s	42s	44s	46s	48s	50s	52s	54s	56s	58s	60s	δ
o																								o
1										·01	·01	·01	·01	·01	·01	·01	·01	·01	·01	·01	·01	·02	·02	89
2					·01	·01	·01	·01	·01	·01	·01	·01	·02	·02	·02	·02	·02	·02	·03	·03	·03	·03	·03	88
3			·01	·01	·01	·01	·01	·01	·01	·02	·02	·02	·02	·03	·03	·03	·03	·04	·04	·04	·04	·05	·05	87
4			·01	·01	·01	·01	·01	·02	·02	·02	·02	·03	·03	·03	·04	·04	·04	·05	·05	·06	·06	·06	·07	86
5		·01	·01	·01	·01	·02	·02	·02	·02	·03	·03	·03	·04	·04	·05	·05	·05	·06	·06	·07	·07	·08	·09	85
6		·01	·01	·01	·02	·02	·02	·03	·03	·03	·04	·04	·05	·05	·06	·06	·07	·07	·08	·08	·09	·10	·10	84
7		·01	·01	·02	·02	·02	·03	·03	·03	·04	·04	·05	·05	·06	·06	·07	·08	·08	·09	·10	·10	·11	·12	83
8		·01	·02	·02	·02	·03	·03	·03	·04	·04	·05	·05	·06	·07	·07	·08	·09	·09	·10	·11	·12	·13	·14	82
9		·01	·02	·02	·02	·03	·03	·04	·04	·05	·05	·06	·07	·07	·08	·09	·10	·11	·11	·12	·13	·14	·15	81
10		·01	·02	·02	·03	·03	·04	·04	·05	·05	·06	·07	·07	·08	·09	·10	·11	·12	·13	·14	·15	·16	·17	80
12	·01	·01	·02	·03	·03	·04	·05	·05	·06	·06	·07	·08	·09	·10	·11	·12	·13	·14	·15	·16	·17	·19	·20	78
14	·01	·01	·03	·03	·04	·04	·05	·06	·07	·07	·08	·09	·10	·11	·12	·14	·15	·16	·17	·19	·20	·22	·23	76
16	·01	·02	·03	·03	·04	·05	·06	·07	·07	·08	·09	·10	·12	·13	·14	·15	·17	·18	·20	·21	·23	·24	·26	74
18	·01	·02	·03	·04	·05	·05	·06	·07	·08	·09	·10	·12	·13	·14	·16	·17	·18	·20	·22	·23	·25	·27	·29	72
20	·01	·02	·04	·04	·05	·06	·07	·08	·09	·10	·11	·13	·14	·15	·17	·19	·20	·22	·24	·26	·28	·29	·32	70
22	·01	·02	·04	·05	·05	·06	·07	·09	·10	·11	·12	·14	·15	·17	·18	·20	·22	·24	·26	·28	·30	·32	·34	68
24	·01	·02	·04	·05	·06	·07	·08	·09	·10	·12	·13	·15	·16	·18	·20	·21	·23	·25	·27	·29	·32	·34	·36	66
26	·01	·02	·04	·05	·06	·07	·08	·10	·11	·12	·14	·15	·17	·19	·21	·23	·25	·27	·29	·31	·34	·36	·39	64
28	·01	·03	·05	·05	·07	·08	·09	·10	·12	·13	·15	·16	·18	·20	·22	·24	·26	·28	·31	·33	·35	·38	·41	62
30	·01	·03	·05	·06	·07	·08	·09	·11	·12	·14	·15	·17	·19	·21	·23	·25	·27	·30	·32	·34	·37	·40	·42	60
32	·01	·03	·05	·06	·07	·08	·10	·11	·13	·14	·16	·18	·20	·22	·24	·26	·28	·31	·33	·36	·39	·41	·44	58
34	·01	·03	·05	·06	·07	·09	·10	·11	·13	·15	·16	·18	·20	·22	·24	·27	·29	·32	·34	·37	·40	·42	·45	56
36	·01	·03	·05	·06	·07	·09	·10	·12	·13	·15	·17	·19	·21	·23	·25	·28	·30	·32	·35	·38	·41	·44	·47	54
38	·01	·03	·05	·06	·08	·09	·10	·12	·13	·15	·17	·19	·21	·23	·26	·28	·30	·33	·36	·39	·41	·44	·48	52
40	·01	·03	·05	·07	·08	·09	·11	·12	·14	·16	·17	·19	·21	·24	·26	·28	·31	·34	·36	·39	·42	·45	·48	50
45	·01	·03	·05	·07	·08	·09	·11	·12	·14	·16	·18	·20	·22	·24	·26	·29	·31	·34	·37	·40	·43	·46	·49	45

If, instead of keeping the instrument in the meridian and observing the star off the line of collimation when it must be observed out of the meridian, the instrument is turned in azimuth and the star observed upon the line of collimation, the formula for the correction to the latitude takes a different form. The correction is now due both to the curvature of the apparent path of the star and to the fact that when the instrument is turned in azimuth the micrometer line describes a small circle upon the celestial sphere of which the zenith is the pole. The correction to the observed zenith distance of a star thus observed off the meridian is

$$m = -\frac{2 \sin^2 \tfrac{1}{2}\tau}{\sin 1''} \frac{\cos \phi \cos \delta}{\sin \zeta},$$

in which ζ is the zenith distance of the star and is to be considered positive whether the star is north or south of the zenith. The resulting *correction to the computed latitude* will be plus for a star north of the zenith and minus for a south star. The formula does not apply to subpolars.

The following table will facilitate the computation of such corrections.

Values of 2 sin²½ τ.

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

Under normal conditions all stars should be observed in the meridian. In the exceptional cases in which tardy preparation, or faintness, or temporary blotting out of the star by clouds makes it necessary either to observe a star off the meridian or to miss the observation, it is advisable to use the first of the two methods of observing off the meridian indicated above rather than the second. The second method involves the necessity of unclamping the azimuth stop for all stars on one side of the zenith, and it always involves a disturbance of the instrument, and particularly of the level, immediately before the observation, while the instrument is being turned in azimuth. It is advisable to miss the observation altogether if it can not be secured by the first method before it leaves the safe limits of the eyepiece field.

COMBINATION OF RESULTS, EACH PAIR OBSERVED MORE THAN ONCE.

52. Separate values of the latitude being computed from each observation upon each pair, it remains to combine these in such a way as to obtain the most probable value of the latitude and to obtain certain probable errors.

Let p be the total number of pairs observed. Let the number of observations upon pair No. 1 be n_1, upon pair No. 2 n_2, and so on, and let the total number of observations at the station be $n = n_1 + n_2 + n_3 \ . \ . \ .$ Let Δ be a residual obtained by subtracting the result from a single observation on a certain pair from the mean result from all the observations upon that pair. Let e be the probable error of a single observation of the latitude, excluding the error arising from defective adopted declinations.

The various values of Δ depend upon and are a measure of the probable error of observation, but are independent of the errors of the adopted declinations. According to the principles of least squares,

$$e^2 = \frac{0.455\,\Sigma\,\Delta^2}{\text{No. obs.} - \text{No. Unknowns}} = \frac{0.455\,\Sigma\,\Delta^2}{n-p}.$$

Let φ_1 be the mean latitude from observations on pair No. 1, φ_2 from pair No. 2, and so on. Let v be the residual obtained by subtracting φ_1, $\varphi_2 \ . \ . \ .$ in turn from the indiscriminate mean for the station of φ_1, φ_2, $\varphi_3 \ . \ . \ .$ There will be p such residuals, and they are a measure of the probable error of the mean result from a pair, which will be called e_p, arising from both errors of observation and errors of declination.

$$e^2_p = \frac{0.455\,\Sigma\,v^2}{p-1}.$$

Let e_{p1}, $e_{p2} \ . \ . \ .$ be the probable errors, respectively, of φ_1, φ_2, $\varphi_3 \ . \ . \ .$ Let $e_{\frac{**}{2}}$ be the probable error of the mean of two declinations. Then

$$e^2_{p1} = e^2_{\frac{**}{2}} + \frac{e^2}{n_1}, \quad e^2_{p2} = e^2_{\frac{**}{2}} + \frac{e^2}{n_2} \ . \ . \ . \ .$$

These various values e^2_{p1}, e^2_{p2}, $\ . \ . \ .$ differ from each other because of the various values of n_1, n_2, $\ . \ . \ .$ even though $e^2_{\frac{**}{2}}$ and e^2 are assumed to be constant, and the value derived above for e^2_p is their mean value. Adding these various equations, p in number, and taking the mean, member by member, there is obtained

$$e^2_p = e^2_{\frac{**}{2}} + \frac{\frac{e^2}{n_1} + \frac{e^2}{n_2} + \frac{e^2}{n_3} \ . \ . \ .}{p} = e^2_{\frac{**}{2}} + \frac{e^2}{p}\left[\frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} \ . \ . \ .\right]$$

Placing

$$\frac{e^2}{p}\left[\frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} \ . \ . \ .\right] = \varepsilon^2$$

to abbreviate the notation, and solving for $e^2_{\frac{**}{2}}$ there is obtained

$$e^2_{\frac{**}{2}} = e^2_p - \varepsilon^2$$

Having determined the values of $e^2_{\frac{**}{2}}$ and e^2, the proper relative weights, w_1, w_2, inversely proportional to the squares of their probable errors, may now be assigned to φ_1, φ_2, φ_3, . . .

$$w_1=\frac{1}{e^2_{p1}} \qquad w_2=\frac{1}{e^2_{p2}} \quad . \quad . \quad .$$

or

$$w_1=\left(e^2_{\frac{**}{2}}+\frac{e^2}{n_1}\right)^{-1} \qquad w_2=\left(e^2_{\frac{**}{2}}+\frac{e^2}{n_2}\right)^{-1} \quad . \quad . \quad .$$

An exception to the above weights arises when two or more north stars are observed at one setting of the telescope in connection with the same south star, or *vice versa*, and the computation is made as if two or more independent pairs had been observed. The results of the component pairs in such a combination are not independent, since they involve in common the error of observation and the error of declination of the common star. The weight to be assigned to each component pair in a doublet is on this account but two-thirds of that given above,* and of each component pair in a triplet is one-half. If a combination observed at one setting of the telescope includes two or more stars on each side of the zenith, it may be broken up in the computation into two or more independent doublets or triplets, each of which may be treated as indicated above.

If a given star on one side of the zenith is observed in connection with a certain star on the other side of the zenith on a certain night (or nights), and on a certain *other* night (or nights) is observed in connection with some *other* star, the two results are independent in so far as the observations are concerned, but involve a common adopted declination for one of the two stars of each pair. The proper weight to be assigned depends in this case upon the relative magnitude of $e_{\frac{**}{2}}$ and e, but is for their ordinary values so nearly equal to the weight for an independent pair that it may, with little error, be assumed to be such without going to the trouble of evaluating it.

The weight to be assigned to a zenith star observed in both positions of the telescope is $\left(2e^2_{\frac{**}{2}}+\frac{e^2}{n}\right)^{-1}$ in which n is the number of nights' observations upon it.

The most probable value φ_0 for the latitude of the station is the weighted mean of the mean results from the various pairs, or

$$\varphi_0=\frac{w_1\varphi_1+w_2\varphi_2+w_3\varphi_3 \quad . \quad . \quad .}{w_1+w_2+w_3 \quad . \quad . \quad .}=\frac{\Sigma w\varphi}{\Sigma w}$$

*This may be made evident as follows: Let a_1 and a_2 be respectively the declination plus the measured zenith distance of a first and second south star, and a_3 the declination minus the measured zenith distance of a north star observed in combination with them. Let the probable errors of a_1, a_2, a_3 be e_1, e_2, e_3, respectively. Note that e_1, e_2, e_3 each include errors both of declination and observation. If the two component pairs are computed separately and the mean taken, the result is of the form $\left\{\frac{a_1+a_3}{2}+\frac{a_2+a_3}{2}\right\}\frac{1}{2}=\frac{a_1}{4}+\frac{a_2}{4}+\frac{a_3}{2}$ and its probable error squared is $\left(\frac{e_1}{4}\right)^2+\left(\frac{e_2}{4}\right)^2+\left(\frac{e_3}{2}\right)^2$. Assuming that $e_1=e_2=e_3$, this becomes $\frac{3}{8}e_1^2$, the square of the probable error of the mean result from the combination. By the same reasoning it may be shown that the square of the probable error of the result from a single independent pair is $\left(\frac{e_1}{2}\right)^2+\left(\frac{e_2}{2}\right)^2=\frac{1}{2}e_1^2$. The weights to be assigned to the combination and to an independent pair are then in the ratio of $(\frac{3}{8}e_1^2)^{-1}$ and $(\frac{1}{2}e_1^2)^{-1}$, or of $\frac{4}{3}$ to 1. If the weight for an independent pair is unity, the weight of *each component* of a doublet is therefore two-thirds.

The probable error of φ_0 is

$$e_\varphi = \sqrt{\frac{0\cdot455\,\Sigma w\,\Delta\varphi^2}{(p-1)\,\Sigma w}}$$

in which $\Delta\varphi$ is the residual obtained by subtracting φ_1, φ_2, φ_3 . . . in turn from φ_0.

A concrete illustration of the processes indicated by the above formulæ is furnished by the following reproduction of certain parts of the computation of the latitude of the New Naval Observatory from observations made in 1897 with a zenith telescope.

Pairs Star Nos.	φ 38° 55′+	Δ	Δ²
(2058)	09″·81	−·01	·00
4440	09 ·80	·00	·00
	09 ·80		
4513	08 ·07	−·07	·00
4550	07 ·92	+·08	·01
	08 ·00		
4513	08 ·12	·00	·00
4555	08 ·13	−·01	·00
	08 ·12		
4526	09 ·31	−·34	·12
4550	08 ·40	+·57	·32
	08 ·80	+·17	·03
	09 ·44	−·47	·22
	09 ·01	−·04	·00
	08 ·85	+·12	·01
	08 ·97		
4526	09 ·36	−·26	·07
4555	08 ·62	+·48	·23
	09 ·51	−·41	·17
	08 ·91	+·19	·04
	09 ·12	−·02	·00
	09 ·11	−·01	·00
	09 ·10		
.....	.....	.....	.....
.....	.....	.....	.....
.. ..	....	.....	.....
Sum			6·69

$$e = \sqrt{\frac{0\cdot455\,\Sigma\Delta^2}{n-p}} = \sqrt{\frac{(0\cdot455)\,(6\cdot69)}{100-21}} = \sqrt{0\cdot039} = \pm 0''\cdot20$$

Pair, Star Nos. B. A. C. (10 yr.)	[C. S.]	φ	v	v^2	n	w	$w\phi$	$\Delta\phi$	$\overline{\Delta\phi}^2$	$w\overline{\Delta\phi}^2$
(2058)	4440	38° 55′ 09″·80	−1·00	1·00	2	11	19·80	−0·99	0·98	10·78
4513	4550	08 ·00	+ ·80	·64	2	5	0·00	+ ·81	·66	3·30
4513	4555	08 ·12	+ ·68	·46	2	5	0·60	+ ·69	·48	2·40
4526	4550	08 ·97	− ·17	·03	6	4*	3·88	− ·16	·03	0·12
4526	4555	09 ·10	− ·30	·09	6	4*	4·40	− ·29	·08	0·32
4577	(2158)	08 ·83	− ·03	·00	6	8	6·64	− ·02	·00	0·00
(2158)	4646	08 ·72	+ ·08	·01	6	8	5·76	+ ·09	·01	0·08
(2195)	4688	09 ·11	− ·31	·10	5	12	13·32	− ·29	·08	0·96
4706	4726	08 ·25	+ ·55	·30	5	12	3·00	+ ·56	·31	3·72
4742	(2233)	08 ·50	+ ·30	·09	5	12	6·00	+ ·31	·10	1·20
(2254)	4847	08 ·93	− ·13	·02	5	12	11·16	− ·12	·01	0·12
4876	4937	08 ·92	− ·12	·01	5	12	11·04	− ·11	·01	0·12
4958	(2341)	08 ·83	− ·03	·00	5	12	9·96	− ·02	·00	0·00
(2350)	5026	09 ·15	− ·35	·12	5	9*	10·35	− ·34	·12	1·08
[1259]	(2365)	09 ·35	− ·55	·30	5	5*	6·75	− ·54	·29	1·45
5076	5084	08 ·64	+ ·16	·03	5	12	7·68	+ ·17	·03	0·36
5115	5153	08 ·87	− ·07	·00	5	12	10·44	− ·06	·00	0·00
5168	5178	08 ·62	+ ·18	·03	5	12	7·44	+ ·19	·04	0·48
5249	5293	08 ·50	+ ·30	·09	5	12	6·00	+ ·31	·10	1·20
5313	5322	09 ·22	− ·42	·18	5	12	14·64	− ·41	·17	2·04
5344	(2537)	08 ·44	+ ·36	·13	5	12	5·28	+ ·37	·14	1·68
Sums		16 ·87	+3·41 −3·48	3·63		203	164 ·14			31·41
Means		38° 55′ 08″·80					08″·81			

* For explanation of these four weights see page 363.

$$e_v^2=\frac{(0\cdot455)\,(3\cdot63)}{20}=0.083 \qquad \varepsilon^2=\frac{0\cdot039}{21}(4\cdot97)=0\cdot009$$

$$e^2_{\frac{**}{2}}=0\cdot083-0\cdot009=0\cdot074 \qquad e_\phi=\sqrt{\frac{(0\cdot455)\,(31\cdot41)}{(20)\,(203)}}=\pm0\cdot06.$$

Latitude = 38° 55′ 08″·81 ± 0″·06.

In computing the values of $w\varphi$, 38° 55′ 08″·00 was first dropped from each value of φ.

An independent determination of $e_{\frac{**}{2}}$ may be obtained from the computation of the mean declinations of the stars observed. Such declinations for use in the latitude computation depend in every case at the present time upon mean place computations made at this Office. To obtain the most probable value for the declination of a star, or rather for its north polar distance, as the computation is actually made in that form, the polar distance and other data is first abstracted from each of about fifty star catalogues. Each of these catalogues shows the results of observations at one observatory during a series of years. To the polar distance from each catalogue is applied a systematic correction for the known errors of that catalogue as developed by the researches* of Prof. Lewis Boss and others. To the corrected north polar distances are assigned relative weights derived from the researches just referred to. These corrected polar distances

* See report on the Survey of the Northern Boundary from the Lake of the Woods to the Rocky Mountains (Washington, 1878), pp. 409–619.

are then reduced to a common epoch—at present, 1890—and combined by the method of least squares, to obtain the most probable values of the north polar distance for 1890, and of the proper motion, whence the most probable value of the north polar distance on any date is derived. During this computation residuals are developed, from which the probable error of the north polar distance, e_*, at any date becomes known. The mean value for the stars observed at a station, of the probable error of the mean of two declinations is then

$$e_{\frac{**}{2}}=\sqrt{\frac{\Sigma e^2_*}{2N}},$$

in which N is the total number of stars observed.

For a particular pair

$$e^2_{\frac{**}{2}}=\frac{\Sigma e^2_*}{4},$$

in which only the two stars of the pair are included in the summation in the numerator. From this formula and from that given on page 358 (viz, $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$) two separate values for $e_{\frac{**}{2}}$ for each pair may be computed. Which should be used in the formula

$$w=\left(e^2_{\frac{**}{2}}+\frac{e^2}{n}\right)^{-1},$$

fixing the weight to be assigned to the mean result from a pair? There are two objections to the rigid use in all cases of the second value (from the latitude computation). That value is a mean for all the pairs of a list, and in using it the fact that some declinations have very much larger probable errors than others in the same list is ignored. Moreover, in practice, the formula $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$ is sometimes found to give a value for $e_{\frac{**}{2}}$ which is so small as to be evidently erroneous, and sometimes $e^2_{\frac{**}{2}}$ is even *negative*, which is an absurdity. On the other hand, whenever the value $e^2_{\frac{**}{2}}=\frac{\Sigma e^2_*}{2N}$ is smaller than $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$, and that is usually the case, it indicates that there is in the observations some error peculiar to each star, which combines with the declination error, and so apparently increases it. If such errors exist, the weights should be correspondingly reduced, and therefore the values of $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$ should be used in the weighting.

The following method of weighting, therefore, seems to be the best for use in the office computation. It is not ordinarily available in the field, because the value of e_* is not usually known in the field for all stars. *In the weight formula* (see page 359), $w=\left(e^2_{\frac{**}{2}}+\frac{e^2}{n}\right)^{-1}$, *use for each pair the larger of the two available values of* $e^2_{\frac{**}{2}}$, namely, $e^2_{\frac{**}{2}}=\frac{\Sigma e^2_*}{4}$ and $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$. By so doing all the disadvantages of each of the two methods discussed in the preceding paragraph are avoided. To find quickly which of the values of $e^2_{\frac{**}{2}}$ from the mean place computation are greater than $e^2_{\frac{**}{2}}=e^2_p-\varepsilon^2$ one may first note

on the list of mean places for what stars e^2_* exceeds 2 $(e^2_p - \varepsilon^2)$. Only pairs involving such stars need be examined further. To illustrate, of the pairs involved in the latitude computation shown on page 361, there were only four for which the mean place computation gave values of $e^2_{\frac{**}{2}}$ exceeding 0·074. The stars involved in these four pairs were 4526, 4550, 4555, (2350), 5026, [1259], 2365, and the corresponding values of e^2_* were 0·37, 0·08, 0·10, 0·18, 0·24, 0·08, 0·73. The weights assigned to these four pairs therefore depend upon $e^2_{\frac{**}{2}} = \frac{\Sigma e^2_*}{4}$ in each case.

COMBINATION OF RESULTS WHEN EACH PAIR IS OBSERVED BUT ONCE.

53. Whenever the plan recommended in § 56 of observing each pair but once at a station is carried out, the method of combining results and computing probable errors outlined in the preceding pages fails, and for it must be substituted the following procedure, for which little additional explanation is needed:

$$e^2_p = \frac{0{\cdot}455\,\Sigma v^2}{p-1},$$

in which e_p is the probable error of the result from a pair, including both the error of observation and the declination errors, and v is the residual obtained by subtracting the latitude from a pair from the indiscriminate mean of all the pairs.

In the field computation this indiscriminate mean may be considered to be the final value of the latitude. Its probable error is

$$e_\phi = \sqrt{\frac{0{\cdot}455\,\Sigma v^2}{p\,(p-1)}}$$

No value of the probable error of observation not involving the declination error is available from such a field computation. But the computed values of e_p and e_ϕ give sufficiently good indications of the accuracy of the observations to decide whether the instrument is in good condition and whether more observations are needed, and that is all that should be required of a field computation.

The office computation, in which e_* is known for each star from the mean place computation, may be carried forward as follows:

The probable error of a single observation is given by the formula $e^2 = e^2_p - \frac{\Sigma e^2_*}{2N}$ in which N is the total number of stars observed.

The weight to be assigned to each pair is

$$w = \left(e^2_{\frac{**}{2}} + e^2\right)^{-1}$$

in which for each pair $e^2_{\frac{**}{2}} = \frac{\Sigma e^2_*}{4}$, the summation covering the two stars of that pair only.

DETERMINATION OF LEVEL AND MICROMETER VALUES.

54. For methods of determining the level value see § 25.

The method most frequently used during the last twenty years for determining the micrometer value is to observe the time required for a close circumpolar star, near elon-

gation, to pass over the angular interval measured by the screw. Near elongation the apparent motion of the star is nearly vertical and nearly uniform. That one of the four close circumpolars given in the Ephemeris, namely, α, δ, and λ Ursæ Minoris and 51 Cephei, may be selected which reaches elongation at the most convenient hour. In selecting the star it may be assumed with sufficient accuracy that the elongations occur when the hour-angle is six hours, on either side of the meridian. In planning the observations and in making the computation it is necessary to know the time of elongation more accurately, and it may be computed from the formula

$$\cos t_E = \cot\delta \tan\varphi$$

Chronometer time of elongation $= \alpha - \Delta T \pm t_E$, the plus sign being used for western elongation and the minus for eastern elongation.

t_e is the hour-angle at elongation reckoned eastward or westward from upper culmination, and ΔT is the chronometer correction.

If desired ζ_E, the zenith distance of the star at elongation may be computed from the formula

$$\cos \zeta_E = \operatorname{cosec}\delta \sin\varphi$$

It is advisable to have the middle of the series of observations about elongation. The observer may obtain an approximate estimate of the rate at which the star moves along the micrometer by a rough observation or from previous record, and time the beginning of his observations accordingly.

To begin observations the star is brought into the field of the telescope and to the proper position, the telescope is clamped both in zenith distance and azimuth, the micrometer is made to read an integral number of turns, and the bubble is brought approximately to the middle of the level tube. The chronometer time of transit of the star across the thread is observed and the level read. The micrometer thread is then moved one whole turn in the direction of the apparent motion of the star, the time of transit again observed and the level read, and the process repeated until a sufficiently large portion of the middle of the screw has been covered by the observations to correspond with what is actually used in the latitude observations. If desired, an observation may be made at every half turn, or even at every quarter turn, by allowing an assistant to read the level. It is well to note the temperature.

The form of record and computation is shown below, the first four columns being the record, and the remainder the computation, of the value of one turn of micrometer from observations made at the New Naval Observatory June 18, 1897.

$\varphi = 38^\circ\ 55'\ 08''.8$.

For the star B. A. C. 8213 at the time of observation $\alpha = 23^h\ 27^m\ 45^s.6$ and $\delta = 86^\circ\ 44'\ 13''.4$. The chronometer correction at the time of the observations was known to be $+2^s.3$. Whence the chronometer time of eastern elongation was computed to be $17^h\ 38^m\ 16^s.5$ and the zenith distance $51^\circ\ 00'.5$.

Computation of value of micrometer.

Station: New Naval Observatory, Washington, D. C. Observer: O. B. F. Star: B. A. C. 8213 E. E.
Date: June 18, 1897. Instrument: Zenith telescope, No. 4.

Micrometer reading.	Chronometer time of observation.	Level. N.	Level. S.	Time from elongation.	Reduction to mean state of level.	Corrections. Time.	Corrections. Level.	Reduced time.	Time at 20 turns.	Δ	Δ′
t.	*h. m. s.*	*d.*	*d.*	*m.*	*d.*	*s.*	*s.*	*h. m. s.*	*h. m. s.*	*s.*	*s.*
35	17 15 08·5	13·1 / 68·4	39·9 / 101·9	23·1	−0·10	+2·3	−0·1	17 15 10·7	17 28 10·7	+4·7	−0·3
34	16 02·0			22·2		+2·1	−0·1	16 04·0	12·0	+3·4	−1·2
33	16 53·5			21·4		+1·9	−0·1	16 55·3	11·3	+4·1	−0·2
32	17 45·0	13·2 / 68·6	40·0 / 102·0	20·5	−0·15	+1·6	+0·1	17 46·7	10·7	+4·7	+0·7
31	18 37·5			19·6		+1·4	+0·1	18 39·0	11·0	+4·4	+0·7
30	19 30.0			18·8		+1·3	+0·1	19 31·4	11·4	+4·0	+0·7
29	20 22·5			17·9		+1·1	+0.1	20 23·7	11·7	+3·7	+0·7
28	21 16·0			17·0		+0·9	+0·1	21 17·0	13·0	+2·4	−0·3
27	22 07·5			16·1		+0·8	+0·1	22 08·4	12·4	+3·0	+0·7
26	23 00·0			15·2		+0·7	+0·1	23 00·8	12·8	+2·6	+0·6
25	23 53·0			14·4		+0·6	+0·1	23 53·7	13·7	+1·7	0·0
24	24 45·5			13·5		+0·5	+0·1	24 46·1	14·1	+1·3	0·0
23	25 37·5			12·6		+0·4	+0·1	25 38·0	14·0	+1·4	+0·4
22	26 30·5			11·8		+0·3	+0·1	26 30·9	14·9	+0·5	−0·2
21	27 23·0	13·2 / 68·3	40·0 / 101·8	10·9	−0·10	+0·2	−0·1	27 23·1	15·1	+0·3	0·0
20	28 16·0			10·0		+0·2	−0·1	28 16·1	16·1	−0·7	−0·7
19	29 08·0	13·2 / 68·5	40·0 / 102·1	9·1	+0·15	+0·1	+0·1	29 08·2	16·2	−0·8	−0·5
18	30 00·5			8·2		+0·1	+0·1	30 00·7	16·7	−1·3	−0·6
17	30 53·0			7·4		+0·1	+0·1	30 53·2	17·2	−1·8	−0·8
16	31 44·5			6·5		+0·1	+0·1	31 44·7	16·7	−1·3	0·0
15	32 37·0			5·7		0·0	+0·1	32 37·1	17·1	−1·7	0·0
14	33 29·5			4·8		0·0	+0·1	33 29·6	17·6	−2·2	−0·2
13	34 22·0	13·2 / 68·3	40·1 / 101·9	3·9	0·00	0·0	0·0	34 22·0	18·0	−2·6	−0·3
12	35 14·0			3·0		0·0	0·0	35 14·0	18·0	−2·6	+0·1
11	36 06·5			2·2		0·0	0·0	36 06·5	18·5	−3·1	−0·1
10	36 58·5			1·3		0·0	0·0	36 58·5	18·5	−3·1	+0·2
9	37 50·5			0·4		0·0	0·0	37 50·5	18·5	−3·1	+0·6
8	38 43·5			−0·4		0·0	0·0	38 43·5	19·5	−4·1	−0·1
7	39 35·5			−1·3		0·0	0·0	39 35·5	19·5	−4·1	+0·2
6	40 28·0			−2·2		0·0	0·0	40 28·0	20·0	−4·6	0·0
5	41 19·5			−3·0		0·0	0·0	41 19·5	19·5	−4·1	+0·9
								Mean	17 28 15·4		

Assumed value of $M = 52^s$.

2 480 m	=	+820·3
m	=	+ 0·3308
$M+m$	=	52^s·3308
log $(M+m)$	=	1·7187573
log 15	=	1·1760913
log cosδ	=	8·7552522
		1·6501008
		44″·679
Corr. for refraction		− 0 ·030
One turn		44″·649

For explanation of notation, see page 367.

Because of the curvature of the apparent path of the star its rate of change of zenith distance is not constant, even near elongation. The rate of change *at elongation* may readily be computed. It is at that instant in seconds of arc 15 cosδ per second of sidereal time. The table of curvature corrections given below enables one to correct the observed times to what they would have been if in the place of the actual star there were substituted an ideal star whose motion was vertical at a constant rate 15 cos δ and which coincided with the actual star at the instant of elongation.

Correction for curvature of apparent path of star, in computation of micrometer value.

[The correction tabulated is $\frac{1}{6}(15 \sin 1'')^2 \tau^3 - \frac{1}{120}(15 \sin 1'')^4 \tau^5$ in which τ is the time from elongation. Apply the corrections given in the table to the observed chronometer times, adding them before either elongation, and subtracting them after either elongation.]

τ	Corr.	τ	Corr.	τ	Corr.	τ	Corr.	τ	Corr.	τ	Corr.
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

In the computation the fifth column shows the values of τ, and the seventh column the resulting curvature corrections.

When the reading of the level changes, it indicates, upon the usual assumption that the relation between the level vial and the telescope remains constant, that the inclination of the telescope has changed. The effect of the movement of the telescope may be eliminated in the computation by applying to each observed time the correction, in seconds of time,

$$\pm \left\{ (n - s) - (n_0 - s_0) \right\} \frac{d}{30 \cos\delta}$$

to reduce it to what it would have been if the readings of the north and south end of the bubble had been n_0 and s_0, respectively.

If, as in the present case, the level graduation is numbered continuously from one end to the other with the numbers increasing toward the eye end, instead of being numbered in both directions from the middle, the required correction becomes

$$\pm \left\{ (n_0 + s_0) - (n + s) \right\} \frac{d}{30 \cos\delta}.$$

In each of these formulæ the plus sign is to be used for western elongation and the minus sign for eastern elongation. It is convenient to take for the assumed n_0 and s_0 the actual readings at some one moment during the set of observations.

Zenith telescope No. 4 had two latitude levels, and the correction was computed by

taking the mean of the two and using the mean value of $d(=1''\cdot482)$. The sixth column shows the mean values of $(n_o+s_o)-(n+s)$ and the eighth column the resulting corrections, the factor $\frac{d}{30\cos\delta}$ being 0·87.

Let M be an assumed approximate value of one turn in time and let m be a required correction to M. Let R be an approximate value of the chronometer time of transit of the star across the micrometer line set at 20 turns (the middle of the screw) and r a required correction to R. Then, upon the assumption that the screw has a uniform value throughout the part observed upon, and that the star moves in the direction of *increasing* readings (western elongation), for each observed time an observation equation may be written of the form

$$t+(20-T)(M+m)-(R+r)=0$$

in which t is the observed time of transit across the line set at the reading T, after correction for curvature and level. After transposition this may be written

$$(20-T)m-r=\Delta$$

in which

$$\Delta=R-[t+(20-T)M]$$

whence the normal equations become

$$\begin{aligned}\Sigma(20-T)^2m-\Sigma(20-T)r&=\Sigma(20-T)\Delta\\ -\Sigma(20-T)\,m+nr\qquad\quad&=-\Sigma\Delta.\end{aligned}$$

If the turns observed upon are symmetrical about 20, $\Sigma(20-T)$ becomes zero. If, moreover, as in the numerical case here shown, R is purposely taken equal to the mean value of $t+(20-T)M$, $\Sigma\Delta$ is zero and r derived from the second normal equation is necessarily zero. Also, the first normal equation reduces to the working form

$$\Sigma(20-T)^2m=\Sigma(20-T)\Delta.$$

If the star is observed at eastern elongation it moves in the direction indicated by *decreasing* micrometer readings and throughout the preceding formulæ $T-20$ must be substituted for $20-T$.

In the computation form printed above, the values of $t+(T-20)M$ are shown in the column headed "Time at 20 turns," M being assumed$=52^s$. R was assumed$=17^h\ 28^m\ 15^s\cdot4$, the mean for this column, and the $\Delta's$ written accordingly.

The equation $\Sigma(T-20)^2m=\Sigma(T-20)\Delta$ reduces numerically to $2480m*=820\cdot3$.

Δ' is the residual obtained by substituting the derived value m in each observation equation, or $\Delta'=\Delta-(T-20)m$.

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*In this computation it becomes necessary to find the sum of the series $1^2+2^2+3^2+4^2\ .\ .\ .\ .\ +15^2$. It is convenient for this purpose to use the formula $1^2+2^2+3^2+4^2\ .\ .\ .\ +x^2=\frac{x^3}{3}+\frac{x^2}{2}+\frac{x}{6}$. Occasionally in least square computations it becomes necessary to compute the sum of a similar series of fourth powers. One may then use the formula $1^4+2^4+3^4+4^4\ .\ .\ +x^4=\frac{x^5}{5}+\frac{x^4}{2}+\frac{x^3}{3}-\frac{x}{30}$. To obtain the sum of the series $(\frac{1}{4})^4+(\frac{1}{2})^4+(\frac{3}{4})^4+(1)^4+(1\frac{1}{4})^4\ .\ .\ .\ +x^4$, apply the formula to the series $1^4+2^4+3^4+4^4\ .\ .\ +(4x)^4$ and divide by $256=4^4$. See *Sammlung von Formeln der reinen und angewandten Mathematik von Dr. W. Láska, p. 88 (Braunschweig, 1888–1894).*

The remainder of the computation needs no explanation except that the correction for refraction to be applied to the value of one turn is the change of refraction for a change of zenith distance equal to one turn, or in the most convenient form for use it is the value of one turn in minutes of arc times the difference of refraction for 1′ at the altitude at which the star was observed (approximately $=\varphi$). The difference of refraction for 1′ may be obtained from any table of mean refractions with sufficient accuracy. The correction for refraction is always negative, since the change of refraction is always such as to make a star appear to move slower than it really does.

It will sometimes be necessary to apply a correction for rate. This correction, to be applied to the computed value of one turn, is in seconds of arc

$$\frac{\text{(rate of chronometer in seconds per day) (value of one turn in seconds of arc)}}{86\ 400}$$

The correction is negative if the chronometer runs too fast.

The micrometer value is sometimes determined by turning the micrometer box 90° and observing upon a close circumpolar near culmination. There are two serious objections to this procedure. The focal adjustment is liable to be disturbed more or less when the micrometer box is turned, and a corresponding constant error introduced into the result. In observing at elongation the telescope is depended upon to be stable in zenith distance, the direction in which it is designed to be stable, and the level readings furnish a means of correcting in large part for small movements in that direction. But when the observations are made at culmination the instrument is depended upon to remain fixed in azimuth, the direction in which because of its peculiar design, it is weakest, and there is no check upon changes in azimuth corresponding to the level readings. Hence it is not advisable to observe for micrometer value at culmination. The only modifications in the computations are that there are no corrections for level or refraction, and that in computing the curvature correction τ is now the hour-angle. The curvature correction is additive before either culmination, and subtractive after it.

It is decidedly questionable whether it is advisable to continue the present practice of determining the mean value of the micrometer screw by observations upon close circumpolars either at culmination or elongation. Such observations consume a great deal of time both in observation and in the subsequent computation, and experience shows that they are subject to unexpectedly large and unexplained errors. For example, during the observations for variation of latitude at Waikiki, Hawaiian Islands, in 1891–92, the micrometer value was thus determined twelve times. The results show a range of about 0″·13 or one three-hundred-and-thirtieth of the mean value, corresponding to a range of about one-sixth inch in the distance between the objective and the micrometer line, though the draw tube was kept clamped continuously, and the range of temperature during the entire year was only about 11° C. (Coast and Geodetic Survey Report 1892, Part II, p. 61.) Similarly, sixteen determinations of the value of a micrometer used at fifteen stations on the Mexican Boundary Survey of 1892–93 showed a range of 0″·33 or one one-hundred-and-ninetieth of the mean value.* In this case the draw tube was unclamped and the telescope refocused at the beginning of the observations at each station. The observed value was apparently not a function of the temperature. The San

*Report of the International Boundary Commission, United States and Mexico, 1891–1896 (Washington, 1898), p. 103.

Francisco series of observations for variation of latitude also show a similar large range in the observed micrometer value (viz: 0''·17). (Coast and Geodetic Survey Report, 1893, Part II, p. 447.) In general, whenever the micrometer value is determined repeatedly by the circumpolar method so large a range of results is developed as to force one to suspect that large constant errors are inherent in this method of observation. It can hardly be urged that the differences between the results represent actual changes in the micrometer value, for such differences are developed even when successive determinations are made during a single evening. Moreover, whenever the mean micrometer value is determined from the latitude observations themselves it is frequently found to differ radically from that derived from circumpolar observations on the same nights. So marked and so frequent has the latter form of disagreement been, that many of the office latitude computations have actually been made during the last few years by rejecting the micrometer value from circumpolar observations, when there is a marked difference between it and the value computed from the latitude observations as indicated below, and using the latter value in the latitude computation.

As to the accuracy of the micrometer value determined from the latitude observations, it may be noted that if it be assumed that the probable error of a single observation of latitude is ± 0''·40, of the mean of two declinations is ± 0''·16,* and of the latitude as derived from independent pairs is ± 0''·10, the probable error of the micrometer value, as determined from a *single observation* upon a pair having a difference of zenith distance of ten turns would be

$$\frac{1}{10}\sqrt{(0''\cdot40)^2+4\,(0''\cdot16)^2+(0''\cdot10)^2}=\pm\,0''\cdot05.$$

There can be little doubt, therefore, that the mean micrometer value determined from all the latitude observations at a station is more accurate than that determined from even three or four sets of circumpolar observations each requiring an hour or more of time.

It has been urged that to determine an instrumental constant from the observations in the computation of which it is to be used is a questionable procedure; that it "smooths out" the results, but probably does not give real accuracy. The force of this objection disappears when one contrasts the proposed practice of deriving a *single* instrumental constant from *between fifteen and one hundred observations* on fifteen or more pairs with the usual and unquestioned practice in transit time computations of deriving *three* instrumental constants (two azimuth and one collimation constant) from only *ten observations* on ten stars.

In view of the facts and principles indicated above, the writer recommends the following plan of operations: Let the micrometer value be determined once only during each working season by a single set of circumpolar observations, during which the micrometer is to be observed upon at each quarter-turn. The purpose of this set is to determine the irregularities and periodic errors of the micrometer screw. If these are found to be so large, which will seldom be the case, that they introduce an accidental probable error of more than ± 0''·05 into each deduced latitude, or may under plausible conditions introduce a constant error of 0''·01 into the mean latitude for a station, the

* See page 371.

circumpolar observations are to be continued for the season and the computations made accordingly and a *new* screw procured before the beginning of the next season. If the irregularities and periodic errors are found to be within these limits, as will usually be the case, no further circumpolar observations for micrometer value are to be made during the season, the field computation is to be made with an approximate value of micrometer, derived from previous observations with that instrument or derived roughly from the latitude observations, and the office computation is to be made as indicated below. Much time, both in the field and office operations, will be thus saved without any sacrifice of accuracy.

It should be noted that the form of the computation of circumpolar micrometer observations given on page 365 is especially adapted to the detection of irregularities and periodic errors, as they will at once become evident from an inspection of the values of Δ'. One common form of irregularity in modern screws is a continuous increase in the value from one end to the other, in which case Δ' tends to have the same sign at the two ends of the set and the opposite sign in the middle. This form of computation differs from that given in Appendix No. 14, 1880, and used in the field computations. It has been in use in the Office for some time. It is slightly preferable to the other form from a theoretical point of view, but its chief recommendation is that it exhibits clearly the periodic errors and the irregularities.

To derive the mean micrometer value from the latitude observations let M be the mean difference in turns of the micrometer readings on the two stars of a pair, taken with the same sign as in the latitude computation, let m be the required correction to the assumed value of *one-half* turn with which the computation of the latitude was made, and let c be a correction to the mean latitude φ_0. Let $\Delta\varphi$ have the same meaning as before, viz, $\varphi_0-\varphi_1$, $\varphi_0-\varphi_2$, etc. (See computation on page 361.) For each pair an observation equation of the form $c-Mm=-\Delta\varphi$ may be written. The resulting normal equations, from which m may be derived, are

$$nc-\Sigma Mm=-\Sigma\Delta\varphi$$
$$-\Sigma Mc+\Sigma M^2m=\Sigma M\Delta\varphi$$

The computation will be sufficiently accurate if M is carried to tenths of turns only, and as here indicated without assigning weights to the separate pairs.

To the preliminary values of φ_1, φ_2 . . . . , the mean results from the separate pairs, may now be applied the corrections Mm and the latitude computation completed as before.*

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*It has been suggested that when *both* the micrometer value and the mean latitude, two unknowns, are thus derived from the latitude observations

$$e_\phi=\sqrt{\frac{0''.455\ \Sigma w\Delta\varphi^2}{(p-2)\Sigma w}}$$

instead of the value given on page 360. This would be true if both the micrometer value and the mean latitude were derived from the *same* least square process. But in this case they are derived from two separate processes, one following the other, and it can be shown that in this case the number to be subtracted from p in the denominator of the expression for e_ϕ is *between* 1 and 2. The formula is therefore sufficiently exact as it stands on page 360.

DISCUSSION OF ERRORS.

55. In discussing the errors of zenith telescope observations it is desirable to consider separately, as in § 26, the external errors, observer's errors, and instrumental errors.

The principal *external errors* are those arising from errors in the adopted declinations, and those due to abnormal refraction.

The adopted declinations used in the computation necessarily have probable errors which are sufficiently large to furnish much, often a half, of the error of the computed latitude. This arises from the fact that a good zenith telescope gives results but little, if any, inferior in accuracy to those obtained with the large instruments of the fixed observatories which were used in determining the declinations.

Of the stars observed at thirty-six latitude stations, nearly on the thirty-ninth parallel, between 1880 and 1898 the average value of $e_{\frac{m}{2}}$ derived from the mean place computations was $\pm 0''.16$ and the extreme values were $\pm 0''.12$ and $\pm 0''.23$. These figures furnish a good estimate of the accidental errors to be expected from the adopted declinations. To estimate the constant errors to be expected from this scource is a rather difficult matter. The principal constant error in declination to be feared is that arising from errors in the adopted systematic corrections applied to the separate catalogues of observed places referred to on page 361. The three principal researches in regard to these systematic corrections have been made by Profs. Lewis Boss, A. Auwers, and Simon Newcomb. Judging by the differences between the results of these three researches, the constant error in the mean declinations as computed at the Coast and Geodetic Survey Office and based upon Professor Boss's researches, may possibly be as great as $0''.3$, but is probably much smaller than that.

In regard to errors arising from abnormal refraction it should be noted that only the *difference* of refraction of the two stars of a pair enters the computed result. The errors in the computed differential refractions are probably very small when all zenith distances are less than 45° and when care is taken to avoid local refraction arising from the temperature inside the observatory being much above that outside, or from masses of heated air from chimneys or other powerful sources of heat near the observatory. If there were a sensible tendency, as has been claimed, for all stars to be seen too far north (or south) on certain nights, because of the existence of a barometric gradient for example, it should be detected by a comparison of the mean results on different nights at the same station. The conclusion from many such comparisons made by the writer is that the variation in the mean results from zenith telescope measurements from night to night is about what should be expected from the known accidental errors of observation and declination; or, in other words, that if there are errors peculiar to each night they are exceedingly small.*

The *observer's errors* are those made in bisecting the star and in reading the level and micrometer. Errors due to unnecessary longitudinal pressure on the head of the micrometer may also be placed in this class.

Indirect evidence indicates that the error of bisection of the star is one of the largest errors concerned in the measurement. The bisections should be made with correspond-

*See Report of the Boundary Commission upon the Survey and Re-marking of the Boundary between the United States and Mexico West of the Rio Grande, 1891 to 1896, (Washington, 1898), pages 107–109, for one such comparison.

ing care. The probable error of a bisection must be but a fraction of the apparent width of the micrometer line if the observations are to be ranked as first-class. It is possible to substitute three or more bisections for the one careful bisection recommended in the directions for observing (page 346), but it is not advisable to do so. On account of the comparative haste with which such bisections must be made, it is doubtful whether the mean of them is much, if any, more accurate than a single careful and deliberate bisection, while the continual handling of the micrometer head, which is necessary when several bisections are made, tends to produce errors.

With care in estimating tenths of divisions on the micrometer head and on the level graduation, each of these readings may be made with a probable error of $\pm 0'' \cdot 1$ division. If one turn of the micrometer screw represents about 60″ and one division of the level about 1″, such reading would produce probable errors of $\pm 0'' \cdot 04$ and $\pm 0'' \cdot 05$, respectively, in the latitude from a single observation. These errors are small, but not negligible, for the whole probable error of a single observation arising from all sources is often less than $\pm 0'' \cdot 30$ and sometimes less than $\pm 0'' \cdot 20$.

While reading the level the observer should keep in mind that a very slight unequal or unnecessary heating of the level tube may cause errors several times as large as the mere reading error indicated above, and that if the bubble is found to be moving, a reading taken after allowing it to come to rest deliberately may not be pertinent to the purpose for which it was taken. The level readings are intended to fix the position of the telescope at the instant when the star was bisected.

It requires great care in turning the micrometer head to insure that so little longitudinal force is applied to the screw that the bisection of the star is not affected by it. Such a displacement of 1–4 000 of an inch in the position of the micrometer line relative to the objective produces an apparent change of more than 1″ in the position of a star if the focal length of the telescope is less than 50 inches. The whole instrument being elastic, the force required to produce such a displacement is small. An experienced observer has found that in a series of his latitude observations, during which the level was read both before and after the bisections of the star, the former readings continually differed from the latter, from $0'' \cdot 1$ to $0'' \cdot 9$, nearly always in one direction.*

Among the *instrumental errors* may be mentioned those due (1) to an inclination of the micrometer line to the horizon; (2) to error in the adopted value of one division of the level; (3) to inclination of the horizontal axis; (4) to erroneous placing of the azimuth stops; (5) to error of collimation; (6) to the instability of the relative positions of different parts of the instrument; (7) to the irregularity of the micrometer screw; (8) to the error of the adopted mean value of one turn of the micrometer screw.

The first of these sources of error must be carefully guarded against, as indicated in § 44, as it tends to introduce a *constant* error into the computed latitudes. The observer, even if he attempts to make the bisection in the middle of the field (horizontally), is apt to make it on one side or the other, according to a fixed habit. If the line is inclined, his micrometer readings are too great on all north stars and too small on all south stars, or *vice versa*.

The error arising from an erroneous level value is smaller the smaller are the level corrections and the more nearly the plus and minus corrections balance each other. If the observer makes it his rule whenever the record shows a level correction of more

* Coast and Geodetic Survey Report, 1892, Part 2, p. 58.

than one division to correct the inclination of the vertical axis between pairs, this error will be negligible. Little time is needed for this if the observer avoids all reversals by simply manipulating a foot-screw so as to move the bubble as much to the northward (or the southward) as the record indicates the required correction to be.

The errors from the third, fourth, and fifth sources may easily be kept within such limits as to be negligible. An inclination of one minute in the horizontal axis, or an error of that amount in either collimation or azimuth, produces only about 0''.01 error in the latitude. All three of these adjustments may easily be kept well within this limit.

The errors arising from instability may be small upon an average, but they undoubtedly become large at times and produce some of the largest residuals. One of the most important functions of the observer is to guard against them by protecting the instrument from sudden temperature changes and from shocks and careless or unnecessary handling, and by avoiding long waits between the two stars of a pair. The closer the agreement in temperature between the observing room and the outer air the more secure is the instrument against sudden and unequal changes of temperature.

Most micrometer screws now used are so regular that the uneliminated error in the mean result for a station arising from the seventh source named above is usually negligible. Irregularities of sufficient size to produce a sensible error in the mean result may be readily detected by inspection of the computation of micrometer value if that computation is made as indicated on pages 365–367. The two forms of irregularity most frequently detected in modern screws on our latitude instruments are those with a period of one turn and those of such a form that the value of one turn increases continuously from one end of the screw to the other. The periodic irregularity operates mainly to increase the computed probable error of observation and must be quite large to have any sensible effect upon the computed mean value of the latitude. If the value of the screw increases continuously and uniformly from one end to the other, the computed results will be free from any error arising from this source, provided all settings are made so that the mean of the two micrometer readings upon a pair falls at the middle of the screw. If this condition is fulfilled within one turn for each pair, the error in the mean result will usually be negligible. If the settings are not so made, it may be necessary to compute and apply a correction for the irregularity.

Evidence has already been presented in § 54 to show that it is difficult to obtain the actual mean micrometer value. It is important, therefore, to guard against errors arising from the eighth source by selecting such pairs that the plus and minus micrometer differences actually observed at a station shall balance as nearly as possible. The final result will be free from error from this source if the weighted mean of the micrometer differences, the signs being preserved, is zero. The only effect of the error in the mean micrometer value in that case is to slightly increase the computed probable errors. The weights are not, however, usually known during the progress of the observations. If the indiscriminate mean of the micrometer differences for each pair, taken with respect to the signs, is made less than one turn at a station, the error of the mean result from this source will usually be less than its computed probable error.

THE ECONOMICS OF LATITUDE OBSERVATIONS.

56. Two questions imperatively demand an answer under this heading. What ratio of number of observations to number of pairs will give the maximum accuracy for

a given expenditure of money and time? What degree of accuracy in the mean result for the station is it desirable and justifiable to strive for?

The answer to the first question depends upon the relative magnitude of the accidental errors of declination and of observation. At thirty-six stations nearly on the thirty-ninth parallel, at which latitude observations have been made since the beginning of 1880, the average value of $e_{\frac{ss}{2}}$, the probable error of the mean of two declinations (derived from the mean place computations), is $\pm$ 0″·16 and the extreme values were $\pm$ 0″·12 and $\pm$ 0″·23. At thirty-seven stations occupied with zenith telescopes along the thirty-ninth parallel the extreme values of e, the probable error of a single observation, were $\pm$ 0″·16 and $\pm$ 0″·98, and at about one-half of the stations it was less than $\pm$ 0″·42.* Similarly, at forty-three stations along that parallel occupied with meridian telescopes e was less than $\pm$ 0″·45 at one-half the stations, and the extreme values were $\pm$ 0″·21 and $\pm$ 1″·27. In the light of these figures one may use the following table to determine the most economical ratio of number of observations to number of pairs.

WEIGHT TO BE ASSIGNED TO MEAN LATITUDE FROM A SINGLE PAIR.

$$= \left(\frac{e^2}{\frac{ss}{2}} - \frac{e^2}{n} \right)^{-1}$$

$e_{\frac{ss}{2}}$ being assumed to be $\pm$ 0″·16.

	Number of observations on the pair.					
	1	2	3	4	5	6
″						
±0·16	20	26	29	31·2	32·6	33·4
±0·20	15	22	26	28·1	29·8	31·0
±0·30	9	14	18	20·8	22·9	24·6
±0·40	5·4	9·5	12·7	15·2	17·4	19·1
±0·60	2·6	4·9	6·9	8·7	10·2	11·7
±0·80	1·5	2·9	4·2	5·4	6·5	7·6
±1·00	1·0	1·9	2·8	3·6	4·4	5·2

The measure of efficiency of the first observation is the weight shown in the first column, and of each succeeding observation is the resulting *increment* of weight. Thus, if $e = \pm$ 0″·16, the first observation gives a weight of 20, while the second observation is less than one-third as efficient, the increment of weight being only 6, and the fifth and sixth observations combined are about one-ninth as efficient as the first observation. Stated otherwise, the probable error of a single observation being in this case the same as the probable error of the mean of two declinations, little is gained by reducing the observation error while the declination error is allowed to remain. If $e = \pm$ 0″·60, the

* One thousand two hundred and seventy-seven observations for variation of latitude at San Francisco in two series gave $e = \pm$ 0″·19 and $e = \pm$ 0″·28. A similar series at the Hawaiian Islands in 1891–92, 2 434 observations, gave $e = \pm$ 0″·16, and another series at Rockville, Md., in 1891–92 gave $e = \pm$ 0″·17 to $\pm$ 0″.26. On the Mexican boundary in 1892–93, 1 362 observations at fifteen stations gave $e = \pm$ 0″·19 to $\pm$ 0″·38. All these observations were made with zenith telescopes. (See Coast and Geodetic Survey Reports, 1893, Part 2, p. 494; 1892, Part 2, pp. 54 and 158; 1892, Part 2, p. 50, and Mexican Boundary Report, 1891–1896, p. 101.)

table shows that the second and third observations are each nearly as efficient as the first. The larger is e the less difference there is between the first and succeeding observations, but in every case the first observation is more efficient than any later observation.

If each observation after the first involved the same amount of time spent in preparation, observation, and computation as the first, it is evident that to secure a maximum of accuracy for a given expenditure each pair should be observed *but once*. Additional observations on new pairs require appreciably more time than the same number of observations on pairs already observed only in the following items: Preparing the observing list, computing mean places, and computing apparent places. In regard to the extra mean places needed, it should be borne in mind that standard places are available in this office for so many of the stars ordinarily observed for latitude that for from one-half to three-quarters of the stars in a given list it is not necessary to make a new mean place computation from the catalogues of observation, but simply to reduce the standard place to date. Several observations per pair save an appreciable amount of time in the apparent place computation only when the successive nights of observation follow each other so closely that the apparent places on certain nights may be obtained by interpolation. (The interval over which a straight-line interpolation may be carried with sufficient accuracy is three days.)

After balancing this slight increase in labor against the greater efficiency of the first observation upon a pair over any succeeding observation, the opinion of the writer is that if e is not greater than $0''.40$, each pair should be observed but once. If e is much greater than $0''.40$, two or possibly even three observations per pair may be advisable.

It is true that if but a single observation is made upon each pair the observer in the field will not be able to determine his error of observation accurately (he may do so approximately by assuming $e_{\frac{aa}{2}} = \pm 0''.16$), but the field computation will still perform its essential function of detecting omissions and deficiencies if they exist.

What degree of accuracy in the mean result for a station is it desirable and justifiable to strive for? Omitting from consideration stations occupied to determine the variation of latitude, and stations occupied upon a boundary at which one purpose of the latitude observations is to furnish a means of recovering the same point again, the ordinary purpose of latitude observations in connection with a geodetic survey is to determine the station error in latitude, or, in other words, to determine the deflection of the vertical, measured in the plane of the meridian, from the normal to the spheroid of reference at the station. Broadly stated, the purpose of astronomical observations of latitude and longitude (and to a large extent of azimuth also) in connection with a geodetic survey is to determine the relation between the actual figure of the earth as defined by the lines of action of gravity and the assumed mean figure upon which the geodetic computations are based. In determining this relation three classes of errors are encountered: The errors of the geodetic observations, the errors of the astronomical observations, and the errors arising from the fact that only a few scattered astronomical stations can be occupied in the large area to be covered, and that the station errors as measured at these few *points* must be assumed to represent the facts for the whole *area*. It suffices here in regard to errors of the first class, which are not within the province of this appendix,

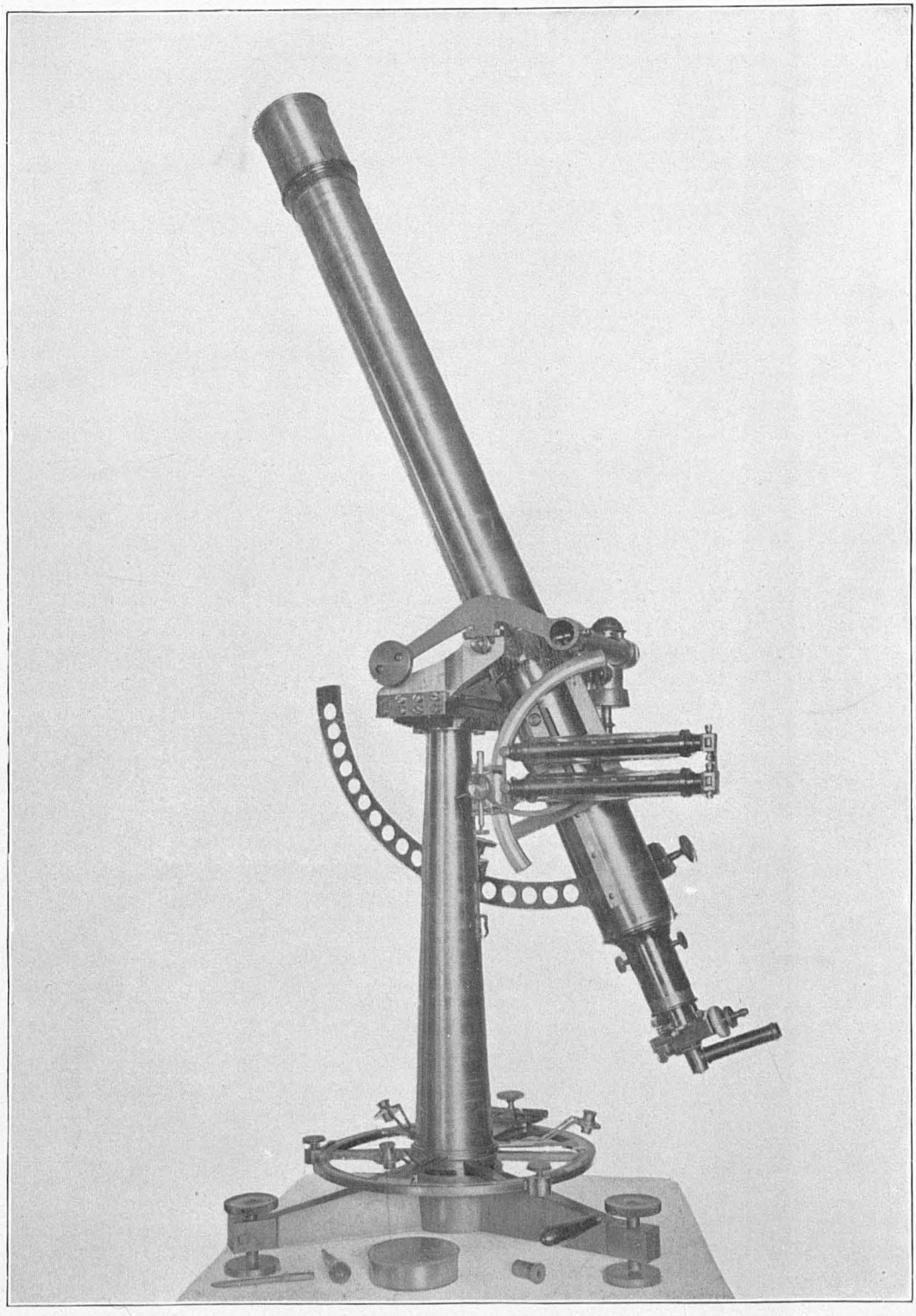
to state that they are in general of about the same order of magnitude as those of the second class.

The average value of the station error in latitude without regard to sign at 111 stations on the oblique arc (Calais, Me., to Atlanta, Ga.), and on the arc of the thirty-ninth parallel between Cape May and Colorado Springs is 2″·4. In the mountainous region along the thirty-ninth parallel farther west the average station error is considerably larger. An examination of a tabular statement of these station errors shows that although there is a slight tendency for their values for a given region to be of one sign and magnitude the values at adjacent stations are nevertheless so nearly independent that the nonpredictable rate of change of the station error per mile is frequently more than 0″·1. Six stations within the District of Columbia show an irregular variation of station error in latitude with a total range of 1″·8. Stating the result of the examination in another form, if the station error at a point is assumed to represent the average value of the station error for an area, and if the error of that assumption is to be not greater than ±0″·10, the area adjacent to the station to which the assumption is applied must not be greater than 10 square miles. If one bears in mind that financial considerations so limit the number of latitude stations that in general the above assumption must be extended over hundreds of square miles, it becomes evident that a probable error of ±0″·10 in the latitude determination is all that it is desirable or justifiable to strive for.* One observation upon each of from 15 to 25 pairs will, upon an average, secure that degree of accuracy, and the observations may be completed in a single evening.

NOTE.—The correction of observed latitudes for variation of the pole is not here treated, because that matter is still being investigated so energetically that any statement that can be made now is apt to become inaccurate in a few years in comparison with what will then be known.

The correction of the observed latitude for curvature of the line of gravity is sensible only at stations of great altitude, and needs only to be applied in a few such cases. It is omitted here for the reason just stated, and because its explanation belongs with a discussion of the earth's figure and geodetic formulæ rather than in an appendix on purely astronomical matters.

*The above discussion also applies, though with less force, to longitude and azimuth observations. In both these cases the errors of observation are necessarily much larger than in latitude observations.



ZENITH TELESCOPE.

PART IV.

DETERMINATION OF THE ASTRONOMICAL AZIMUTH OF A DIRECTION.

GENERAL REMARKS.

57. 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 that line with respect to the meridian, 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 several methods now in use, and 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.

INSTRUMENTS.

58. So great a variety of instruments is used for azimuth determinations that it is of little avail to describe any particular instrument in detail. Illustration No. 9 shows a 12-inch* direction theodolite (No. 146) made at this office and now in use for the measurement of horizontal angles and azimuths in primary triangulation. It carries a very accurate graduation, which is read to seconds directly and to tenths by estimation by three microscopes.† A glass-hard steel center also contributes largely toward making this theodolite and others of identical construction furnish results of a degree of accuracy unsurpassed by any other portable theodolite. Illustration No. 10 shows a 20-inch direction theodolite, which has been used extensively on primary triangulation. It is read to seconds directly by three microscopes and to tenths by estimation. The graduation of the horizontal circle on each of these two instruments is to 5′ spaces. An 8-inch repeating theodolite reading to five seconds by two opposite verniers is shown in Illustration No. 11. For observations upon the sun for azimuth in connection with magnetic determinations a small 4-inch theodolite is often used. (See Illustration No. 12.) This instrument reads to minutes on each of two opposite verniers. The transit instruments and meridian telescopes described in connection with time observations in §§ 2, 3 are also frequently used for azimuth either in the meridian (§ 69) or in the vertical plane of a circumpolar star at or near elongation (§ 67).

Sometimes the azimuth of the line to a station of the triangulation is measured directly, but more frequently a special azimuth mark is erected, which is afterwards referred to the triangulation by measurements of horizontal angles. There has been considerable variety in the azimuth marks so used, each chief of party adapting the mark to the special conditions in which he finds himself and to his own convenience. Frequently the mark has been a box similar to that shown in Illustration No. 8, having in its front face a round hole of suitable 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. In constructing such a box the amount of ventilation must be so adjusted that the lamp will neither smoke because of too small a supply of fresh air nor be blown out in strong winds because of too many or poorly placed openings. For day observations white and black stripes are painted upon the front of the box. In some instances, notably in the primary triangulation in Colorado, Utah, and Nevada, all the azimuth observations were taken in daylight and the azimuth mark consisted merely of a firmly fixed board carrying a vertical black stripe of suitable width flanked by white stripes. An incidental advantage of putting the mark nearly in the horizon of the instrument is that small errors of inclination of the horizontal axis of the instrument will not affect the pointings upon the mark and corresponding readings of the striding level are unnecessary. The distance of the mark is generally determined, in part, at least, by the configuration of the ground surrounding the station, but on no account should it be placed any nearer than about one statute mile, in order that the sidereal focus of the telescope may not require changing between pointings upon the star and upon the mark, since any such change is likely to change the error of collimation.

* The size of the theodolite is here, as usual, designated by giving the diameter of the graduated horizontal circle.

† For a more complete description of this instrument see Report for 1894, pp. 265–274.

In choosing the position of the mark it should be kept in mind that the higher is the line of sight to it above the intervening ground the more steady the light may be expected to show and the smaller the errors to be expected from lateral refraction

The diameter of the aperture through which a light used for an azimuth mark shines should be adjusted with reference to its distance from the instrument, the power of the telescope, and the local atmospheric conditions. 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, 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.
		mm.	*mm.*
1·5	0·9	7	4
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

Occasionally it is difficult to find a satisfactory location for an azimuth mark. For example, the astronomical station may be one of the stations of a triangulation located on the flat top of a mountain in such a position that none but very near or very distant points are visible from it. In such a case one may resort to a collimator for an azimuth mark. A collimator is an auxiliary telescope, of which the aperture should be about as large as that of the telescope of the instrument, rigidly mounted so as to face the instrument and adjusted to sidereal focus. The instrument telescope being also at sidereal focus and pointed at the collimator, the two objectives then being toward each other, the lines of the recticle of the collimator may be seen as if they were at an infinite distance, for rays of light proceeding from them are parallel rays in the space between the two objectives. Any line of the reticle of the collimator defines, therefore, a fixed direction from the instrument and serves the same purpose as the ordinary distant azimuth mark, *provided* the collimator remains fixed in direction. Great care is necessary in mounting the collimator and protecting it from changes of temperature to insure that this last condition is sufficiently well satisfied, and hence the use of a collimator should be avoided, if possible.

Instead of determining the inclination of the horizontal axis by readings of a striding level, observations are sometimes taken upon the image of the star as seen reflected from the free surface of mercury (an artificial horizon) in addition to the direct observations upon the star. The error in azimuth produced by an inclination of the horizontal axis is of the same numerical value for the reflected observations as for the direct observations, but is reversed in sign, and the mean result is free from error from this source,

provided the cross-section of each pivot is circular, or at least that the two pivots have similar cross-sections similarly placed. Considerable care and ingenuity is necessary to protect the mercury effectually against tremors and against wind, either of which will by disturbing the mercury surface make the reflected star image so unsteady as to make accurate pointing upon it difficult or impossible. A glass roof over the mercury to protect it from the wind should never be employed in connection with azimuth observations, since reversal of it does not sufficiently correct for errors arising from refraction at the glass. Large boxes, or tubes of considerable size, with their openings covered with mosquito netting have proved the most satisfactory protection of the mercury against the wind.

The pointings in azimuth observations are usually taken by using either a single vertical line in a reticle (or attached to a micrometer) or a pair of parallel vertical lines a few seconds (of arc) apart. The first has the advantage over the second that it does not involve the necessity of bisecting a space by eye, as the observation consists simply of noting when the star image appears symmetrical with respect to the line. On the other hand, it has the disadvantage that frequently when a very bright star (or light) is observed the line appears to be "burned off" near the star image; that is, it becomes invisible because of its comparative faintness, and the pointing is correspondingly uncertain. So also if a very faint star (or light) is observed its image may nearly or completely disappear behind the line and so make accurate pointing difficult. For many stars of intermediate degrees of brightness one or the other of these difficulties exists to a greater or less degree. If two vertical lines are used and the distance between them is properly chosen these two difficulties will be avoided and both star (or mark) and lines will always be distinctly visible at the same instant. The observation now consists in noting when the image of the star (or mark) bisects the space between the two lines. This process is probably but slightly less accurate under any conditions of brightness than the direct bisection of a star image under most favorable conditions as to brightness. In measuring horizontal angles and azimuth in Colorado, Utah, and Nevada along the thirty-ninth parallel* two vertical lines about 20″ apart were used, and the central black stripe on the azimuth mark upon which pointings were made was of such a width as to subtend about 7″ at the instrument. The accuracy of the results speaks loudly for the method of pointing used. Other observers may possibly find it advantageous to place the lines somewhat nearer together.

GENERAL CONSIDERATIONS.

59. Let the hour angle (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

* These observations were made by Assistant William Eimbeck and party. The star observations were usually made by observing the time of transit over each of the two lines, swinging the instrument in azimuth and rereading the horizontal circle between the two lines when the time interval became too long to be convenient (near elongation). The above remarks apply with full force to the pointings upon the mark, and to all the telescope pointings usually upon heliotropes, concerned in the measurement of horizontal angles.

case of a circumpolar star at 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 minimum, but the star (or sun) should not be 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.*

These considerations have led to the plan of making first-class azimuth observations almost exclusively upon the close circumpolars α, δ, and λ Ursæ Minoris and 51 Cephei. The apparent places of these four stars are given in the American Ephemeris for every day of the year. Illustration No. 7 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 far from its elongation; and, likewise when the pole star culminates, the other two are on opposite sides of the meridian, near their elongations. A similar approximate relation exists between α and λ Ursæ Minoris. Polaris offers the advantage of being observable in daytime 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.

GENERAL FORMULÆ.

60. Four methods of determining azimuth will be treated in detail in this appendix, namely, (1) the method in which a direction theodolite is used, as in the measurement of horizontal directions; (2) the method of repetitions with a repeating theodolite;

* The statements made in a general and somewhat indefinite form in this paragraph may be stated in accurate mathematical form by deriving dA in terms of dt, $d\varphi$, $d\delta$, respectively, from the formula

$$\tan A = \frac{-\sin t}{\cos\varphi \tan\delta - \sin\varphi \cos t}$$

(see § 60), or from the formulæ used in its derivation.

(3) the micrometric method, using an eyepiece micrometer; (4) the determination of azimuth from time observations with a transit or meridian telescope approximately in the meridian.* Certain formulæ which are common to the first three of these methods will be stated here for convenient reference.

The computation of the azimuth of a terrestrial line of sight from a set of azimuth observations consists essentially of a computation of the azimuth of the star at the instant of observation, a computation of the horizontal angle between the star and the mark, and the combination of these two results by addition or subtraction.

In the spherical triangle defined by the pole, the zenith, and a star, the side zenith-pole is the co-latitude, the side star-pole is the polar distance of the star, and the angle at the pole is the hour angle† or its explement. Starting from these three as known parts, the spherical triangle may be solved by the ordinary formulæ of spherical trigonometry. The solution to obtain the azimuth of the star, which is the angle of this triangle at the zenith, may, *without any approximations*, be put in the form

$$\tan A = -\frac{\sin t}{\cos \varphi \tan \delta - \sin \varphi \cos t}$$

in which A is the azimuth of the star counted from the north in a clockwise direction,‡ and the hour angle t is counted westward from upper culmination continuously to 24^h, or 360°, at the next upper culmination. This is the most convenient formula for use with either of the first three methods. The first term of the denominator changes very slowly and may be tabulated for slightly different values of δ during the period of observation. The second term, for a close circumpolar star, may be computed with sufficient accuracy by five-place logarithms.

The computation of the azimuth from this formula may be considerably shortened by transforming it as indicated below and using the table given on pp. 399–407.§

$$\tan A = -\frac{\sin t}{\cos \varphi \tan \delta - \sin \varphi \cos t}$$

$$= -\frac{\cot \delta \sec \varphi \sin t}{1 - \cot \delta \tan \varphi \cos t}$$

$$= -\cot \delta \sec \varphi \sin t \left(\frac{1}{1-a}\right)$$

in which $a = \cot \delta \tan \varphi \cos t$.

---

* The method of determining azimuth by observations upon the sun at any hour angle is not to be treated in this appendix because it is used mainly in making observations for magnetic declinations, and an elaborate account of it, with tables for making the curvature correction, is soon to be published in that connection.

† In this appendix the hour angle will be reckoned westward from zero at upper culmination (increasing with the lapse of time) to 360° or 24^h.

‡ In astronomical computations it is more convenient to count the azimuth from the north instead of from the south, as in geodetic computations. If the direction of the count is clockwise, as here stated, to change from one reckoning to the other it is only necessary to add or subtract 180°.

§ The formula and the table are both copied from *Formeln und Hülfstafeln für Geographische Ortsbestimmungen* von Prof. Dr. Th. Albrecht, Leipzig, 1894. The range of the table has, however, been considerably extended.

The second form of this formula is about as convenient as the first form. It involves the same number of logarithms as the first and one less reduction from logarithms to numbers. For a computation made by using the first form see p. 390.

The third form in connection with the tables given on pp. 399–407 gives a much quicker computation process than either of the other two. In using this form and the tables, log cot δ sec φ sin t must be carried to six places and log cot δ tan φ cos t to five places. The most convenient arrangement of the computation is shown on p. 387. The formula and tables involve no approximations, and the only errors resulting from their use are those arising from the cast-off decimal places (logarithms limited to *six* places). These errors are of the accidental class, and will seldom exceed 0″·04 for any case covered by the table, and for most observations made below latitude 50° the error will not exceed 0″·01. These quantities are so small in comparison with the errors of observation as to be negligible. A few observations made in Alaska may be beyond the range of the tables on pp. 399–407, and when that is found to be the case, one may easily substitute the second formula on p. 382 for the third.*

To compute the azimuth of a star at the time of *each* pointing made upon it during a set of observations is an unnecessarily laborious process. If for the hour angle, t, of the azimuth formula is taken the mean of the hour angles of the set, the computed azimuth is that corresponding *to the mean hour angle*, but is not the required *mean of the azimuths corresponding to the separate hour angles*, since the rate of change of the azimuth is continually varying because of the curvature of the apparent path of the star. The difference between the two quantities indicated by the italics is small, though not usually negligible, for the interval of time covered by a set of observations. The most convenient way of making the computation for a set of observations is to use the mean hour angle in the azimuth formula and apply to the result a

$$\text{Curvature Correction} = \tan A \, \frac{1}{n} \, \Sigma \frac{2 \sin^2 \frac{1}{2} \tau}{\sin 1''}$$

in which n is the number of pointings upon the star in the set and τ for each observation is the difference† between the time of that observation and the mean of the times for the set. The sign of this curvature correction is always such as to decrease numerically the azimuth reckoned from the north, or in other words if azimuths are counted clockwise its algebraic sign will be + when the star is west of north and — when the star is east of north. If the star crosses the meridian during the progress of a set the curvature correction will ordinarily be zero. The formula is approximate, but for circumpolars

* Various other formulæ for computing the azimuth of circumpolar stars have been proposed and used. Each of them requires either the same or a greater time for the computation than that here given, when the whole computation, including the preparation of the auxiliary tables required with some of them, is taken into account. As uniformity of practice is conducive to rapid computation, it is considered desirable that all should use the formulæ given and therefore no others are here stated. It should be noted that the formula given is accurate and general; that is, it applies to any of the close circumpolars at any hour angle.

If the star observed is Polaris, a convenient rough check on the computation may be obtained by using the azimuth tables of Appendix No. 10 of the report for 1895, by Assistant G. R. Putnam.

† 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 one hundred and eightieth part.

and for the interval of time usually covered by a set of observations its errors are negligible. The value of the term $\frac{2 \sin^2 \frac{1}{2} \tau}{\sin 1''}$ may be found tabulated for various values of τ in Doolittle's Practical Astronomy, pp. 634–641; in Albrecht's Hülfstafeln (1894), pp. 199–200; in Hayford's Astronomy, pp. 316–319, and in various other places.

Because of the rapid motion of the observer, due to the rotation of the earth on its axis, a star is seen slightly displaced from its real position. The required

$$\text{Correction for Diurnal Aberration} = 0''.32 \frac{\cos A \cos \varphi}{\sin \zeta}$$

The sign of the correction is always positive when applied to azimuths counted clockwise. The greatest variation of the correction from its mean value, 0''.32, for the four circumpolars ordinarily observed and for latitudes not greater than 50°, is 0''.02. The correction for diurnal aberration need not be applied to the separate sets but simply to the mean result for a station.

If the horizontal axis is inclined when the pointings are made upon either the star or the mark the corrections indicated below must be applied.

$$\textit{Level Correction} = \frac{d}{4} \left\{ (w + w') - (e + e') \right\} \cot \zeta$$

if the striding level carries a graduation numbered in both directions from the middle. d is the value of one division of the level and w, e and w', e' are the west and east readings of the level before and after reversing it. ζ is the zenith distance of the star. It is only necessary to know ζ approximately—an occasional reading of the setting circle will give it with abundant accuracy.

If the graduation on the striding level is numbered continously in one direction the

$$\textit{Level Correction} = \frac{d}{4} \left\{ (w - w') - (e - e') \right\} \cot \zeta$$

in which the primed letters refer to readings taken in the position in which the numbering increases toward the east.*

If the mark is not in the horizon of the instrument a similar correction, if appreciable, must be applied to readings upon the mark, ζ now being the zenith distance of the mark. Ordinarily the mark is so nearly in the horizon of the instrument that cot ζ is nearly zero and the corrections required to pointings upon the mark are negligible.

The formula as written gives the sign of the correction to be applied to the readings of a horizontal circle of which the numbering increases in a clockwise direction. This is also the sign of the correction to the computed azimuth (counted clockwise) for level readings in connection with pointings upon the mark, but in connection with pointings upon the star the sign must be reversed to give corrections to the computed azimuth of the mark.

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*See footnote on page 280.

DIRECTION METHOD—ADJUSTMENTS.

61. The measurement of an azimuth by this method is essentially similar to the process of measuring a difference of two horizontal directions with a direction theodolite. The quantity measured in this case is the difference of azimuth of a circumpolar star and a mark instead of a difference of azimuth of two triangulation signals. The fact that the azimuth of the star is continually changing adds new features to the computation, and makes it necessary to know the time of each pointing upon the star. The fact that the star is at a considerable altitude makes readings of the striding level a necessity and decreases the accuracy of the measurement because errors of inclination of the horizontal axis have a marked influence as contrasted with their comparatively unimportant effects upon the measurements of horizontal angles in a triangulation.

The adjustments required are identical with those which are necessary when the instrument is to be used for the measurement of horizontal directions. The adjustments of the focus of the telescope, of the line of collimation, for bringing the vertical lines of the reticle into vertical planes, of the setting circle, and of the striding level may be made as described in connection with a transit on pp. 271–273. The vertical axis of the instrument must be made to point as nearly as is feasible to the zenith by bringing the striding level to the proper reading in each of two positions at right angles to each other.

The microscopes with which the horizontal circle is read must be kept in adjustment. Ordinarily it will only be found necessary to adjust the eyepiece by pushing it in or pulling it out until the most distinct vision is obtained of the micrometer lines and of the circle graduation. If the micrometer lines are not apparently parallel to the graduation upon which the pointing is to be made, they should be made so by rotating the micrometer box about the axis of figure of the microscope. If to do this it is necessary to loosen the microscope in its supporting clamp, great caution is necessary to insure that the distance of the objective from the circle graduation is not changed. The error of run of the reading micrometers should be kept small. In other words, the value of one turn of the micrometer in terms of the circle graduation should not be allowed to differ much from its nominal value. The value of the micrometer may be adjusted by changing the distance of the objective from the graduation. The nearer the objective is to the graduation the smaller is the value of one turn. A change in this distance also necessitates a change in the distance from the objective to the micrometer lines, these lines and the graduation being necessarily at conjugate foci of the objective. This adjustment of the micrometer value is a difficult one to make, but when once well made it usually remains sufficiently good for a long period.

Direction method—Example of record and computation.

62. RECORD.

Station: Mount Nebo, Utah. Date: July 21, 1887.

Observer: W. E. Instrument: 20-in. Theodolite No. 5.

Star: Polaris, near lower culmination. Position X.

Object observed.	Chronometer time.	Pos. of tel.	Mic.	Circle reading.								Levels and remarks.
				°	′	For. d.	Back. d.	B–F. d.	Mean d.	Corr. for run.	Cor'd mean	
	h. m. s.											
Az. mark		D	A	140	53	14·8	14·2					
			B			14·6	13·4					
			C			32·3	29·7					
						20·6	19·1	−1·5	19·8	−0·2	19·6	
Az. mark		D	A	140	53	14·7	14·2					
			B			14·4	13·5					
			C			32·1	30·0					
						20·4	19·2	−1·2	19·8	−0·2	19·6	
												W. E.
*	15 06 10·0	D	A	136	09	45·3	43·0					43·5 27·0
	07 24·0		B			44·3	43·8					
			C			60·7	59·2					
	15 06 47·0											
						50·1	48·7	−1·4	49·4	−0·5	48·9	
*	15 09 46·5	D	A	136	11	07·0	06·5					53·7 17·5
	11 00·0		B			07·2	06·3					
			C			22·6	21·0					97·2 44·5
	15 10 23·25											+52·7
						12·3	11·3	−1·0	11·8	+0·3	12·1	
*	15 15 21·0	R	A	316	13	41·3	40·5					39·5 32·3
	16 34·5		B			32·0	30·3					
			C			44·0	43·7					
	15 15 57·75											
						39·1	38·2	−0·9	38·6	−0·2	38·4	
*	15 19 03·0	R	A	316	15	09·5	08·5					27·4 44·6
	20 20·5		B			57·5	57·3					
			C			10·5	10·0					69·9 76·9
	15 19 41·75											−10·0
						05·8	05·3	−0·5	05·6	+0·5	06·1	
Mean of four times Az. mark	15 13 12·44	R	A	320	53	27·0	26·0					Mean circle reading
			B			17·8	16·5					On star 136°12′26″.38
			C			29·0	27·5					On Mark 140 53 21 .90
						24·6	23·3	−1·3	24·0	−0·2	23·8	
Az. mark		R	A	320	53	28·3	26·5					
			B			18·7	16·7					
			C			29·7	28·7					
						25·6	24·0	−1·6	24·8	−0·2	24·6	

Azimuth computation.

Mount Nebo, Utah, July, 1887. $\varphi = 39° 48' 33''.44$.

Explanation.			
Date and position	July 21, X	July 21, XI	July 21, XII
Mean chronometer time	$15^h 13^m 12^s.44$	$0^h 55^m 10^s.06$	$1^h 26^m 37^s.88$
Chronometer correction	$-35^s.40$	$-34^s.62$	$-34^s.58$
Sidereal time	15 12 37 .04	0 54 35 .44	1 26 03 .30
α of polaris	1 17 58 .16	1 17 58 .48	1 17 58 .50
t of polaris (time)	13 54 38 .88	−0 23 23 .04	0 08 04 .80
t " " (arc)	208 39 43 .20	−5 50 45 .60	2 01 12 .00
δ " "	88 42 06 .13	88 42 06 .20	88 42 06 .20
log. cot δ	8.35532	8.35532	8.35532
log. tan φ	9.92087	9.92087	9.92087
log. cos t	9.94323 n	9.99773	9.99973
log. a	8.21942 n	8.27392	8.27592
log. cot δ	8.355325	8.355319	8.355319
log. sec φ	0.114537	0.114537	0.114537
log. sin t	9.680917 n	9.007983 n	8.547139
log. $1/1-a$	9.992861	0.008237	0.008276
log. $(-\tan A)/A$	8.143640 n	7.486076 n	7.025271
	$+0°47'51''.02$	$+0°10'31''.68$	$-0°03'38''.62$
τ and $\frac{2\sin^2 \frac{1}{2}\tau}{\sin 1''}$	$6^m 25^s.4$ 81''.0	$7^m 08^s.8$ 100''.3	$6^m 59^s.9$ 96''.2
	2 49 .2 15 .6	3 23 .1 22 .5	2 43 .9 14 .7
	2 45 .3 14 .9	3 19 .4 21 .7	2 59 .6 17 .6
	6 29 .3 82 .6	7 12 .4 102 .0	6 44 .1 89 .1
	194 .1	246 .5	217 .6
	48 .5	61 .6	54 .4
$\log. \frac{1}{n}\Sigma \frac{2\sin^2 \frac{1}{2}\tau}{\sin 1''}$	1.68574	1.78958	1.73560
log. (curvature correction)	9.82938	9.27566	8.76087
Curvature correction	+0''.68	+0''.19	−0''.06
Mean azimuth of star	$+0°47'50''.34$	$+0°10'31''.49$	$-0°03'38''.56$
Circle reads on star	136 12 26 .38	151 14 14 .30	166 38 57 .12
Circle reads on north	135 24 36 .04	151 03 42 .81	166 42 35 .68
Circle reads on mark	140 53 21 .90	156 32 25 .95	172 11 19 .22
Approx. azimuth of mark	+5 28 45 .86	43 .14	43 .54
Level correction	−3 .94	−0 .73	−0 .57
Azimuth of mark	5 28 41 .92	42 .41	42 .97

The summary of the results from 26 sets of observations similar to that shown, made on four nights and in 23 positions of the circle (the measurement being repeated in 3 of the 23 positions), indicates the azimuth of the mark to be from—

14 sets observed near upper culmination	=	5°	28′	42″·54
12 " lower "	=	5	28	42 ·46
All 26 sets	=	5	28	42 ·50
The correction for diurnal aberration	=		+ 0	·32
Whence azimuth of mark east of north		5	28	42 ·82

with a probable error of $\pm 0''\cdot09 = \sqrt{\frac{0\cdot455\Sigma v^2}{n(n-1)}}$. The computed probable error of a single observation $\pm 0''\cdot46 = \sqrt{\frac{0\cdot455\Sigma v^2}{n-1}}$ (n = number of sets).

DIRECTION METHOD—EXPLANATION OF RECORD AND COMPUTATION.

63. The record shows the order in which the observations were taken, and needs explanation only in a few particulars. The *two* times recorded opposite each circle reading upon the star are the times of transit across the *two* vertical lines of the reticle, which in this instrument take the place of the single vertical line ordinarily used (see page 380). The striding level was left in position during the whole course of the observations, and was read at the times indicated in the record. The mark was only 1° 53′ below the horizon of the instrument, and it was therefore not necessary to read the striding level when pointing upon it. The observations were made in daylight. To eliminate the effect of graduation errors of the horizontal circle as far as possible, the measurements were made in 23 positions of the circle, just as they were in the measurements of horizontal angles in the corresponding triangulation.

Each micrometer is always read twice upon the two circle graduations which are adjacent (on opposite sides) to the zero of the micrometer. That reading which gives directly the positive correction to be applied to the index microscope (with which the degrees and the nearest five minutes is read) is called the forward reading. The values of the run B–F (backward–forward), shown in the record, were used to determine the correction for run as follows: The mean of the values of B–F was taken from all the azimuth observations at the station, and found to be $-1^{d}\cdot049$, from which the following table of corrections to be applied to the mean of two readings (forward and backward) resulted:

Reading of micrometer.	Correction.	Reading of micrometer.
0′ 00″·0 to 0′ 21″·3	+0·5—	4′ 38″·8 to 5′ 00″·0
0 21 ·4 to 0 49 ·9	+0·4—	4 10 ·2 to 4 38 ·7
0 50 ·0 to 1 18 ·5	+0·3—	3 41 ·6 to 4 10 ·1
1 18 ·6 to 1 47 ·1	+0·2—	3 13 ·0 to 3 41 ·5
1 47 ·2 to 2 15 ·7	+0·1—	2 44 ·4 to 3 12 ·9
2 15 ·8 to 2 44 ·3	0·0	2 15 ·8 to 2 44 ·3

The right-hand signs are to be used with the right-hand argument, and *vice versa*.

The chronometer corrections shown in the computation resulted from a special series of time observations at the station. The computation of A was made by use of the tables shown on pages 399–407. Much time is saved in such a computation as this by carrying along all the different sets at one time and thus working along the horizontal

lines of the form shown instead of down each column. Also, tan φ and sec φ are constants for the station, cos t and sin t may be taken out at one opening of the logarithm table, etc. A comparison of corresponding parts of different columns furnishes rough checks which serve to locate any large error quickly. The value of one division of the striding level $=0''.88$. The sum of the plus level corrections and of the minus level corrections were very nearly the same for the station and the computed mean result is there fore very nearly independent of the adopted value of one division of the level. The record shows that at this station, when no interruptions occurred, a set of observations like that shown required from 30^m to 34^m, including the shifting of the circle and releveling at the beginning of each set.

METHOD OF REPETITIONS—EXAMPLE OF RECORD AND COMPUTATION.

64. Remarks similar to those appearing at the beginning of §61 apply here also. The observations required to determine the azimuth of a mark by the method of repetitions are the same as those required to measure a horizontal angle in a triangulation with the same repeating theodolite, with the addition of level readings, and readings of the chronometer at the instants of the pointings upon the star.

The adjustments required are those mentioned in §61 with the exception that a repeating theodolite is ordinarily read by verniers instead of microscopes.

Record—Azimuth by repetitions.

Station: Kahatchee △ State: Ala. Date: June 6, 1898.

Instrument: 10-in. Gambey No. 63.

Observer: O. B. F. Star: Polaris.

Objects.	Chr. Time on Star.	Pos. of Tel.	Repetitions.	Level Readings. W.	Level Readings. E.	Circle Readings. °	′	A ″	B ″	Mean.	Angle.
Mark.	$14^h\ 46^m\ 30^s$	D	1	4·5	10·7	178	03	22·5	20	21·2	
				9·2	5·9						
Star.	49 08		2								
	52 51	D	3	9·6	5·6						
				5·2	10·0						
	56 10	R	4	11·3	4·0						
				7·8	7·4						
Set No. 5.	14 59 12		5								
	15 01 55	R	6	8·7	6·6	100	16	20	20	20	$72° 57' 50''.2$
				11·9	3·4						
	14 54 17·7			68·2	53·6						
				+14·6							
Star	15 04 44	R	1	11·9	3·4						
Mark.	07 18		2	8·5	6·8						
				7·9	7·3						
	09 54	R	3	11·2	4·1						
				9·0	6·1						
Set No. 6.	14 15	D	4	5·9	9·6						
	16 14		5								
				5·9	9·6						
	15 18 24	D	6	9.1	6·2	177	27	00	00	00	$72° 51' 46''.7$
	15 11 48·2			69·4	53·1						
				+16·3							

COMPUTATION.

The first step in the computation was to prepare the following Ephemeris of Polaris at Upper Transit, at Washington, D. C. (from American Ephemeris):

$$\left\{\begin{array}{l}\varphi \text{ of Kahatchee} = 33^\circ\ 13'\ 40''\cdot33 \\ \lambda \quad\ \text{“} \quad\ = 86^\circ\ 21'\ 36''\cdot7\end{array}\right\}$$

1898.	α	δ	Cos φ tan δ
June 6	$1^h\ 21^m\ 20^s\cdot75$	88° 45′ 46″·9	38·7400
“ 7	21·62	46 ·8	·7392
“ 8	22·46	46 ·7	·7383
“ 9	23·29	46 ·6	38·7374

	June 6.	June 9.
log. cos φ	9·9224648	9·9224648
log. tan δ	1·6656952	1·6656660
log. cos φ tan δ	1·5881600	1·5881308
	+38·7400	38·7374

Change for 0″·3 = 0·0026
“ 0″·1 = 0·0009

Computation—Azimuth by repetitions.

KAHATCHEE, ALA.

Explanation.		
Date	June 6.	June 6.
Chronometer time	$14^h54^m\ 17^s\cdot7$	$15^h11^m\ 48^s\cdot2$
Chronometer correction	−31 ·1	−31 ·1
Sidereal time	14 53 46 ·6	15 11 17 ·1
α	1 21 20 ·3	1 21 20 ·3
Hour-angle (t)	13 32 26 ·3	13 49 56 ·8
t in arc	203°06′34″·5	207°29′12″·0
log. sin φ	9·73876	9·73876
log. cos t	9·96367n	9·94798n
log. sin φ cos t	9·70243n	9·68674n
sin φ cos t	− 0·5040	− 0·4861
cos φ tan δ	+38·7399	+38·7399
cos φ tan δ—sin φ cos t	+39·2439	+39·2260
log. sin t	9·593830 n	9·664211 n
log. (cos φ tan δ—sin φ cos t)	1·593772	1·593574
log. (−tan A)	8·000058 n	8·070637 n
A	+0°34′22″·7	0°40′26″·9
τ and $\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}$	$7^m47^s\cdot7$ 119″·3	$7^m04^s\cdot2$ 98″·1
	5 09 ·7 52 ·3	4 30 ·2 39 ·8
	1 26 ·7 4 ·1	1 54 ·2 7 ·1
	1 52 ·3 6 ·9	2 26 ·8 11 ·8
	4 54 ·3 47 ·2	4 25 ·8 38 ·5
	7 37 ·3 114 ·0	6 35 ·8 85 ·4
	343 ·8	280 ·7
	57 ·3	46 ·8
$\log.\frac{1}{n}\Sigma\frac{2\sin^2\frac{1}{2}\tau}{\sin 1''}$	1·7582	1·6702
log. (curvature corr.)	9·7583	9·7408
Curvature corr	+0·6	+ 0·6
Mean azimuth of star	+ 0°34′22″·1	+ 0°40′26″·3
Angle Star-Mark	72 57 50 ·2	72 51 46 ·7
Level correction	− 1 ·6	− 1·8
Corrected angle	48 ·6	44·9
Azimuth of Mark E. of N	73 32 10 ·7	73 32 11 ·2

METHOD OF REPETITIONS—EXPLANATION OF RECORD AND COMPUTATION.

65. Throughout the observations the instrument was always turned in a clockwise direction about its vertical axis. In set No. 5 the swing from the mark to the star was made with the upper motion loose and lower motion clamped, and therefore with the circle reading changing, and in set No. 6 the reverse was the case. In set No. 5 the explement of the small angle between the star and the mark was really measured, while in No. 6 the angle itself was measured. Both results may be computed directly in terms of the angle by making the subtractions thus, in set No. 5,

$$\text{angle}=\frac{(360^\circ+178^\circ\ 03'\ 21''\cdot2)-100^\circ\ 16'\ 20''\cdot0}{6}=72^\circ\ 57'\ 50''\cdot2$$

in set No. 6,

$$\text{angle}=\frac{(360+177^\circ\ 27'\ 00''\cdot0)-100^\circ\ 16'\ 20''\cdot0}{6}=72^\circ\ 51'\ 46''\cdot7*$$

If the clamp on the horizontal circle produces a constant error, either by dragging or overrunning, these two results will be equally in error with opposite signs, and their mean will be free from the constant part of the clamp error. Hence, it is desirable to observe the sets alternately in the sense Mark-Star, Star-Mark, as here indicated.

The summary of results for this station shows 37 sets of observations were made on four nights. From the 18 sets observed in the sense Star-Mark the mean azimuth was 73° 32′ 12″·07, and from the 19 sets observed in the sense Mark-Star the mean was 73° 32′ 12″·89, showing that the clamp error was very small. The adopted indiscriminate mean of all the 37 sets was 73° 32′ 12″·49. The correction for diurnal aberration (+0″·31) being applied gave for the azimuth of the mark, E. of N., 73° 32′ 12″·80± 0″·16. The probable error of a single set $=\sqrt{\frac{0\cdot455\ \Sigma v^2}{n\ (n-1)}}=\pm0''\cdot98$.

The instrument was, during these observations, supported upon its tripod, the legs of which were set upon large stakes driven solidly into the ground.

The level readings were taken with the first, third, fourth, and sixth pointings upon the star, that is, at the beginning and end of the set and just before and just after the reversal of the telescope. In each case the level was read in one position just before perfecting the pointing upon the star and reversed, and the second reading taken immediately after the pointing upon the star. The value of one division of the level was 2″·67.

The computation needs no further explanation. The formula

$$\tan A=-\frac{\sin t}{\cos\varphi\tan\delta-\sin\varphi\cos t}$$

was used. The preliminary computation or ephemeris serves to evaluate the term

$$\cos\varphi\tan\delta,$$

which changes but little during the period of observation.

* The computer should notice the convenient fact that in dividing an angle by six the remainder, when the degrees are divided, is the tens figure in the minutes, and the remainder in the minutes is the tens figure in the seconds.

MICROMETRIC METHOD—EXAMPLE OF RECORD AND COMPUTATION.

66. In the micrometric method* the small difference of azimuth of the star and the mark is measured with an eyepiece micrometer, independently of the graduated horizontal circle of the instrument, even if it has one. The mark must therefore be placed nearly in the vertical of the star at the time at which it is to be observed. The method may be used with the star at any hour-angle, but unless the star is near elongation it will pass beyond the safe range of the micrometer after but two or three sets of observations have been taken, whereas if the mark is placed nearly under the star at elongation (preferably one or two minutes of arc inside) the observations may be continued for two hours or more and the results will also be nearly independent of the chronometer error. The instrument used may be a theodolite, a meridian telescope, a transit, or, in fact, any instrument having a stable horizontal axis and furnished with an eyepiece micrometer capable of measuring angles in the plane defined by the telescope and its horizontal axis.

Record and computation—azimuth by micrometric method.

Station: No. 10, Mexican Boundary. Date: October 13, 1892.

Observer: J. F. H. Instrument: Fauth Repeating Theodolite, No. 725 (10 in.).

Star: Polaris near eastern elongation.

Circle.	Level readings. W.	Level readings. E.	Chronometer time.		$\frac{2 \sin^2 \frac{1}{2} \tau}{\sin 1''}$.	Micrometer readings— On star.	Micrometer readings— On mark.	
E	8·0	9·9	$9^h 06^m 38^s \cdot 0$	$3^m 58^s \cdot 6$	31·05	18t·379	18t·310	$\lambda = 2^h 12^m$ W. of
	10·0	7·3	07 32 ·0	3 04 ·6	18·59	·388	·315	W.
								$\varphi = 31° 19' 35''$.
	+18·0	−17·2	08 05 ·5	2 31 ·1	12·45	·400	·315	1 div. of level =
	+ 0·8		09 13 ·0	1 23 ·6	3·82	·424	·311	3″·68.
E			09 48 ·0	0 48 ·6	1·29	·430	·316	1 turn of mic. =
								123″·73.
						18 ·4042	18 ·3134	Means.
W	9·0	9·0	9 12 01 ·8	1 25 ·2	3·96	18 ·100	18 ·290	
	7·0	10·9	12 24 ·7	1 48 ·1	6·37	·100	·275	
	+16·0	−19·9	12 48 ·3	2 11 ·7	9·46	·090	·279	
	−3·9		13 36 ·3	2 59 ·7	17·61	·086	·281	
W	Mean	$-1^d \cdot 55$	13 58 ·1	3 21 ·5	22·14	·080	·279	
			9 10 36 ·6		12·67	18 ·0912	18 ·2808	Means.

ζ of star at middle of first half of set = 58° 48′ cosec ζ = 1·1690 cot 58° 47′ = 0·606.

ζ of star at middle of second half of set = 58° 46′ cosec ζ = 1·1695.

$\alpha = 1^h 20^m 07^s \cdot 4$ $\delta = 88° 44' 10'' \cdot 4$.

* For an account of this method, together with some historical notes, see Appendix No. 2 of the Report for 1891.

Collimation reads 1/2 (18·3134+18·2808) *	= 18·2971		
Mark east of collimation 18·3134 — 18·2971	= 0·0163	=	02″·02
Circle E., star E. of collimation (18·4042 — 18·2971) (1·1690)	= 0·1252		
Circle W., star E. of collimation (18·2971 — 18·0912) (1·1695)	= 0·2408		
Mean, star E. of collimation	= 0·1835	=	22 ·70
Mark west of star		=	20 ·68
Level correction (1·55) (0·92) (0·606)		= —	0 ·86
Mark west of star, corrected		=	19 ·82

Mean chronometer time of observation	=	21h	10m	36s ·6
Chronometer correction	= —	2	11	28 ·2
Sidereal time	=	18	59	08 ·4
α	=	1	20	07 ·4
Hour-angle, t, in time		17	39	01 ·0
" in arc		264°	45′	15″·0

log. cot δ	=	8·34362
log. tan φ	=	9·78436
log. cos t	=	8·96108 n
log. a	=	7·08906 n
log. cot δ	=	8·343618
log. sec φ	=	0·068431
log. sin t	=	9·998177 n
log. 1/1 — a	=	9·999467
log. (— tan A)	=	8·409693 n
A	=	+ 1° 28′ 16″·91
log. 12·67	=	1·10278
log. curvature corr.	=	9·51247
Curvature corr.	=	—0·33
Diur. Aber. Corr.	=	+0·32
Mean azimuth of star	=	+ 1° 28′ 16″·90
Mark west of star		19 ·82
Azimuth of mark, E. of N.	=	+ 1° 27′ 57″·08

MICROMETRIC METHOD—EXPLANATION OF RECORD AND COMPUTATION.

67. The compact form of record shown above does not indicate the order in which the observations were taken. The micrometer line is placed nearly in the line of collimation† of the telescope, a pointing made upon the mark by turning the horizontal

* In this instrument increased readings of the micrometer correspond to a movement of the line of sight toward the east when the vertical circle is to the east, and toward the west when the vertical circle is to the west.

† As no fixed line in the reticle is used in these observations, the line of collimation must here be defined as a line through the optical center of the objective and at right angles to the horizontal axis. A glance at the computation shows that this is the line to which all pointings are directly referred.

circle, and the instrument is then clamped in azimuth. The programme is then to take five pointings upon the mark; direct the telescope to the star; place the striding level in position; take three pointings upon the star with chronometer times; read and reverse the striding level; take two more pointings upon the star, noting the times; read the striding level. This completes a half-set. The horizontal axis of the telescope is then reversed in its Y's; the telescope pointed approximately to the star; the striding level placed in position; three pointings taken upon the star with observed chronometer times; the striding level is read and reversed; two more pointings are taken upon the star, with observed times; the striding level is read and finally five pointings upon the mark are taken.

Three such complete sets may be observed in from thirty to fifty minutes. The effect of a uniform twisting of the instrument in azimuth is eliminated from the result. The bubble of the striding level has plenty of time to settle, without delaying the observer an instant for that purpose.

The zenith distance of the star should be read occasionally, once during each set, say, as it is needed in making the computation. If it is read with one of the star pointings in each set, its value at any other time may be obtained with sufficient accuracy by interpolation.

It should be borne in mind in making the computation that the micrometer measures angles in the plane defined by the telescope and its horizontal axis. To reduce the measured angle between the line of collimation and the star to a horizontal angle, it must be multiplied by $\operatorname{cosec}\zeta$ as indicated in the computation. To avoid all approximation in the computation, it would be necessary to reduce each pointing upon the star separately, as the zenith distance is constantly changing. It is sufficiently accurate, however, to reduce the mean of the pointings of a half-set with the mean zenith distance of that half-set, as indicated in the computation. To use a single zenith distance for the *whole* set will sometimes introduce errors which are rather large to be neglected. The factor $\operatorname{cosec}\zeta$ will not, in general, be necessary in connection with pointings upon the mark, because the mark will usually be nearly in the horizon of the instrument, and $\operatorname{cosec}\zeta$ therefore nearly unity, and because the line of collimation is purposely placed as nearly as possible upon the mark and the angle concerned is therefore very small.

The micrometer value may be determined by observations upon a star near culmination by the process outlined in § 54. If the striding level is read in connection with such observations, the correction to be applied to each observed time to reduce it to what it would have been with the transverse axis horizontal is

$$\left\{ (w+w')-(e+e') \right\} \frac{d \cos\zeta \sec\delta}{60}$$

for upper culmination and for a level of which the graduation is numbered both ways from the middle. For lower culmination the sign of the correction must be reversed.

Another convenient way of determining the micrometer value, all in daylight, is to measure a small horizontal angle at the instrument between two terrestrial objects, both with the micrometer and the horizontal circle of the theodolite. This method is less liable to constant errors than the circumpolar method.

If the azimuth mark is placed to the *southward* of the station, the programme of observing and the computation are but slightly modified.

DISCUSSION OF ERRORS.

68. It is convenient and conducive to conciseness to discuss separately the external errors, observer's errors, and instrumental errors, which together comprise the errors of observation.

The *external errors* affecting azimuth determinations are those due to lateral refraction of the rays of light from the star or mark to the instrument, to errors in the adopted right ascension and declination of the star observed, and to error in the adopted latitude of the station of observation.

Examination of many series of azimuth observations indicates that, in general, they are subject to some error which is peculiar to each night of observation, and constant for that night, but changes from night to night. For example, from 144 sets of micrometric observations of azimuth, made on 36 different nights at 15 stations on the Mexican boundary in 1892–93, it was found that the error peculiar to each night was represented by the probable error $\pm 0''.38$, and that the probable error of each set, exclusive of this error, was $\pm 0''.54$.* In other words, in this series of observations the error peculiar to each night, which could not have been eliminated by increasing the number of observations on that night, was two-thirds as large, on an average, as the error of observation in the result from a single set. Similarly, from the published results of 418 sets of micrometric observations on 8 nights at a European station,† it follows that the error peculiar to each night was $\pm 0''.55$, while the probable error of a single set was $\pm 0''.80$. The micrometric observations are peculiarly adapted to exhibiting this error, because of their great accuracy and the rapidity with which they may be taken. Azimuth was observed at 73 stations on the transcontinental triangulation along the thirty-ninth parallel. Most of these observations were taken by the direction method, and although they are, for various reasons, but poorly adapted, as a rule, to exhibiting the errors peculiar to the separate nights, there are no less than 16 cases out of the 73 in which a mere inspection indicates that there were errors of that character.

The most plausible explanation of the above facts seems to be that there is lateral refraction between the mark and the instrument, dependent upon the peculiar atmospheric conditions of each night. Whether that explanation be true or not, the fact remains that an increase of accuracy in an azimuth determination at a given station may be attained much more readily by increasing the number of nights of observation than by increasing the number of sets on each night. If one series of observations is made early in the evening and another series just before dawn on the same night, these series may be considered, in so far as the preceding sentence is concerned, to be on different nights, as the atmospheric conditions will have been given an opportunity to change.

The positions of the four principal close circumpolars have been determined by so many observations at the fixed observatories under such favorable conditions that it is difficult to believe that the errors in their adopted right ascensions and declinations are sufficiently large to produce errors in the computed azimuths that are otherwise than small in comparison with the other errors involved in the azimuth observations. On

* See Report of International Boundary Commission, United States and Mexico, 1891–96 (Washington, 1898), pp. 69–72.

† Station Kampenwand. See pp. 68–92, Veröffentlichung der Königl. Bayerischen Commission für die Internationale Erdmessung, Astronomische-Geodätische Arbeiten, Heft 2 (München, 1897).

the other hand, when Polaris (or some other circumpolar) has been observed at both culminations or both elongations, at a given station, the observations at one culmination (or elongation) have often shown a tendency to differ by a constant from those at the other culmination (or elongation), as if the adopted right ascension (or declination) was in error. It should be borne in mind in such cases that the atmospheric conditions have been reversed, so to speak, between the culminations (or elongations); for in one case the temperature will be rising and in the other falling, in general, the two cases occurring at the extreme ends of darkness or of light, or one in the darkness and the other in the light. Hence only a long and careful investigation will determine whether such constant differences are due to defective star places or to changed atmospheric conditions. It is important from a practical point of view to note that if the azimuth observations at a station are all made upon one star and are equally distributed between two hour-angles, differing by about twelve hours, the mean result will be sensibly independent of the errors of the adopted right ascension and declination, and the conditions will be decidedly favorable to eliminating the effects of lateral refraction from the mean result.

An error in the adopted latitude of the station produces the maximum effect when the star is observed at elongation and is without effect if the star is observed at culmination. For Polaris at elongation, to produce an error of 0″·01 in the computed azimuth the adopted latitude must be in error by 0″·70 for a station in latitude 30°, and by 0″·14 for a station in latitude 60°. The error in the computed latitude from this source will be larger for a star farther from the pole. The astronomic latitude (defined by the actual line of gravity at the station) is required for the computation, and not the geodetic latitude. This error, which will in general be very small, will also be eliminated by observing the star at two positions about twelve hours apart.

The *observer's errors* are his errors of pointing upon the mark and star, errors of pointing upon the circle graduation if reading microscopes are used, errors of vernier reading if verniers are used, errors of reading the micrometer heads, errors in reading the striding level, and errors in estimating the times of the star pointings. There is such a large range of difference in the designs of the various instruments used for azimuth observations that little can be said of the relative and absolute magnitude of these errors that will be of general application. Each observer should investigate these errors for himself with the particular instrument in hand. It will be found in general that the observer's errors play a minor part in furnishing the final errors of the results, except perhaps in the micrometric method.

The effect of errors in time, either errors in estimating the times of the star pointings, the personal equation of the observer, or errors in the adopted chronometer correction, may be estimated by noting the rate at which the star was moving in azimuth when the observations were made. Such errors are usually small, but not insensible except near elongation, and will tend to be eliminated by observations of the same star at two hour-angles differing by about twelve hours.

Of the magnitude of the *instrumental errors* arising from imperfect adjustment and imperfect construction and imperfect stability little of general application can be said, because of the great variety of the instruments.

With the larger and more powerful instruments the errors due to instability become relatively great and should be guarded against by careful manipulation and rapid observ-

ing, by using a carefully planned programme of observations, and by protecting the instrument against temperature changes as far as possible. In this connection it should be noted that each of the programmes of observation given on the preceding pages is especially adapted to elimination of the effect of any continuous twisting of the instrument in azimuth, and is so planned that the observer will not ordinarily lose time in waiting for the bubble of the striding level to come to rest. That observer of azimuth will be most successful in avoiding errors due to instability who keeps it most clearly and continuously in mind that the instrument and its support are made of elastic material of such a large coefficient of thermal expansion that no part remains of fixed dimensions or shape. He will be especially careful about the thermal conditions and the stresses to which his instrument is subjected and will observe with the greatest rapidity consistent with allowable observer's errors.

The errors due to the striding level become more serious the farther north is the station, as may be seen by inspection of the formula for the level correction (p. 384).

The errors of graduation of the horizontal circle have the same effect in azimuth observations as in observations of horizontal angles. The number of positions in which the circle must be used in the direction method may therefore be decided upon the same basis as in the angle measurements.

The micrometric method gives a higher degree of accuracy than either the method of repetitions or the method of directions. This is probably due largely to the great rapidity with which the observations may be made, a condition which is very favorable to the elimination of errors due to instability of the instrument and its support. The error, in the final result for a station by this method, due to an error in the adopted value of one turn of the micrometer may be made very small by so placing the azimuth mark (or marks) and so timing the observations that the sum of the angles measured eastward from the mark (or marks) to the star shall be nearly equal to the sum of such angles measured westward.

AZIMUTH FROM TIME OBSERVATIONS.

69. Azimuths of a secondary degree of accuracy for use in connection with rapid triangulation in Alaska, or in connection with a small triangulation serving to connect a longitude station with the nearest triangulation station, may be obtained with little extra work from the observations with a transit or meridian telescope nearly in the meridian, which serve to determine the time. To do so, establish a meridian mark approximately in the meridian of the transit either to the southward or northward of it. At the beginning, or end, or during each half-set of time observations, turn the telescope upon the mark and measure from the middle line of the reticle to the azimuth mark with the eyepiece micrometer, if the instrument is provided with one which is in the proper position. If not, estimate the interval from the middle line to the azimuth mark in terms of the space between the middle line and the adjacent line of the reticle. The azimuth and collimation corrections as derived from the time observations combined by simple addition and subtraction with the equatorial interval of the middle line, and with the observed interval between the middle line and the mark, will give the azimuth of the mark.

The following computation will serve as a concrete illustration:

Computation of azimuth from time observations.

St. Michael, Alaska. 1898. Meridian telescope No. 13.

One space of reticle, $3^{s}\cdot455$.

Mark to southward.

Date	July 13.		July 14.		July 15.	
Circle	E.	W.	E.	W.	E.	W.
	s.	s.	s.	s.	s.	s.
a	+0·39	+0·86	+0·40	+0·72	+1·75	+1·63
c	+0·12	−0·12	+0·18	−0·18	+1·16	−1·16
Eq. int. of center line	0·00	0·00	0·00	0·00	0·00	0·00
	sp.	sp.	sp.	sp.	sp.	sp.
Mark east of " "	−0·2 −0·69	0·00 0·00	−0·175 −0·60	−0·025 −0·09	−0·75 −2·59	−0·15 −0·52
	s.	s.	s.	s.	s.	s.
Mark E. of S	−0·18	+0·74	−0·02	+0·45	+0·32	−0·05
"	−2″·7	+11″·1	−0″·3	+6″·8	+4″·8	−0″·8
Mean for set	+4″·2		+3″·2		+2″·0	

Date	July 18.		Sept. 13.		Sept. 17.	
Circle	E.	W.	E.	W.	E.	W.
	s.	s.	s.	s.	s.	s.
a	+2·78	+2·64	+0·41	+0·06	−2·01	−1·42
c	+1·32	−1·32	0·00	0·00	+0·52	−0·52
Eq. int. of center line	0·00	0·00	0·00	0·00	0·00	0·00
	sp.	sp.	sp.	sp.	sp.	sp.
Mark east of " "	−0·975 −3·37	−0·05 −0·17	0·00 0·00	0·00 0·00	+0·25 +0·86	+0·825 +2·85
	s.	s.	s.	s.	s.	s.
Mark E. of S	+0·73	+1·15	+0·41	+0·06	−0·63	+0·91
"	+11″·0	+17″·2	+6″·2	+0″·9	−9″·4	+13″·6
Mean for set	+14″·1		+3″·5		+2″·1	

Final mean, mark east of south 0° 00′ 04″·8.

The quantities *a* and *c*, azimuth and collimation *corrections*, being taken directly from the time computation without change of sign, the resulting computed azimuth is east of south (or west of north), the mark being to the southward (or northward). If the mark is very much above or below the horizon of the instrument it may be necessary to read the striding level and to multiply *c*, the equatorial interval of the center line, and the angle between the center line and mark each by $\operatorname{cosec}\zeta$.

The range of results here shown is a fair indication of the accuracy to be expected under the very unfavorable climatic and trigonometric conditions encountered in Alaska. Under the more favorable conditions encountered within the main portion of the United States a much higher degree of accuracy is attainable by this method.

NOTE.—The corrections of the computed azimuth for variation of the pole and for curvature of the vertical have not been treated in this Appendix. The law of variation of the pole can not yet be said to be satisfactorily known, and the correction for curvature of the vertical seems to be a geodetic rather than an astronomic matter.

$$Log \frac{I}{I-a}$$

Log a	0	1	2	3	4	5	6	7	8	9
9·00	+0·045758	5869	5980	6092	6204	6317	6429	6542	6656	6769
8·99	+0·044660	4769	4878	4987	5096	5205	5315	5425	5536	5647
98	3591	3697	3803	3909	4016	4122	4229	4337	4444	4552
97	2549	2652	2755	2858	2962	3066	3171	3275	3380	3486
96	1532	1633	1733	1834	1936	2037	2139	2241	2343	2446
95	+0·040541	0639	0737	0836	0935	1034	1133	1232	1332	1432
94	+0·039575	9670	9766	9862	9959	0055	0152	0249	0346	0443
93	8633	8726	8819	8913	9007	9101	9195	9290	9385	9480
92	7714	7805	7896	7987	8079	8171	8263	8355	8447	8540
91	6818	6907	6996	7085	7174	7263	7353	7443	7533	7624
8·90	+0·035944	6031	6118	6204	6291	6379	6466	6554	6642	6730
89	5092	5177	5261	5346	5431	5516	5601	5687	5772	5858
88	4261	4343	4426	4508	4591	4674	4757	4841	4924	5008
87	3451	3531	3611	3692	3772	3853	3934	4016	4097	4179
86	2660	2738	2816	2895	2974	3053	3132	3211	3291	3371
85	+0·031888	1965	2041	2118	2195	2272	2349	2426	2504	2582
84	1136	1210	1285	1360	1435	1510	1585	1660	1736	1812
83	0402	0474	0547	0620	0693	0766	0840	0914	0987	1061
82	+0·029685	9756	9827	9898	9970	0041	0113	0185	0257	0329
81	8987	9056	9125	9194	9264	9334	9404	9474	9544	9615
8·80	+0·028305	8372	8440	8508	8576	8644	8712	8780	8849	8918
79	7640	7705	7771	7838	7904	7970	8037	8103	8170	8237
78	6990	7055	7119	7183	7248	7313	7378	7443	7509	7574
77	6357	6420	6482	6545	6608	6672	6735	6799	6862	6926
76	5739	5800	5861	5923	5984	6046	6108	6170	6232	6294
75	+0·025136	5195	5255	5315	5375	5435	5496	5556	5617	5678
74	4547	4605	4664	4722	4781	4840	4899	4958	5017	5076
73	3973	4029	4086	4143	4201	4258	4316	4373	4431	4489
72	3412	3467	3523	3579	3635	3691	3747	3803	3859	3916
71	2865	2919	2973	3027	3082	3137	3191	3246	3301	3357
8·70	+0·022331	2383	2436	2489	2543	2596	2649	2703	2757	2811
69	1809	1861	1913	1964	2016	2068	2121	2173	2225	2278
68	1301	1351	1401	1452	1503	1553	1604	1655	1707	1758
67	0804	0853	0902	0952	1001	1051	1100	1150	1200	1250
66	0319	0367	0415	0463	0512	0560	0609	0657	0706	0755
65	+0·019846	9893	9940	9987	0034	0081	0128	0176	0223	0271
64	9384	9430	9475	9521	9567	9613	9660	9706	9752	9799
63	8933	8978	9022	9067	9112	9157	9202	9247	9293	9338
62	8493	8536	8580	8624	8667	8711	8755	8800	8844	8888
61	8063	8105	8148	8191	8233	8276	8319	8363	8406	8449
8·60	+0·017643	7685	7726	7768	7810	7852	7894	7936	7978	8020
59	7233	7274	7315	7355	7396	7437	7478	7519	7560	7602
58	6833	6873	6913	6952	6992	7032	7072	7112	7153	7193
57	6443	6482	6520	6559	6598	6637	6676	6715	6755	6794
56	6062	6099	6137	6175	6213	6251	6289	6328	6366	6404
55	+0·015689	5726	5763	5800	5837	5874	5912	5949	5986	6024
54	5326	5362	5398	5434	5470	5507	5543	5579	5616	5653
53	4971	5006	5041	5077	5112	5147	5183	5218	5254	5290
52	4624	4659	4693	4727	4762	4797	4831	4866	4901	4936
51	4286	4319	4353	4387	4420	4454	4488	4522	4556	4590
8·50	+0·013955	3988	4021	4054	4087	4120	4153	4186	4219	4253

Proportional parts

	111	108	105	102	99
1	11·1	10·8	10·5	10·2	9·9
2	22·2	21·6	21·0	20·4	19·8
3	33·3	32·4	31·5	30·6	29·7
4	44·4	43·2	42·0	40·8	39·6
5	55·5	54·0	52·5	51·0	49·5
6	66·6	64·8	63·0	61·2	59·4
7	77·7	75·6	73·5	71·4	69·3
8	88·8	86·4	84·0	81·6	79·2
9	99·9	97·2	94·5	91·8	89·1

	96	93	90	87	84
1	9·6	9·3	9·0	8·7	8·4
2	19·2	18·6	18·0	17·4	16·8
3	28·8	27·9	27·0	26·1	25·2
4	38·4	37·2	36·0	34·8	33·6
5	48·0	46·5	45·0	43·5	42·0
6	57·6	55·8	54·0	52·2	50·4
7	67·2	65·1	63·0	60·9	58·8
8	76·8	74·4	72·0	69·6	67·2
9	86·4	83·7	81·0	78·3	75·6

	81	78	75	72	69
1	8·1	7·8	7·5	7·2	6·9
2	16·2	15·6	15·0	14·4	13·8
3	24·3	23·4	22·5	21·6	20·7
4	32·4	31·2	30·0	28·8	27·6
5	40·5	39·0	37·5	36·0	34·5
6	48·6	46·8	45·0	43·2	41·4
7	56·7	54·6	52·5	50·4	48·3
8	64·8	62·4	60·0	57·6	55·2
9	72·9	70·2	67·5	64·8	62·1

	66	63	60	57	55
1	6·6	6·3	6·0	5·7	5·5
2	13·2	12·6	12·0	11·4	11·0
3	19·8	18·9	18·0	17·1	16·5
4	26·4	25·2	24·0	22·8	22·0
5	33·0	31·5	30·0	28·5	27·5
6	39·6	37·8	36·0	34·2	33·0
7	46·2	44·1	42·0	39·9	38·5
8	52·8	50·4	48·0	45·6	44·0
9	59·4	56·7	54·0	51·3	49·5

	53	51	49	47	45
1	5·3	5·1	4·9	4·7	4·5
2	10·6	10·2	9·8	9·4	9·0
3	15·9	15·3	14·7	14·1	13·5
4	21·2	20·4	19·6	18·8	18·0
5	26·5	25·5	24·5	23·5	22·5
6	31·8	30·6	29·4	28·2	27·0
7	37·1	35·7	34·3	32·9	31·5
8	42·4	40·8	39·2	37·6	36·0
9	47·7	45·9	44·1	42·3	40·5

	43	41	39	37	35
1	4·3	4·1	3·9	3·7	3·5
2	8·6	8·2	7·8	7·4	7·0
3	12·9	12·3	11·7	11·1	10·5
4	17·2	16·4	15·6	14·8	14·0
5	21·5	20·5	19·5	18·5	17·5
6	25·8	24·6	23·4	22·2	21·0
7	30·1	28·7	27·3	25·9	24·5
8	34·4	32·8	31·2	29·6	28·0
9	38·7	36·9	35·1	33·3	31·5

$$Log \frac{I}{I-a}$$

Log a	0	1	2	3	4	5	6	7	8	9
8·50	+0·013955	3988	4021	4054	4087	4120	4153	4186	4219	4253
49	3633	3665	3697	3729	3761	3793	3825	3858	3890	3923
48	3318	3349	3380	3411	3443	3474	3506	3537	3569	3601
47	3010	3040	3071	3101	3132	3163	3194	3225	3256	3287
46	2709	2739	2769	2799	2829	2859	2889	2919	2949	2979
45	+0·012416	2445	2474	2503	2532	2562	2591	2621	2650	2680
44	2129	2158	2186	2215	2243	2272	2300	2329	2358	2387
43	1849	1877	1905	1933	1961	1989	2017	2045	2073	2101
42	1576	1603	1630	1657	1685	1712	1739	1767	1794	1822
41	1309	1335	1362	1388	1415	1442	1468	1495	1522	1549
8·40	+0·011048	1074	1100	1126	1152	1178	1204	1230	1256	1283
39	0794	0819	0844	0869	0895	0920	0946	0971	0997	1023
38	0545	0570	0594	0619	0644	0669	0694	0718	0743	0769
37	0302	0326	0350	0374	0399	0423	0447	0472	0496	0520
36	0065	0088	0112	0135	0159	0183	0207	0230	0254	0278
35	+0·009833	9856	9879	9902	9925	9948	9972	9995	$\bar{0}$018	$\bar{0}$041
34	9607	9629	9652	9674	9697	9719	9742	9765	9787	9810
33	9386	9408	9430	9452	9474	9496	9518	9540	9562	9584
32	9170	9191	9213	9234	9256	9277	9299	9320	9342	9364
31	8959	8980	9001	9022	9043	9064	9085	9106	9127	9149
8·30	+0·008753	8773	8794	8814	8835	8855	8876	8897	8917	8938
29	8552	8572	8592	8612	8632	8652	8672	8692	8712	8733
28	8355	8375	8394	8414	8433	8453	8473	8492	8512	8532
27	8163	8182	8201	8220	8239	8259	8278	8297	8316	8336
26	7976	7994	8013	8031	8050	8069	8088	8106	8125	8144
25	+0·007792	7811	7829	7847	7865	7884	7902	7920	7939	7957
24	7614	7631	7649	7667	7685	7702	7720	7738	7756	7774
23	7439	7456	7473	7491	7508	7526	7543	7561	7578	7596
22	7268	7285	7302	7319	7336	7353	7370	7387	7404	7421
21	7101	7118	7134	7151	7167	7184	7201	7218	7234	7251
8·20	+0·006938	6954	6971	6987	7003	7019	7036	7052	7068	7085
19	6779	6795	6811	6826	6842	6858	6874	6890	6906	6922
18	6624	6639	6654	6670	6685	6701	6716	6732	6748	6763
17	6472	6487	6502	6517	6532	6547	6562	6578	6593	6608
16	6323	6338	6353	6367	6382	6397	6412	6427	6442	6457
15	+0·006178	6193	6207	6221	6236	6250	6265	6279	6294	6309
14	6037	6051	6065	6079	6093	6107	6121	6135	6150	6164
13	5898	5912	5926	5940	5953	5967	5981	5995	6009	6023
12	5763	5777	5790	5803	5817	5830	5844	5857	5871	5885
11	5631	5644	5657	5670	5684	5697	5710	5723	5737	5750
8·10	+0·005502	5515	5528	5541	5553	5566	5579	5592	5605	5618
09	5376	5389	5401	5414	5426	5439	5451	5464	5477	5489
08	5253	5265	5277	5290	5302	5314	5327	5339	5351	5364
07	5133	5145	5157	5169	5181	5193	5205	5217	5229	5241
06	5015	5027	5038	5050	5062	5074	5085	5097	5109	5121
05	4900	4912	4923	4935	4946	4957	4969	4980	4992	5004
04	4788	4799	4810	4822	4833	4844	4855	4866	4878	4889
03	4679	4690	4700	4711	4722	4733	4744	4755	4766	4777
02	4572	4582	4593	4603	4614	4625	4636	4646	4657	4668
01	4467	4477	4488	4498	4509	4519	4529	4540	4550	4561
8·00	+0·004365	4375	4385	4395	4405	4416	4426	4436	4446	4457

Proportional parts

	34	33	32	31	30
1	3·4	3·3	3·2	3·1	3·0
2	6·8	6·6	6·4	6·2	6·0
3	10·2	9·9	9·6	9·3	9·0
4	13·6	13·2	12·8	12·4	12·0
5	17·0	16·5	16·0	15·5	15·0
6	20·4	19·8	19·2	18·6	18·0
7	23·8	23·1	22·4	21·7	21·0
8	27·2	26·4	25·6	24·8	24·0
9	30·6	29·7	28·8	27·9	27·0

	29	28	27	26	25
1	2·9	2·8	2·7	2·6	2·5
2	5·8	5·6	5·4	5·2	5·0
3	8·7	8·4	8·1	7·8	7·5
4	11·6	11·2	10·8	10·4	10·0
5	14·5	14·0	13·5	13·0	12·5
6	17·4	16·8	16·2	15·6	15·0
7	20·3	19·6	18·9	18·2	17·5
8	23·2	22·4	21·6	20·8	20·0
9	26·1	25·2	24·3	23·4	22·5

	24	23	22	21	20
1	2·4	2·3	2·2	2·1	2·0
2	4·8	4·6	4·4	4·2	4·0
3	7·2	6·9	6·6	6·3	6·0
4	9·6	9·2	8·8	8·4	8·0
5	12·0	11·5	11·0	10·5	10·0
6	14·4	13·8	13·2	12·6	12·0
7	16·8	16·1	15·4	14·7	14·0
8	19·2	18·4	17·6	16·8	16·0
9	21·6	20·7	19·8	18·9	18·0

	19	18	17	16	15
1	1·9	1·8	1·7	1·6	1·5
2	3·8	3·6	3·4	3·2	3·0
3	5·7	5·4	5·1	4·8	4·5
4	7·6	7·2	6·8	6·4	6·0
5	9·5	9·0	8·5	8·0	7·5
6	11·4	10·8	10·2	9·6	9·0
7	13·3	12·6	11·9	11·2	10·5
8	15·2	14·4	13·6	12·8	12·0
9	17·1	16·2	15·3	14·4	13·5

	14	13	12	11	10
1	1·4	1·3	1·2	1·1	1·0
2	2·8	2·6	2·4	2·2	2·0
3	4·2	3·9	3·6	3·3	3·0
4	5·6	5·2	4·8	4·4	4·0
5	7·0	6·5	6·0	5·5	5·0
6	8·4	7·8	7·2	6·6	6·0
7	9·8	9·1	8·4	7·7	7·0
8	11·2	10·4	9·6	8·8	8·0
9	12·6	11·7	10·8	9·9	9·0

$$Log \frac{I}{I-a}$$

Log a.	0	1	2	3	4	5.	6	7	8	9
8·00	+0·004365	4375	4385	4395	4405	4416	4426	4436	4446	4457
7·99	4265	4275	4285	4295	4305	4315	4325	4335	4345	4355
98	4167	4177	4187	4196	4206	4216	4226	4235	4245	4255
97	4072	4082	4091	4100	4110	4119	4129	4139	4148	4158
96	3979	3988	3997	4007	4016	4025	4035	4044	4053	4063
95	+0·003888	3897	3906	3915	3924	3933	3942	3951	3961	3970
94	3799	3808	3817	3826	3834	3843	3852	3861	3870	3879
93	3712	3721	3729	3738	3747	3755	3764	3773	3782	3790
92	3627	3636	3644	3653	3661	3670	3678	3687	3695	3704
91	3545	3553	3561	3569	3577	3586	3594	3602	3611	3619
7·90	+0·003463	3472	3480	3488	3496	3504	3512	3520	3528	3536
89	3384	3392	3400	3408	3416	3424	3432	3440	3448	3456
88	3307	3315	3322	3330	3338	3345	3353	3361	3369	3377
87	3231	3239	3246	3254	3261	3269	3277	3284	3292	3299
86	3158	3165	3172	3180	3187	3194	3202	3209	3217	3224
85	+0·003086	3093	3100	3107	3114	3121	3129	3136	3143	3150
84	3015	3022	3029	3036	3043	3050	3057	3064	3071	3078
83	2946	2953	2960	2967	2974	2980	2987	2994	3001	3008
82	2879	2886	2892	2899	2906	2912	2919	2926	2933	2939
81	2813	2820	2826	2833	2839	2846	2852	2859	2866	2872
7·80	+0·002749	2755	2762	2768	2774	2781	2787	2794	2800	2807
79	2686	2692	2699	2705	2711	2717	2724	2730	2736	2743
78	2625	2631	2637	2643	2649	2655	2661	2668	2674	2680
77	2565	2571	2577	2583	2589	2595	2601	2607	2613	2619
76	2506	2512	2518	2524	2530	2535	2541	2547	2553	2559
75	+0·002449	2455	2460	2466	2472	2478	2483	2489	2495	2501
74	2393	2399	2404	2410	2415	2421	2427	2432	2438	2443
73	2339	2344	2349	2355	2360	2366	2371	2377	2382	2388
72	2285	2290	2296	2301	2306	2312	2317	2322	2328	2333
71	2233	2238	2243	2249	2254	2259	2264	2269	2275	2280
7·70	+0·002182	2187	2192	2197	2202	2207	2213	2218	2223	2228
69	2132	2137	2142	2147	2152	2157	2162	2167	2172	2177
68	2084	2088	2093	2098	2103	2108	2113	2118	2122	2127
67	2036	2041	2046	2050	2055	2060	2065	2069	2074	2079
66	1990	1994	1999	2003	2008	2013	2017	2022	2027	2031
65	+0·001944	1949	1953	1958	1962	1967	1971	1976	1980	1985
64	1900	1904	1909	1913	1918	1922	1926	1931	1935	1940
63	1857	1861	1865	1869	1874	1878	1882	1887	1891	1896
62	1814	1818	1823	1827	1831	1835	1840	1844	1848	1852
61	1773	1777	1781	1785	1789	1793	1798	1802	1806	1810
7·60	+0·001732	1736	1740	1744	1748	1753	1757	1761	1765	1769
59	1693	1697	1701	1705	1709	1713	1716	1720	1724	1728
58	1654	1658	1662	1666	1670	1673	1677	1681	1685	1689
57	1617	1620	1624	1628	1632	1635	1639	1643	1647	1650
56	1580	1583	1587	1591	1594	1598	1602	1605	1609	1613
55	+0·001544	1547	1551	1554	1558	1562	1565	1569	1572	1576
54	1508	1512	1515	1519	1522	1526	1529	1533	1537	1540
53	1474	1477	1481	1484	1488	1491	1495	1498	1502	1505
52	1440	1444	1447	1450	1454	1457	1461	1464	1467	1471
51	1408	1411	1414	1417	1421	1424	1427	1431	1434	1437
7·50	+0·001376	1379	1382	1385	1388	1391	1395	1398	1401	1404

Proportional parts

	11	10
1	1·1	1·0
2	2·2	2·0
3	3·3	3·0
4	4·4	4·0
5	5·5	5·0
6	6·6	6·0
7	7·7	7·0
8	8·8	8·0
9	9·9	9·0

	9	8
1	0·9	0·8
2	1·8	1·6
3	2·7	2·4
4	3·6	3·2
5	4·5	4·0
6	5·4	4·8
7	6·3	5·6
8	7·2	6·4
9	8·1	7·2

	7	6
1	0·7	0·6
2	1·4	1·2
3	2·1	1·8
4	2·8	2·4
5	3·5	3·0
6	4·2	3·6
7	4·9	4·2
8	5·6	4·8
9	6·3	5·4

	5	4
1	0·5	0·4
2	1·0	0·8
3	1·5	1·2
4	2·0	1·6
5	2·5	2·0
6	3·0	2·4
7	3·5	2·8
8	4·0	3·2
9	4·5	3·6

$$Log \frac{I}{I-a}$$

Log a	0	1	2	3	4	5	6	7	8	9
7'50	+0'001376	1379	1382	1385	1388	1391	1395	1398	1401	1404
49	1344	1347	1350	1354	1357	1360	1363	1366	1369	1372
48	1314	1317	1320	1323	1326	1329	1332	1335	1338	1341
47	1284	1287	1290	1292	1295	1298	1301	1304	1307	1311
46	1254	1257	1260	1263	1266	1269	1272	1275	1278	1281
45	+0'001226	1229	1231	1234	1237	1240	1243	1246	1249	1251
44	1198	1201	1203	1206	1209	1212	1214	1217	1220	1223
43	1170	1173	1176	1179	1181	1184	1187	1190	1192	1195
42	1144	1146	1149	1152	1154	1157	1160	1162	1165	1168
41	1118	1120	1123	1126	1128	1131	1133	1136	1139	1141
7'40	+0'001092	1095	1097	1100	1102	1105	1107	1110	1113	1115
39	1067	1070	1072	1075	1077	1080	1082	1085	1087	1090
38	1043	1045	1048	1050	1053	1055	1058	1060	1062	1065
37	1019	1022	1024	1026	1029	1031	1033	1036	1038	1041
36	+0'000996	998	1001	1003	1005	1008	1010	1012	1015	1017
35	+0'000973	976	978	980	982	985	987	989	991	994
34	951	953	956	958	960	962	964	967	969	971
33	929	932	934	936	938	940	942	945	947	949
32	908	910	913	915	917	919	921	923	925	927
31	888	890	892	894	896	898	900	902	904	906
7'30	+0'000867	869	871	873	875	877	879	882	884	886
29	848	850	852	854	855	857	859	861	863	865
28	828	830	832	834	836	838	840	842	844	846
27	809	811	813	815	817	819	821	823	825	826
26	791	793	795	796	798	800	802	804	806	808
25	+0'000773	775	777	778	780	782	784	786	787	789
24	755	757	759	761	762	764	766	768	769	771
23	738	740	742	743	745	747	748	750	752	754
22	721	723	725	726	728	730	731	733	735	736
21	705	707	708	710	711	713	715	716	718	720
7'20	+0'000689	690	692	694	695	697	698	700	702	703
19	673	675	676	678	679	681	683	684	686	687
18	658	659	661	662	664	665	667	669	670	672
17	643	644	646	647	649	650	652	653	655	656
16	628	630	631	633	634	635	637	638	640	641
15	+0'000614	615	617	618	620	621	622	624	625	627
14	600	601	603	604	605	607	608	610	611	612
13	586	588	589	590	592	593	594	596	597	599
12	573	574	576	577	578	580	581	582	584	585
11	560	561	562	564	565	566	568	569	570	572
7'10	+0'000547	548	550	551	552	553	555	556	557	559
09	535	536	537	538	540	541	542	543	545	546
08	522	524	525	526	527	529	530	531	532	533
07	511	512	513	514	515	516	518	519	520	521
06	499	500	501	502	504	505	506	507	508	509
05	+0'000488	489	490	491	492	493	494	495	497	498
04	476	478	479	480	481	482	483	484	485	486
03	466	467	468	469	470	471	472	473	474	475
02	455	456	457	458	459	460	461	462	463	465
01	445	446	447	448	449	450	451	452	453	454
7'00	+0'000435	436	437	438	439	440	441	442	443	444

Proportional parts

	4	3
1	0'4	0'3
2	0'8	0'6
3	1'2	0'9
4	1'6	1'2
5	2'0	1'5
6	2'4	1'8
7	2'8	2'1
8	3'2	2'4
9	3'6	2'7

	2	1
1	0'2	0'1
2	0'4	0'2
3	0'6	0'3
4	0'8	0'4
5	1'0	0'5
6	1'2	0'6
7	1'4	0'7
8	1'6	0'8
9	1'8	0'9

$$Log \frac{I}{I-a}$$

Log a.	0	1	2	3	4	5	6	7	8	9
7·00	+0·000435	436	437	438	439	440	441	442	443	444
6·9	345	353	361	370	378	387	396	405	415	425
8	274	280	287	294	301	308	315	322	330	337
7	218	223	228	233	239	244	250	256	262	268
6	173	177	181	185	190	194	199	203	208	213
5	+0·000137	141	144	147	151	154	158	161	165	169
4	109	112	114	117	120	122	125	128	131	134
3	87	89	91	93	95	97	100	102	104	107
2	69	70	72	74	75	77	79	81	83	85
1	55	56	57	59	60	61	63	64	66	67
6·0	+0·000043	44	45	47	48	49	50	51	52	53
5·9	34	35	36	37	38	39	40	41	41	42
8	27	28	29	29	30	31	31	32	33	34
7	22	22	23	23	24	24	25	26	26	27
6	17	18	18	19	19	19	20	20	21	21
5	+0·000014	14	14	15	15	15	16	16	17	17
4	11	11	11	12	12	12	13	13	13	13
3	9	9	9	9	10	10	10	10	10	11
2	7	7	7	7	8	8	8	8	8	8
1	5	6	6	6	6	6	6	6	7	7
5·0	+0·000004	4	5	5	5	5	5	5	5	5
4	+0·000000	1	1	1	1	1	2	2	3	3
4· n	1·000000	9999	9999	9999	9999	9999	9998	9998	9997	9997
5·0 n	9·999996	96	95	95	95	95	95	95	95	95
1 n	95	94	94	94	94	94	94	94	93	93
2 n	93	93	93	93	92	92	92	92	92	92
3 n	91	91	91	91	90	90	90	90	90	89
4 n	89	89	89	88	88	88	87	87	87	87
5 n	9·999986	86	86	85	85	85	84	84	83	83
6 n	83	82	82	81	81	81	80	80	79	79
7 n	78	78	77	77	76	76	75	74	74	73
8 n	73	72	71	71	70	69	69	68	67	66
9 n	66	65	64	63	62	61	60	59	59	58
6·0 n	9·999957	56	55	53	52	51	50	49	48	47
1 n	45	44	43	41	40	39	37	36	34	33
2 n	31	30	28	26	25	23	21	19	17	15
3 n	13	11	09	07	05	03	01	898	896	893
4 n	9·999891	888	886	883	880	878	875	872	869	866
5 n	9·999863	859	856	853	849	846	842	839	835	831
6 n	827	823	819	815	810	806	802	797	792	787
7 n	782	777	772	767	761	756	750	744	738	732
8 n	726	720	713	706	700	693	685	678	671	663
9 n	655	647	639	631	622	613	604	595	585	576
7·00 n	9·999566	565	564	563	562	561	560	559	558	557

Proportional parts.

	10	9
1	1·0	0·9
2	2·0	1·8
3	3·0	2·7
4	4·0	3·6
5	5·0	4·5
6	6·0	5·4
7	7·0	6·3
8	8·0	7·2
9	9·0	8·1

	8	7
1	0·8	0·7
2	1·6	1·4
3	2·4	2·1
4	3·2	2·8
5	4·0	3·5
6	4·8	4·2
7	5·6	4·9
8	6·4	5·6
9	7·2	6·3

	6	5
1	0·6	0·5
2	1·2	1·0
3	1·8	1·5
4	2·4	2·0
5	3·0	2·5
6	3·6	3·0
7	4·2	3·5
8	4·8	4·0
9	5·4	4·5

	4	3
1	0·4	0·3
2	0·8	0·6
3	1·2	0·9
4	1·6	1·2
5	2·0	1·5
6	2·4	1·8
7	2·8	2·1
8	3·2	2·4
9	3·6	2·7

	2	1
1	0·2	0·1
2	0·4	0·2
3	0·6	0·3
4	0·8	0·4
5	1·0	0·5
6	1·2	0·6
7	1·4	0·7
8	1·6	0·8
9	1·8	0·9

$$Log \frac{1}{1-a}$$

Log a.	0	1	2	3	4	5	6	7	8	9
7·00 n	9·999566	565	564	563	562	561	560	559	558	557
01 n	556	555	554	553	552	551	550	549	548	547
02 n	545	544	543	542	541	540	539	538	537	536
03 n	535	534	533	532	531	530	528	527	526	525
04 n	524	523	522	521	520	519	517	516	515	514
05 n	9·999513	512	511	510	508	507	506	505	504	503
06 n	502	501	499	498	497	496	495	494	492	491
07 n	490	489	488	487	485	484	483	482	481	479
08 n	478	477	476	475	473	472	471	470	469	467
09 n	466	465	464	462	461	460	459	457	456	455
7·10 n	9·999454	452	451	450	449	447	446	445	443	442
11 n	441	440	438	437	436	434	433	432	430	429
12 n	428	427	425	424	423	421	420	419	417	416
13 n	415	413	412	410	409	408	406	405	404	402
14 n	401	400	398	397	395	394	393	391	390	388
15 n	9·999387	386	384	383	381	380	378	377	376	374
16 n	373	371	370	368	367	365	364	363	361	360
17 n	358	357	355	354	352	351	349	348	346	345
18 n	343	342	340	339	337	336	334	333	331	329
19 n	328	326	325	323	322	320	319	317	315	314
7·20 n	9·999312	311	309	307	306	304	303	301	299	298
21 n	296	295	293	291	290	288	286	285	283	282
22 n	280	278	277	275	273	272	270	268	266	265
23 n	263	261	260	258	256	255	253	251	249	247
24 n	246	244	242	241	239	237	235	234	232	230
25 n	9·999228	227	225	223	221	219	218	216	214	212
26 n	210	209	207	205	203	201	199	198	196	194
27 n	192	190	188	186	185	183	181	179	177	175
28 n	173	171	169	168	166	164	162	160	158	156
29 n	154	152	150	148	146	144	142	140	138	136
7·30 n	9·999134	132	130	128	126	124	122	120	118	116
31 n	114	112	110	108	106	104	102	100	098	096
32 n	094	091	089	087	085	083	081	079	077	075
33 n	072	070	068	066	064	062	060	057	055	053
34 n	051	049	047	044	042	040	038	036	033	031
35 n	9·999029	027	024	022	020	018	015	013	011	009
36 n	006	004	002	8999	8997	8995	8992	8990	8988	8985
37 n	9·998983	8981	8978	8976	8974	8971	8969	8967	8964	8962
38 n	8959	8957	8955	8952	8950	8947	8945	8943	8940	8938
39 n	8935	8933	8930	8928	8925	8923	8920	8918	8915	8913
7·40 n	9·998910	8908	8905	8903	8900	8898	8895	8893	8890	8888
41 n	8885	8883	8880	8877	8875	8872	8870	8867	8864	8862
42 n	8859	8857	8854	8851	8849	8846	8843	8841	8838	8835
43 n	8833	8830	8827	8825	8822	8819	8816	8814	8811	8808
44 n	8805	8803	8800	8797	8794	8792	8789	8786	8783	8781
45 n	9·998778	8775	8772	8769	8766	8764	8761	8758	8755	8752
46 n	8749	8746	8744	8741	8738	8735	8732	8729	8726	8723
47 n	8720	8717	8714	8711	8708	8705	8702	8699	8696	8693
48 n	8690	8687	8684	8681	8678	8675	8672	8669	8666	8663
49 n	8660	8657	8654	8651	8648	8644	8641	8638	8635	8632
7·50 n	9·998629	8626	8622	8619	8616	8613	8610	8607	8603	8600

Proportional parts.

	1	2
1	0·1	0·2
2	0·2	0·4
3	0·3	0·6
4	0·4	0·8
5	0·5	1·0
6	0·6	1·2
7	0·7	1·4
8	0·8	1·6
9	0·9	1·8

	3	4
1	0·3	0·4
2	0·6	0·8
3	0·9	1·2
4	1·2	1·6
5	1·5	2·0
6	1·8	2·4
7	2·1	2·8
8	2·4	3·2
9	2·7	3·6

$$Log \frac{I}{I-a}$$

Log a	0	1	2	3	4	5	6	7	8	9
7·50 n	9·998629	8626	8622	8619	8616	8613	8610	8607	8603	8600
51 n	8597	8594	8590	8587	8584	8581	8577	8574	8571	8568
52 n	8564	8561	8558	8554	8551	8548	8544	8541	8538	8534
53 n	8531	8528	8524	8521	8517	8514	8511	8507	8504	8500
54 n	8497	8493	8490	8486	8483	8479	8476	8472	8469	8465
55 n	9·998462	8458	8455	8451	8448	8444	8440	8437	8433	8430
56 n	8426	8422	8419	8415	8411	8408	8404	8400	8397	8393
57 n	8389	8386	8382	8378	8375	8371	8367	8363	8360	8356
58 n	8352	8348	8344	8341	8337	8333	8329	8325	8321	8318
59 n	8314	8310	8306	8302	8298	8294	8290	8286	8282	8278
7·60 n	9·998274	8271	8267	8263	8259	8255	8251	8246	8242	8238
61 n	8234	8230	8226	8222	8218	8214	8210	8206	8202	8197
62 n	8193	8189	8185	8181	8177	8172	8168	8164	8160	8156
63 n	8151	8147	8143	8139	8134	8130	8126	8121	8117	8113
64 n	8108	8104	8100	8095	8091	8087	8082	8078	8073	8069
65 n	9·998064	8060	8055	8051	8047	8042	8038	8033	8028	8024
66 n	8019	8015	8010	8006	8001	7997	7992	7987	7983	7978
67 n	7973	7969	7964	7959	7955	7950	7945	7941	7936	7931
68 n	7926	7922	7917	7912	7907	7902	7898	7893	7888	7883
69 n	7878	7873	7868	7863	7859	7854	7849	7844	7839	7834
7·70 n	9·997829	7824	7819	7814	7809	7804	7799	7794	7789	7783
71 n	7778	7773	7768	7763	7758	7753	7748	7742	7737	7732
72 n	7727	7722	7716	7711	7706	7700	7695	7690	7685	7679
73 n	7674	7669	7663	7658	7652	7647	7642	7636	7631	7625
74 n	7620	7614	7609	7603	7598	7592	7587	7581	7576	7570
75 n	9·997565	7559	7553	7548	7542	7537	7531	7525	7519	7514
76 n	7508	7502	7497	7491	7485	7479	7473	7468	7462	7456
77 n	7450	7444	7438	7433	7427	7421	7415	7409	7403	7397
78 n	7391	7385	7379	7373	7367	7361	7355	7349	7343	7337
79 n	7330	7324	7318	7312	7306	7300	7293	7287	7281	7275
7·80 n	9·997268	7262	7256	7250	7243	7237	7231	7224	7218	7211
81 n	7205	7199	7192	7186	7179	7173	7166	7160	7153	7147
82 n	7140	7134	7127	7120	7114	7107	7100	7094	7087	7080
83 n	7074	7067	7060	7053	7047	7040	7033	7026	7019	7013
84 n	7006	6999	6992	6985	6978	6971	6964	6957	6950	6943
85 n	9·996936	6929	6922	6915	6908	6901	6894	6887	6880	6872
86 n	6865	6858	6851	6844	6836	6829	6822	6814	6807	6800
87 n	6792	6785	6778	6770	6763	6755	6748	6740	6733	6725
88 n	6718	6710	6703	6695	6688	6680	6672	6665	6657	6650
89 n	6642	6634	6626	6619	6611	6603	6595	6587	6580	6572
7·90 n	9·996564	6556	6548	6540	6532	6524	6516	6508	6500	6492
91 n	6484	6476	6468	6460	6452	6444	6435	6427	6419	6411
92 n	6403	6394	6386	6378	6369	6361	6353	6344	6336	6328
93 n	6319	6311	6302	6294	6285	6277	6268	6260	6251	6242
94 n	6234	6225	6217	6208	6199	6190	6182	6173	6164	6155
95 n	9·996146	6138	6129	6120	6111	6102	6093	6084	6075	6066
96 n	6057	6048	6039	6030	6021	6012	6003	5993	5984	5975
97 n	5966	5956	5947	5938	5929	5919	5910	5900	5891	5882
98 n	5872	5863	5853	5844	5834	5825	5815	5805	5796	5786
99 n	5777	5767	5757	5747	5738	5728	5718	5708	5698	5689
8·00 n	9·995679	5669	5659	5649	5639	5629	5619	5609	5599	5589

Proportional parts

	4	5
1	0·4	0·5
2	0·8	1·0
3	1·2	1·5
4	1·6	2·0
5	2·0	2·5
6	2·4	3·0
7	2·8	3·5
8	3·2	4·0
9	3·6	4·5

	6	7
1	0·6	0·7
2	1·2	1·4
3	1·8	2·1
4	2·4	2·8
5	3·0	3·5
6	3·6	4·2
7	4·2	4·9
8	4·8	5·6
9	5·4	6·3

	8	9
1	0·8	0·9
2	1·6	1·8
3	2·4	2·7
4	3·2	3·6
5	4·0	4·5
6	4·8	5·4
7	5·6	6·3
8	6·4	7·2
9	7·2	8·1

	10	11
1	1·0	1·1
2	2·0	2·2
3	3·0	3·3
4	4·0	4·4
5	5·0	5·5
6	6·0	6·6
7	7·0	7·7
8	8·0	8·8
9	9·0	9·9

$$Log \frac{I}{I-a}$$

Log a	0	1	2	3	4	5	6	7	8	9
8·00 n	9·995679	5669	5659	5649	5639	5629	5619	5609	5599	5589
01 n	5578	5568	5558	5548	5538	5528	5517	5507	5497	5486
02 n	5476	5466	5455	5445	5434	5424	5413	5403	5392	5382
03 n	5371	5361	5350	5339	5329	5318	5307	5296	5286	5275
04 n	5264	5253	5242	5231	5220	5209	5198	5187	5176	5165
05 n	9·995154	5143	5132	5121	5110	5098	5087	5076	5065	5053
06 n	5042	5031	5019	5008	4996	4985	4973	4962	4950	4939
07 n	4927	4916	4904	4892	4881	4869	4857	4845	4833	4822
08 n	4810	4798	4786	4774	4762	4750	4738	4726	4714	4702
09 n	4690	4677	4665	4653	4641	4628	4616	4604	4591	4579
8·10 n	9·994567	4554	4542	4529	4517	4504	4492	4479	4466	4454
11 n	4441	4428	4415	4403	4390	4377	4364	4351	4338	4325
12 n	4312	4299	4286	4273	4260	4247	4234	4220	4207	4194
13 n	4181	4167	4154	4141	4127	4114	4100	4087	4073	4060
14 n	4046	4032	4019	4005	3991	3978	3964	3950	3936	3922
15 n	9·993908	3894	3880	3866	3852	3838	3824	3810	3796	3782
16 n	3767	3753	3739	3725	3710	3696	3681	3667	3652	3638
17 n	3623	3609	3594	3579	3565	3550	3535	3521	3506	3491
18 n	3476	3461	3446	3431	3416	3401	3386	3371	3356	3340
19 n	3325	3310	3295	3279	3264	3248	3233	3218	3202	3186
8·20 n	9·993171	3155	3140	3124	3108	3092	3077	3061	3045	3029
21 n	3013	2997	2981	2965	2949	2933	2917	2900	2884	2868
22 n	2852	2835	2819	2803	2786	2770	2753	2736	2720	2703
23 n	2687	2670	2653	2636	2619	2603	2586	2569	2552	2535
24 n	2518	2501	2483	2466	2449	2432	2414	2397	2380	2362
25 n	9·992345	2327	2310	2292	2275	2257	2239	2222	2204	2186
26 n	2168	2150	2132	2114	2096	2078	2060	2042	2024	2006
27 n	1987	1969	1951	1932	1914	1896	1877	1858	1840	1821
28 n	1803	1784	1765	1746	1727	1709	1690	1671	1652	1633
29 n	1613	1594	1575	1556	1537	1517	1498	1478	1459	1440
8·30 n	9·991420	1400	1381	1361	1341	1322	1302	1282	1262	1242
31 n	1222	1202	1182	1162	1142	1122	1101	1081	1061	1040
32 n	1020	0999	0979	0958	0938	0917	0896	0875	0855	0834
33 n	0813	0792	0771	0750	0729	0708	0686	0665	0644	0622
34 n	0601	0580	0558	0537	0515	0493	0472	0450	0428	0406
35 n	9·990385	0363	0341	0319	0297	0274	0252	0230	0208	0186
36 n	0163	0141	0118	0096	0073	0051	0028	0005	9982	9960
37 n	9·989937	9914	9891	9868	9845	9821	9798	9775	9752	9728
38 n	9705	9682	9658	9634	9611	9587	9563	9540	9516	9492
39 n	9468	9444	9420	9396	9372	9348	9323	9299	9275	9250
8·40 n	9·989226	9201	9177	9152	9127	9103	9078	9053	9028	9003
41 n	8978	8953	8928	8903	8877	8852	8827	8801	8776	8750
42 n	8725	8699	8673	8647	8622	8596	8570	8544	8518	8492
43 n	8465	8439	8413	8386	8360	8334	8307	8280	8254	8227
44 n	8200	8173	8147	8120	8093	8066	8038	8011	7984	7957
45 n	9·987929	7902	7874	7847	7819	7791	7764	7736	7708	7680
46 n	7652	7624	7596	7568	7539	7511	7483	7454	7426	7397
47 n	7369	7340	7311	7282	7253	7224	7195	7166	7137	7108
48 n	7079	7049	7020	6990	6961	6931	6902	6872	6842	6812
49 n	6782	6752	6722	6692	6662	6631	6601	6571	6540	6510
8·50 n	9·986479	6448	6418	6387	6356	6325	6294	6263	6232	6200

Proportional parts

	10	11	12	13	14
1	1·0	1·1	1·2	1·3	1·4
2	2·0	2·2	2·4	2·6	2·8
3	3·0	3·3	3·6	3·9	4·2
4	4·0	4·4	4·8	5·2	5·6
5	5·0	5·5	6·0	6·5	7·0
6	6·0	6·6	7·2	7·8	8·4
7	7·0	7·7	8·4	9·1	9·8
8	8·0	8·8	9·6	10·4	11·2
9	9·0	9·9	10·8	11·7	12·6

	15	16	17	18	19
1	1·5	1·6	1·7	1·8	1·9
2	3·0	3·2	3·4	3·6	3·8
3	4·5	4·8	5·1	5·4	5·7
4	6·0	6·4	6·8	7·2	7·6
5	7·5	8·0	8·5	9·0	9·5
6	9·0	9·6	10·2	10·8	11·4
7	10·5	11·2	11·9	12·6	13·3
8	12·0	12·8	13·6	14·4	15·2
9	13·5	14·4	15·3	16·2	17·1

	20	21	22	23	24
1	2·0	2·1	2·2	2·3	2·4
2	4·0	4·2	4·4	4·6	4·8
3	6·0	6·3	6·6	6·9	7·2
4	8·0	8·4	8·8	9·2	9·6
5	10·0	10·5	11·0	11·5	12·0
6	12·0	12·6	13·2	13·8	14·4
7	14·0	14·7	15·4	16·1	16·8
8	16·0	16·8	17·6	18·4	19·2
9	18·0	18·9	19·8	20·7	21·6

	25	26	27	28	29
1	2·5	2·6	2·7	2·8	2·9
2	5·0	5·2	5·4	5·6	5·8
3	7·5	7·8	8·1	8·4	8·7
4	10·0	10·4	10·8	11·2	11·6
5	12·5	13·0	13·5	14·0	14·5
6	15·0	15·6	16·2	16·8	17·4
7	17·5	18·2	18·9	19·6	20·3
8	20·0	20·8	21·6	22·4	23·2
9	22·5	23·4	24·3	25·2	26·1

	30	31	32
1	3·0	3·1	3·2
2	6·0	6·2	6·4
3	9·0	9·3	9·6
4	12·0	12·4	12·8
5	15·0	15·5	16·0
6	18·0	18·6	19·2
7	21·0	21·7	22·4
8	24·0	24·8	25·6
9	27·0	27·9	28·8

$$Log \frac{I}{I-a}$$

Log. a	0	1	2	3	4	5	6	7	8	9
8·50 n	9·986479	6448	6418	6387	6356	6325	6294	6263	6232	6200
51 n	6169	6138	6106	6075	6043	6011	5980	5948	5916	5884
52 n	5852	5820	5788	5756	5723	5691	5659	5626	5593	5561
53 n	5528	5495	5462	5429	5396	5363	5330	5297	5263	5230
54 n	5197	5163	5129	5096	5062	5028	4994	4960	4926	4892
55 n	9·984858	4823	4789	4755	4720	4685	4651	4616	4581	4546
56 n	4511	4476	4441	4406	4370	4335	4300	4264	4228	4193
57 n	4157	4121	4085	4049	4013	3977	3941	3904	3868	3831
58 n	3795	3758	3721	3684	3648	3611	3573	3536	3499	3462
59 n	3424	3387	3349	3312	3274	3236	3198	3160	3122	3084
8·60 n	9·983046	3007	2969	2930	2892	2853	2814	2776	2737	2698
61 n	2658	2619	2580	2541	2501	2462	2422	2382	2343	2303
62 n	2263	2223	2183	2142	2102	2062	2021	1981	1940	1899
63 n	1858	1817	1776	1735	1694	1653	1611	1570	1528	1486
64 n	1444	1403	1361	1319	1276	1234	1192	1149	1107	1064
65 n	9·981022	0979	0936	0893	0850	0807	0763	0720	0677	0633
66 n	0589	0546	0502	0458	0414	0370	0325	0281	0237	0192
67 n	0147	0103	0058	0013	9968	9923	9878	9832	9787	9741
68 n	9·979695	9650	9604	9558	9512	9466	9420	9373	9327	9280
69 n	9234	9187	9140	9093	9046	8999	8952	8904	8857	8809
8·70 n	9·978762	8714	8666	8618	8570	8522	8473	8425	8376	8328
71 n	8279	8230	8181	8132	8083	8034	7985	7935	7885	7836
72 n	7786	7736	7686	7636	7586	7535	7485	7434	7384	7333
73 n	7282	7231	7180	7128	7077	7026	6974	6922	6870	6818
74 n	6766	6714	6662	6610	6557	6505	6452	6399	6346	6293
75 n	9·976240	6187	6133	6080	6026	5972	5918	5864	5810	5756
76 n	5702	5647	5593	5538	5483	5428	5373	5318	5262	5207
77 n	5152	5096	5040	4984	4928	4872	4816	4759	4703	4646
78 n	4589	4532	4475	4418	4361	4304	4246	4188	4131	4073
79 n	4015	3957	3898	3840	3781	3723	3664	3605	3546	3487
8·80 n	9·973428	3368	3309	3249	3189	3129	3069	3009	2949	2888
81 n	2828	2767	2706	2645	2584	2523	2461	2400	2338	2276
82 n	2215	2153	2090	2028	1966	1903	1840	1777	1714	1651
83 n	1588	1525	1461	1398	1334	1270	1206	1141	1077	1013
84 n	0948	0883	0818	0753	0688	0623	0557	0492	0426	0360
85 n	9·970294	0228	0161	0095	0028	9962	9895	9828	9760	9693
86 n	9·969626	9558	9490	9422	9354	9286	9218	9149	9081	9012
87 n	8943	8874	8804	8735	8666	8596	8526	8456	8386	8316
88 n	8245	8175	8104	8033	7962	7891	7819	7748	7676	7604
89 n	7532	7460	7388	7316	7243	7170	7097	7024	6951	6878
8·90 n	9·966804	6731	6657	6583	6509	6435	6360	6285	6211	6136
91 n	6061	5985	5910	5834	5759	5683	5607	5531	5454	5378
92 n	5301	5224	5147	5070	4992	4915	4837	4759	4681	4603
93 n	4525	4446	4368	4289	4210	4130	4051	3972	3892	3812
94 n	3732	3652	3571	3491	3410	3329	3248	3167	3086	3004
95 n	9·962922	2840	2758	2676	2594	2511	2428	2345	2262	2179
96 n	2095	2012	1928	1844	1760	1675	1591	1506	1421	1336
97 n	1251	1165	1080	0994	0908	0822	0735	0649	0562	0475
98 n	9·960388	0301	0213	0126	0038	9950	9862	9773	9685	9596
99 n	9·959507	9418	9329	9239	9149	9059	8969	8879	8789	8698
9·00 n	8607	8516	8425	8334	8242	8150	8058	7966	7874	7781

Proportional parts.					
	32	34	36	38	40
1	3·2	3·4	3·6	3·8	4·0
2	6·4	6·8	7·2	7·6	8·0
3	9·6	10·2	10·8	11·4	12·0
4	12·8	13·6	14·4	15·2	16·0
5	16·0	17·0	18·0	19·0	20·0
6	19·2	20·4	21·6	22·8	24·0
7	22·4	23·8	25·2	26·6	28·0
8	25·6	27·2	28·8	30·4	32·0
9	28·8	30·6	32·4	34·2	36·0
	42	44	46	48	50
1	4·2	4·4	4·6	4·8	5·0
2	8·4	8·8	9·2	9·6	10·0
3	12·6	13·2	13·8	14·4	15·0
4	16·8	17·6	18·4	19·2	20·0
5	21·0	22·0	23·0	24·0	25·0
6	25·2	26·4	27·6	28·8	30·0
7	29·4	30·8	32·2	33·6	35·0
8	33·6	35·2	36·8	38·4	40·0
9	37·8	39·6	41·4	43·2	45·0
	52	54	56	58	60
1	5·2	5·4	5·6	5·8	6·0
2	10·4	10·8	11·2	11·6	12·0
3	15·6	16·2	16·8	17·4	18·0
4	20·8	21·6	22·4	23·2	24·0
5	26·0	27·0	28·0	29·0	30·0
6	31·2	32·4	33·6	34·8	36·0
7	36·4	37·8	39·2	40·6	42·0
8	41·6	43·2	44·8	46·4	48·0
9	46·8	48·6	50·4	52·2	54·0
	62	64	66	68	70
1	6·2	6·4	6·6	6·8	7·0
2	12·4	12·8	13·2	13·6	14·0
3	18·6	19·2	19·8	20·4	21·0
4	24·8	25·6	26·4	27·2	28·0
5	31·0	32·0	33·0	34·0	35·0
6	37·2	38·4	39·6	40·8	42·0
7	43·4	44·8	46·2	47·6	49·0
8	49·6	51·2	52·8	54·4	56·0
9	55·8	57·6	59·4	61·2	63·0
	72	74	76	78	80
1	7·2	7·4	7·6	7·8	8·0
2	14·4	14·8	15·2	15·6	16·0
3	21·6	22·2	22·8	23·4	24·0
4	28·8	29·6	30·4	31·2	32·0
5	36·0	37·0	38·0	39·0	40·0
6	43·2	44·4	45·6	46·8	48·0
7	50·4	51·8	53·2	54·6	56·0
8	57·6	59·2	60·8	62·4	64·0
9	64·8	66·6	68·4	70·2	72·0
	82	84	86	88	90
1	8·2	8·4	8·6	8·8	9·0
2	16·4	16·8	17·2	17·6	18·0
3	24·6	25·2	25·8	26·4	27·0
4	32·8	33·6	34·4	35·2	36·0
5	41·0	42·0	43·0	44·0	45·0
6	49·2	50·4	51·6	52·8	54·0
7	57·4	58·8	60·2	61·6	63·0
8	65·6	67·2	68·8	70·4	72·0
9	73·8	75·6	77·4	79·2	81·0

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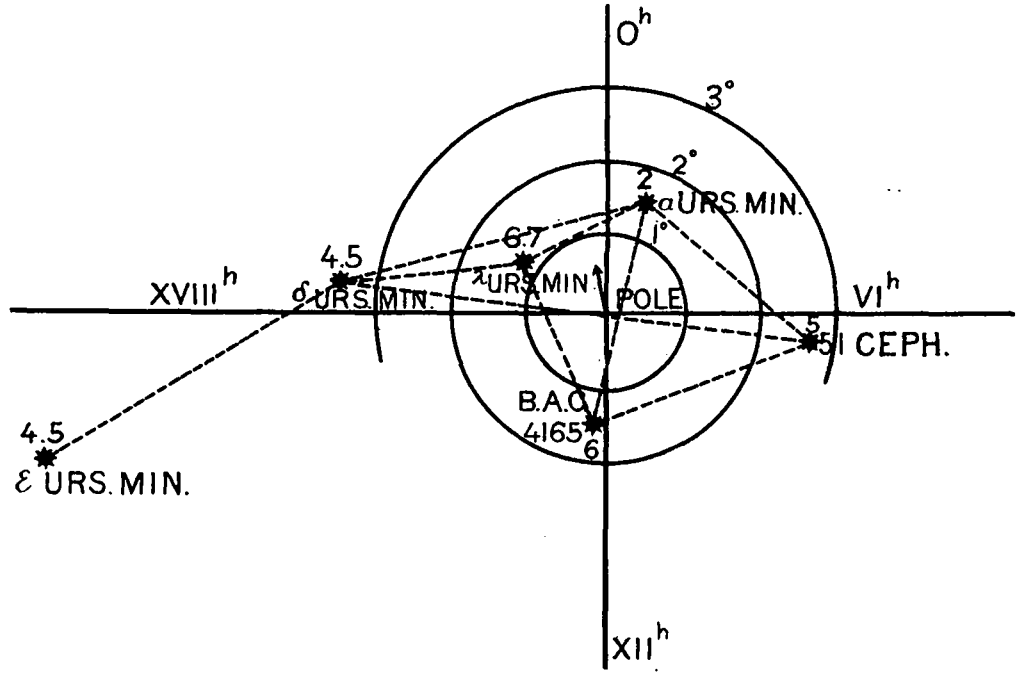
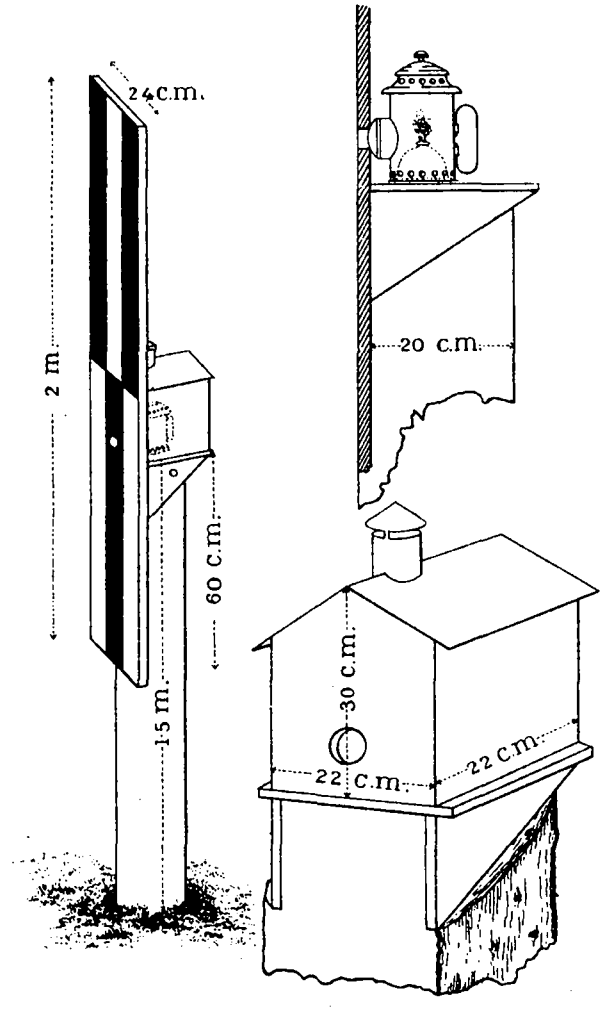


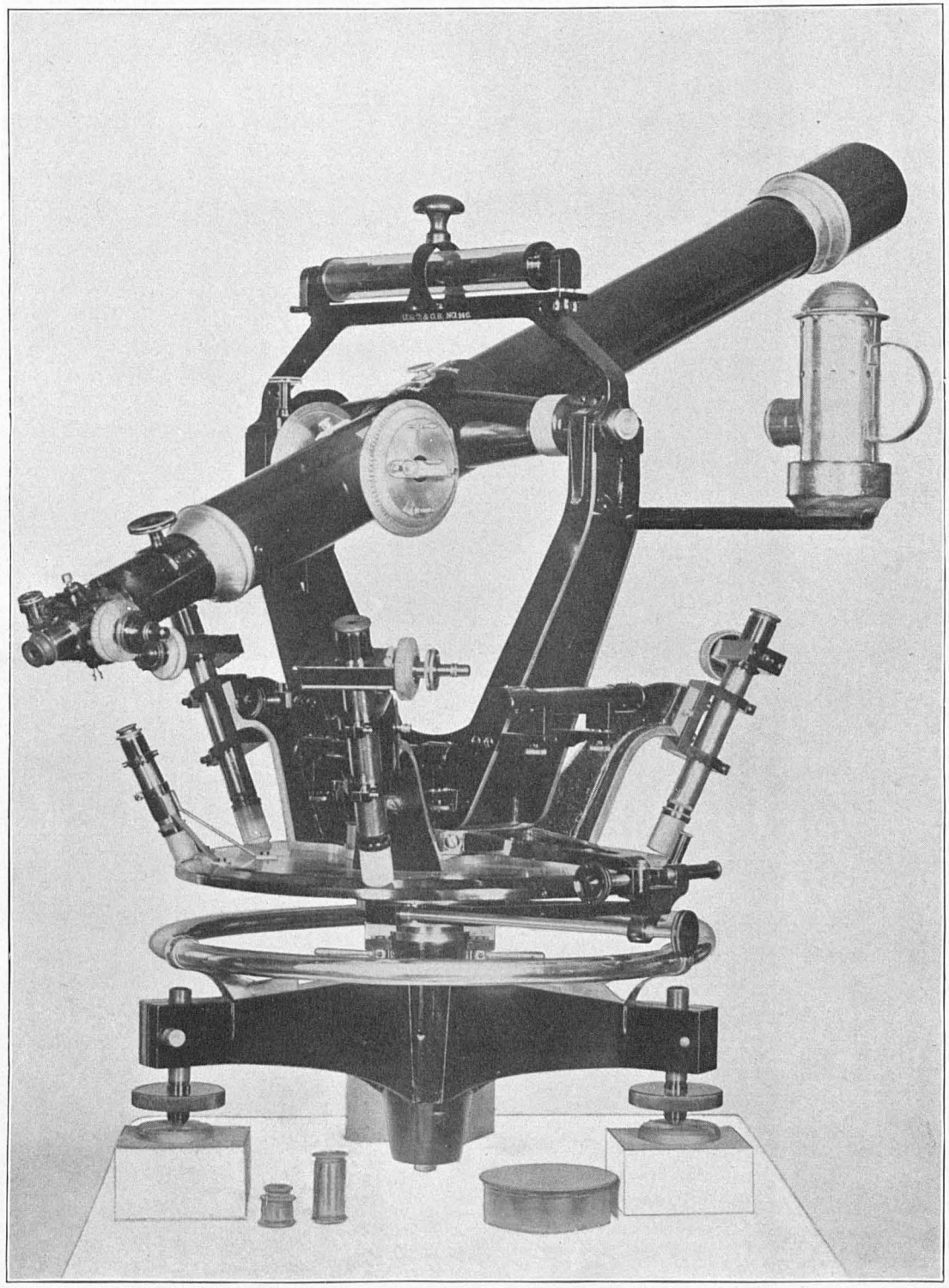
THE HORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

CIRCUMPOLARS

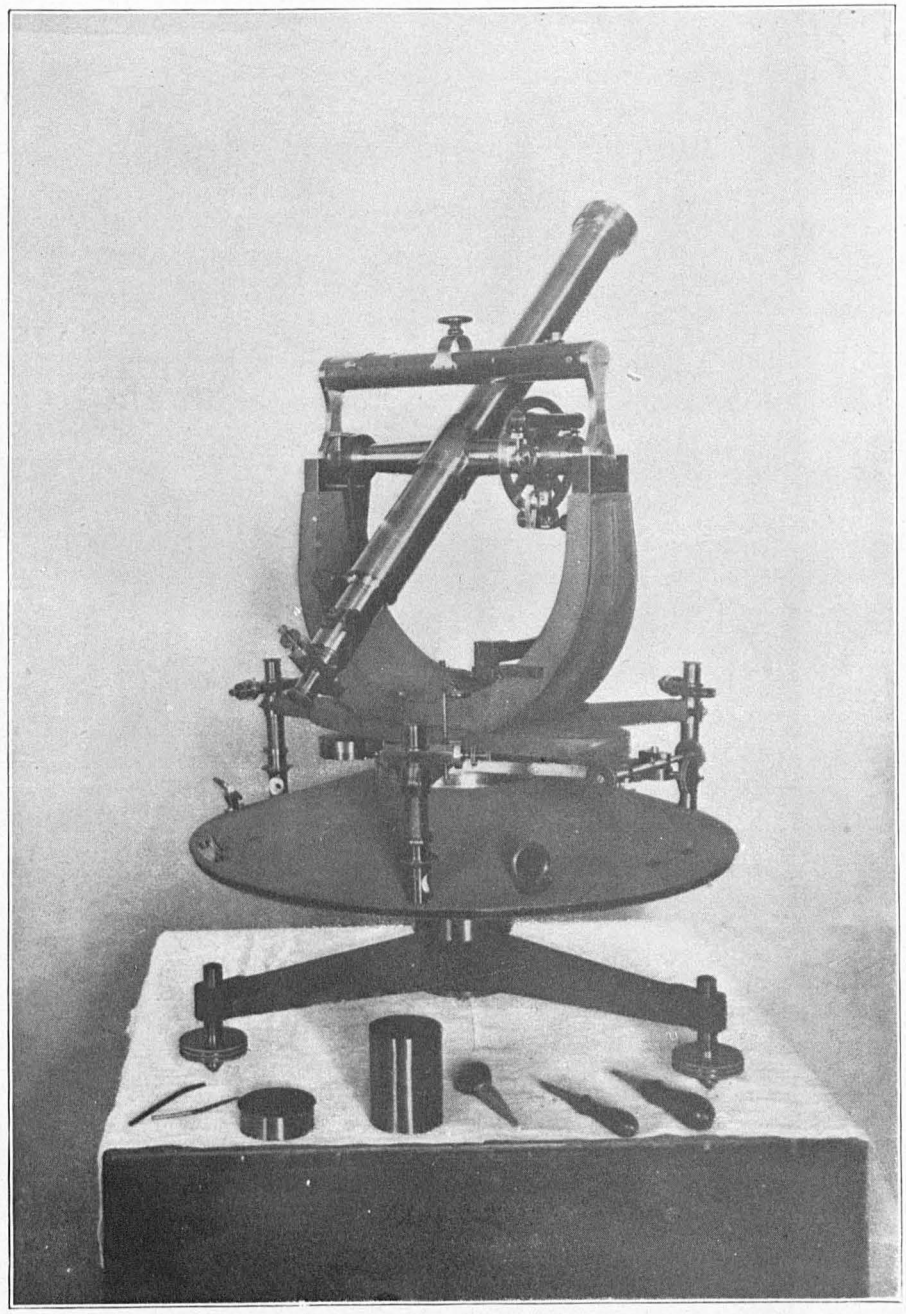


THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

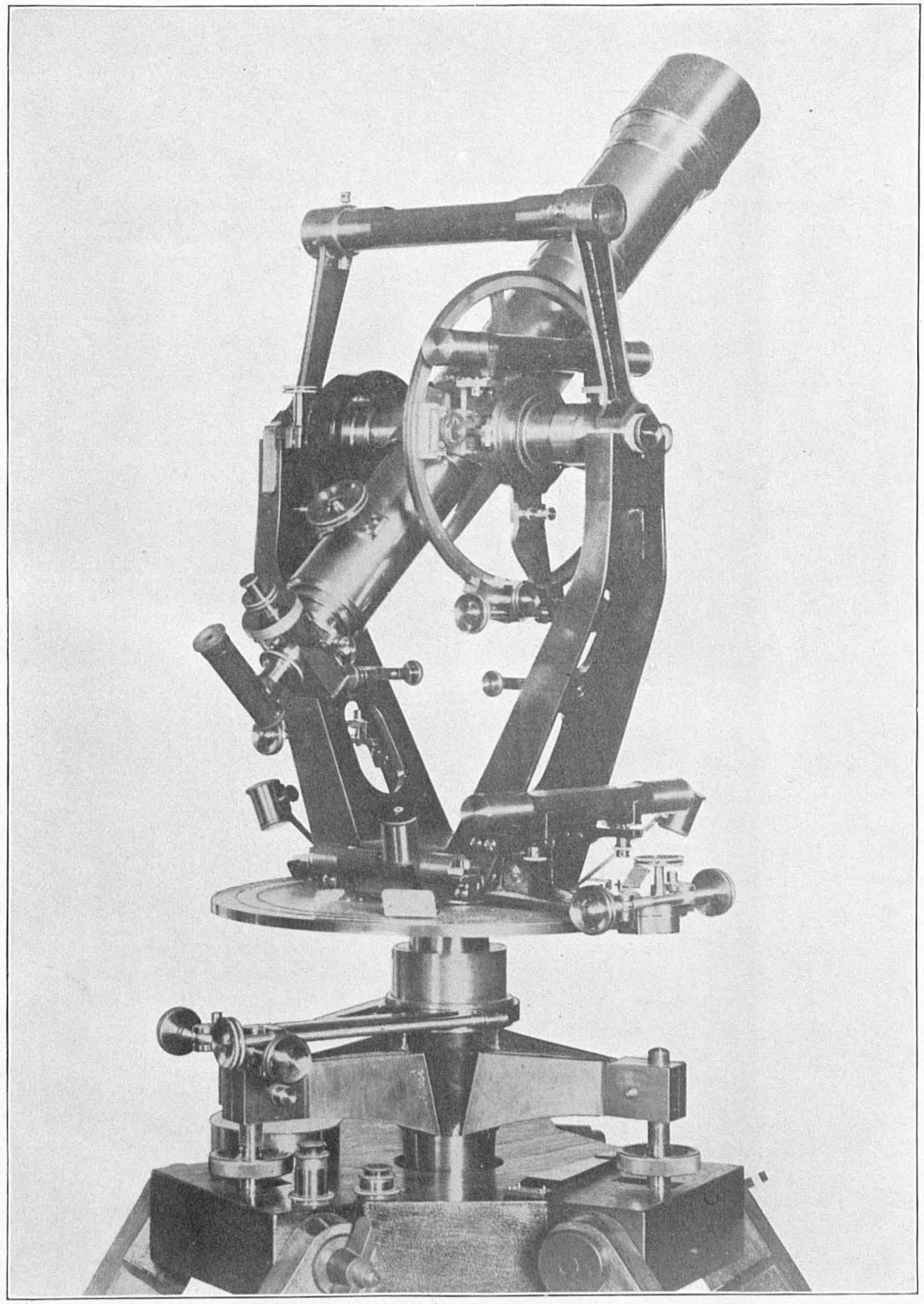
AZIMUTH MARK



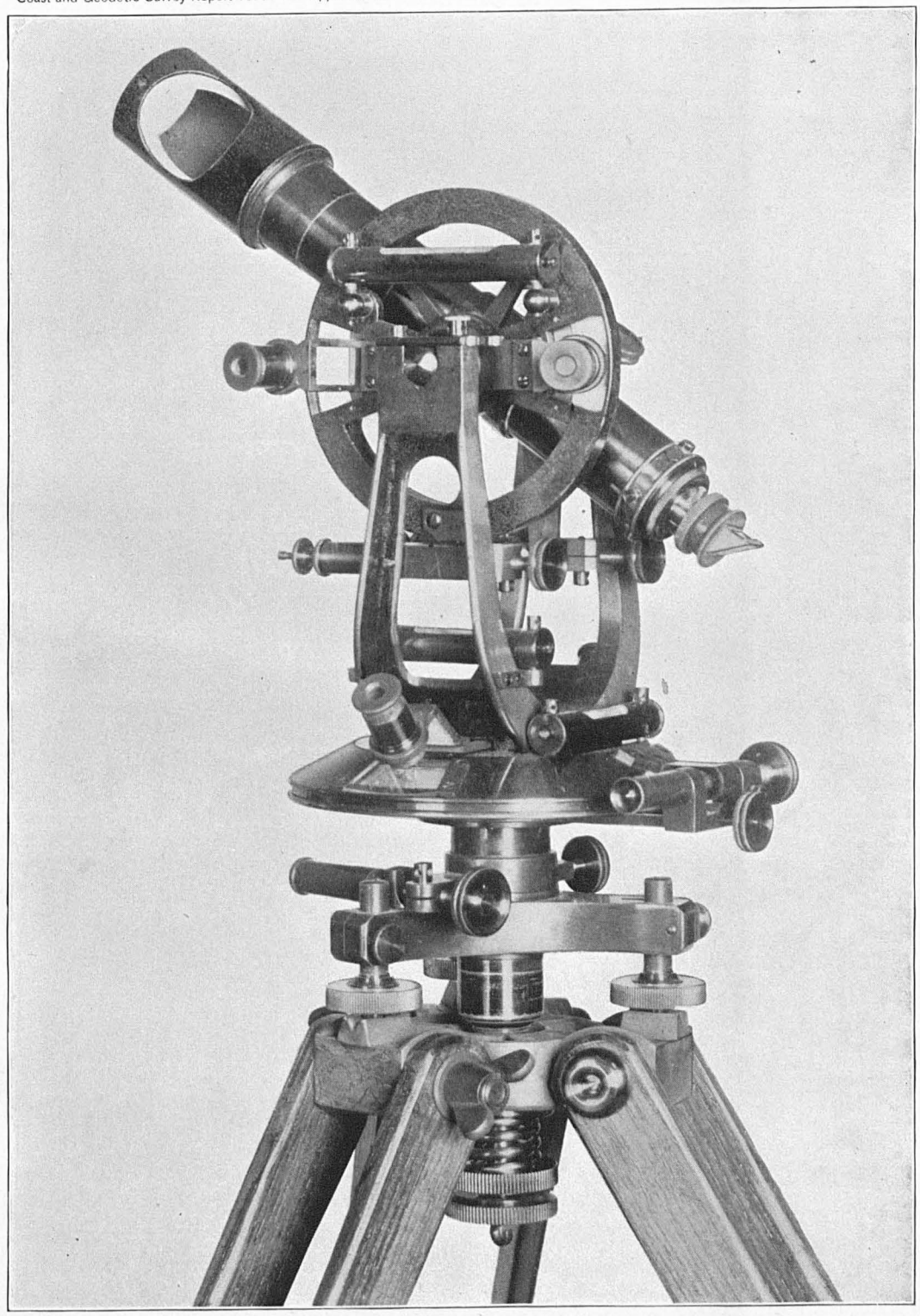
MODERN TWELVE-INCH THEODOLITE.



TWENTY-INCH THEODOLITE.



EIGHT-INCH REPEATING THEODOLITE.



FOUR-INCH THEODOLITE.

APPENDIX No. 8—1897-98.

A PLANE TABLE MANUAL.

By D. B. WAINWRIGHT, Assistant.

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APPENDIX No. 8—1897-98.

A PLANE TABLE MANUAL.

By D. B. WAINWRIGHT, *Assistant.*

a. PRELIMINARY STATEMENT.

A topographical map is the delineation upon a plane surface, by means of conventional signs, of the natural and artificial features of a locality.

Every point of the drawing corresponds to some geographical position, according to some method adopted for representing the surface of the spheroid on a plane, which is called the *projection.*

Since it is a representation in miniature, the distance between any two points on the map is a certain definite fraction of the distance between the same points in nature. This ratio is called the *scale.*

Each point, besides being projected on a horizontal plane, has its height, either within, above, or below a level surface, in some way indicated. The level surface adopted for the map is called the *datum plane*, and the representation of the variations in the vertical element, the modeling of the country, is called the *relief.*

CONTROL.

All topographical surveys of importance are based upon a system of triangulation.

A sufficient number of points, whose geographical positions have been determined in this manner, properly distributed over the area to be surveyed, forms a strong framework for controlling the accurate location of the various details.

a The edition of Appendix No. 13, Report of 1880, "A treatise on the plane table," by E. Hergesheimer, Assistant, being exhausted, a new edition has been prepared by the direction of the Superintendent, in which the material has been rearranged, some portions rewritten, and some additions made.

b. Instruments and Adjustments.

THE PLANE TABLE.

The principal instrument in use by the United States Coast and Geodetic Survey for mapping these details is the plane table. For this purpose it is a universal instrument. All the necessary operations for producing a map are executed with it in the field and directly from the country as a model.

Other instruments are employed as auxiliaries to it under certain conditions, as will be seen later on under the head of "Field practice," but in general it fulfills all requirements alone.

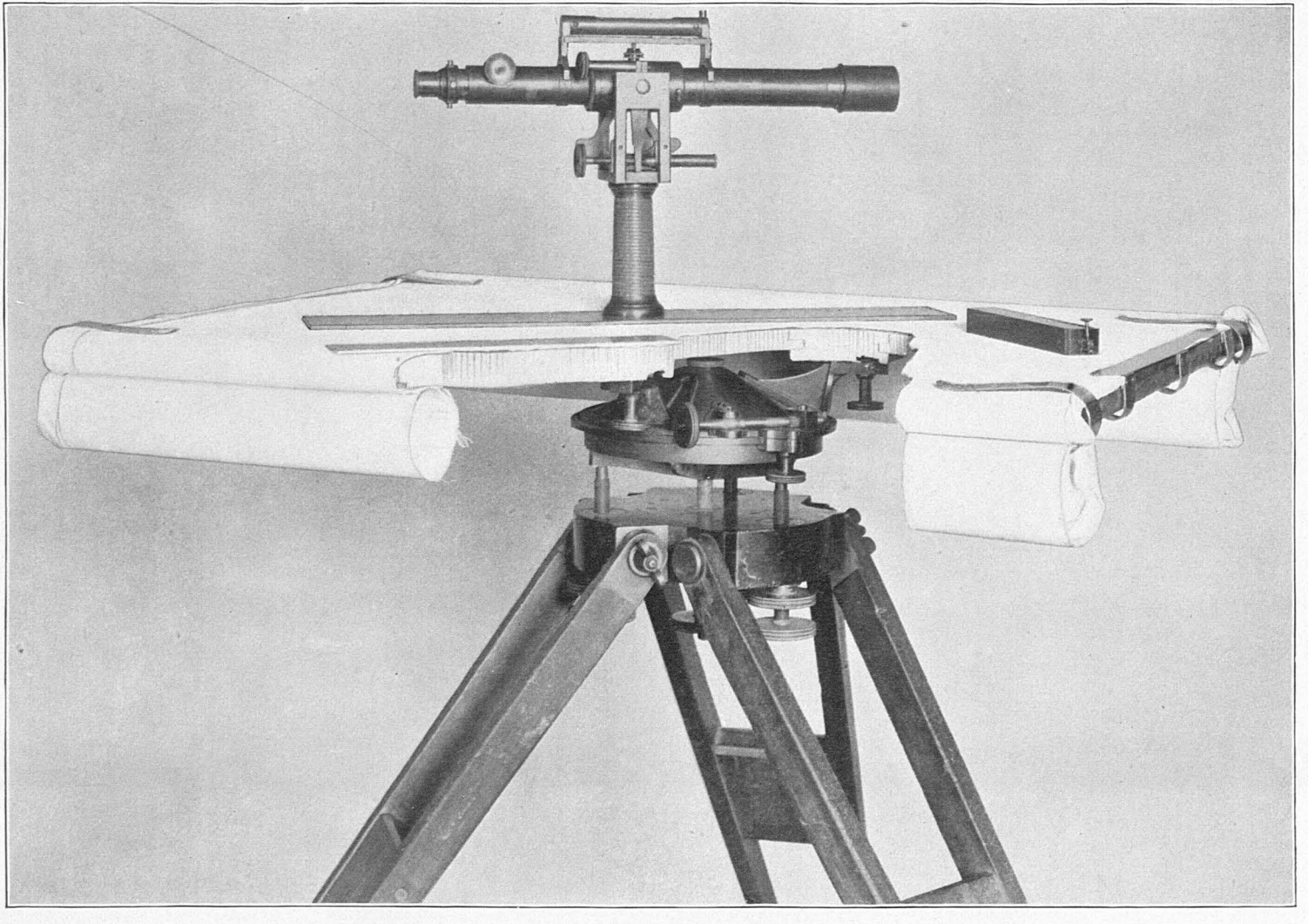
Description (Pl. 1).—The plane table is composed of a well-seasoned drawing board about 30 inches in length, 24 in width, three-quarters of an inch thick, with beveled or rounded edges. It is commonly made of several pieces of white pine, tongued and grooved together, with the grain running in different directions to prevent warping. It is supported upon three strong brass arms, to which it is attached by screws passing through them and entering the underside of the board, the three holes for the reception of the screws being guarded by brass bushings and situated equidistant from each other and from the center of the table. By means of these screws the board can be removed at will.

The movements (Pls. 1 and 2) of the tables in use by the Coast and Geodetic Survey are made from several different models, but as the principal features are the same in all designs the description of one type will to a large extent suffice for all.

The arms to which the board is fastened rest upon the sloping upper face of a rather flat hollow cone of brass, to which they are permanently fixed. Upon its lower edge or periphery this cone is fashioned into a horizontally projecting rim, the inferior face of which is as nearly as possible a perfect plane, and this in its turn rests upon a corresponding rim of somewhat greater diameter projecting slightly beyond it. This second rim forms the upper and outer flange of a circular metal disk in the form of a very shallow cylinder. The inferior face or plane of the upper flange or rim has, at its contact with the superior face of the lower, a horizontal rotary movement about a common center which is also the center of the instrument, and the two are held together by means of a solid conical axis of brass extending upward from the center of the inner face of the lower disk. A socket of similar shape fits exactly over this axis, projecting downward from the inner side of the apex of the conical or upper disk. The two plates are held together by means of a mill-headed screw, capping the cone from the outside, and which can be loosened or removed at pleasure.

A tangent screw and clamp fastened to the edge of the upper rim permit, when loose, the revolution of the table about its center, and, when clamped to the lower limb, hold the table firm while the tangent screw gives a more delicate movement.

Three equidistant vertical projections of brass grooved on the underside, and cast in one piece with the under face of the lower disk, extending from the periphery toward the center, rest upon the points of three large screws which come through a heavy wooden block below. This block, which is the top of the stand and is approximate in form to an equilateral triangle, is 2¼ inches thick when made of wood.



PLANE TABLE AND ALIDADE.

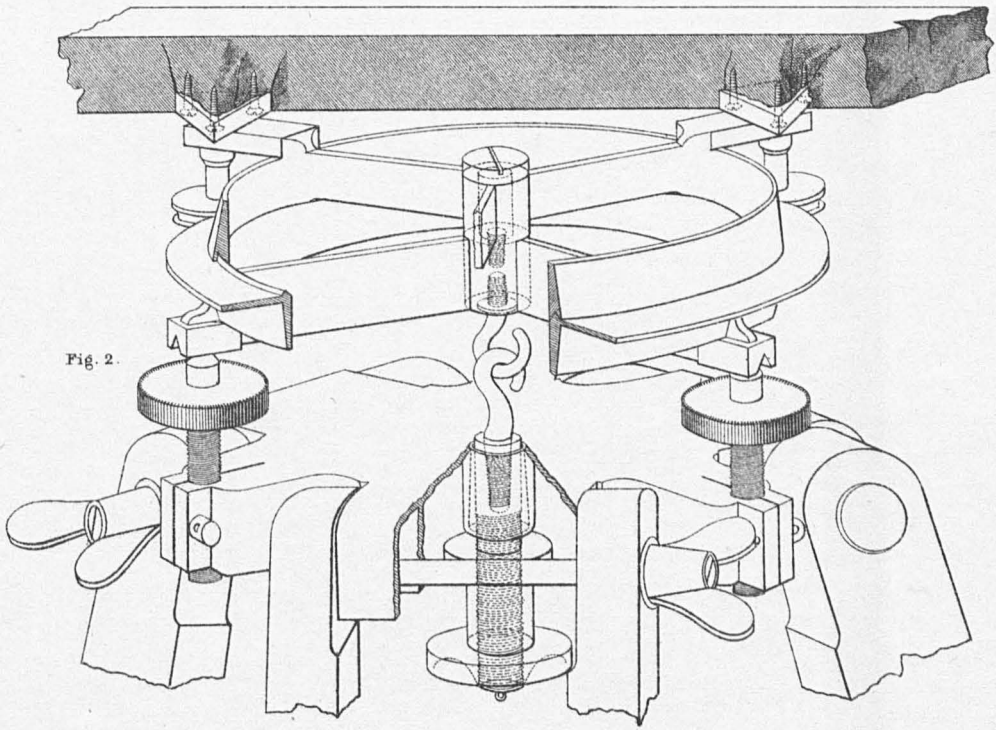


Fig. 2.

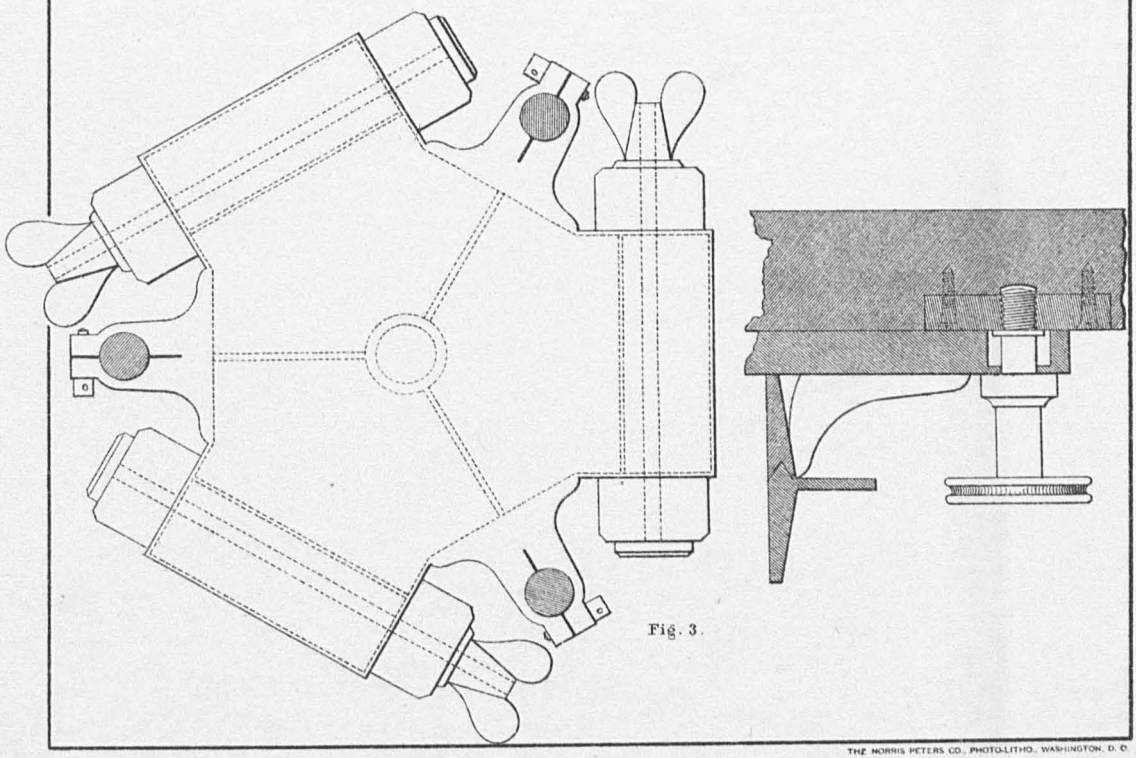
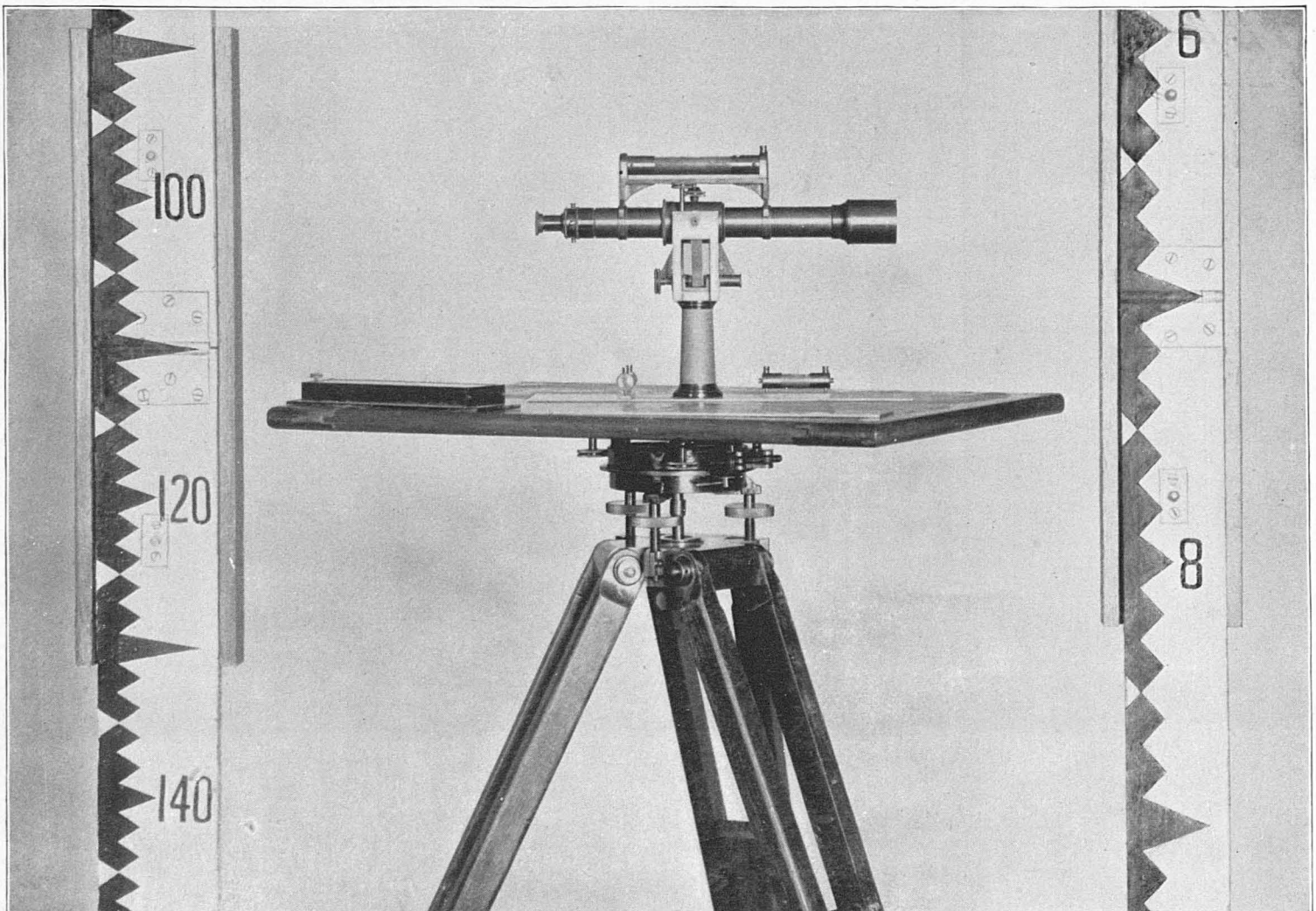
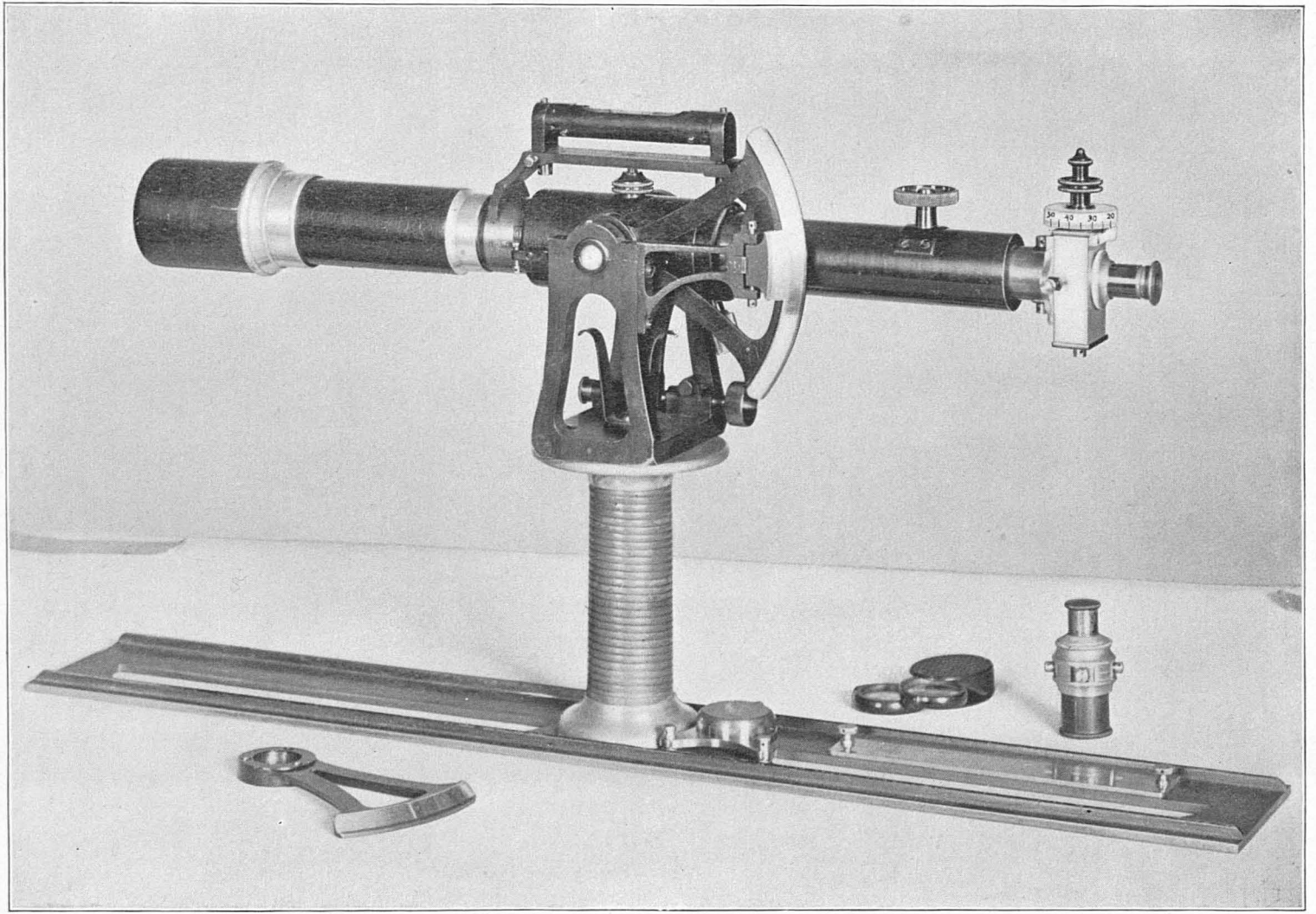


Fig. 3.

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



MOUNTAIN PLANE TABLE AND RODS.



ALIDADE (LATEST FORM).

The three screws last mentioned have large milled heads, are quite stout, and play through the block below by means of brass female screws let into it. They are the leveling screws of the instrument and are equidistant from its center.

Upon the underside and center of the metal lower disk is a socket containing a ball with a brass arm, which projects through the center of the block from beneath. The lower end of the arm is threaded, and upon it plays a female screw with a large milled head, which can be relaxed or tightened at pleasure. The screw clamps the whole upper part of the instrument to the stand; it is loosened only before leveling and kept securely clamped at all other times.

The block, made either of wood or brass, is supported upon three legs, and with them forms the tripod or stand of the instrument, the legs being of such a length as to bring the table to a convenient height for working, and so arranged as to be taken off at will, or closed so that their brass shod and pointed ends can be brought together or moved outward, as may be required. They are made on the open or skeleton pattern, and each is securely attached to a segment of the tripod head by a long brass bolt.

MOUNTAIN PLANE TABLE.

(Pl. 3.)

A small plane table, with a board measuring only 14 by 17 inches, is employed in reconnaissance, mountain work, or as an auxiliary to one of the standard size. All the various parts are reduced in size to correspond with the board, and the construction of the movement simplified.

THE ALIDADE.

The type of alidade in general use (Pl. 1) 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 Y's, 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 *o*°, an accompanying vernier being attached to the lower part of the Y support. The arc moves with the telescope as it is raised or depressed, and it is used in the measurement of the vertical angles for height. A clamp and a tangent screw placed on the other side of the telescope, opposite the arc, controls its vertical movement.

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 the 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 revolution of the telescope.

Upon the tube of the telescope are turned two shoulders, on which rest a striding spirit level, which can be readily reversed or removed at pleasure. The eye piece carries the usual reticule with screws for the collimation adjustment, and to this is attached a glass diaphragm, having one vertical and three horizontal lines engraved upon it. One of the horizontal lines crosses the middle of the diaphragm, the other two are placed equidistant from it, one above and one below. The interval between them remains a constant chord for the measurement of distance upon a graduated staff or rod. In some cases short auxiliary lines have been added dividing the interval into still smaller chords.

Several of the alidades are furnished with a micrometer eyepiece so attached that the thread is horizontal, and has a vertical movement 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.

The latest Coast and Geodetic Survey alidade (Pl. 4) differs from the preceding type in having the vertical arc so placed that the vernier can be read without the observer moving away from the eye end of the telescope. This is effected by placing the arc in the quadrant nearest the eyepiece and the graduation of the arc upon its outer periphery. The weight of this alidade has also been reduced by using aluminum bronze in its construction, and by providing it with a skeleton rule.

A declinatoire (shown in Pls. 1 and 3) accompanies the alidade and is carried in the same packing box. It consists of a rectangular brass box 7 inches long by 2 wide, with an arc at each end graduated to 15° on each side of the o°. It contains a needle long enough to extend from arc to arc, and resting on a pivot midway the box. The sides running lengthwise the box are parallel to a line connecting the zero marks of the two graduations.

The metal clamps, for holding the projection on the board, are of two kinds: The V-shaped for the ends, and the side clamps, the latter being made of thin metal strips about 12 inches in length, with two or more springs to grip the under side of the board.

THE ADJUSTMENTS OF THE ALIDADE.

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 can not 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 levels attached to the rule.*—Place the instrument in the middle of the table and bring the bubble of either level 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 remains 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. The other level should now be examined and adjusted in a like manner.

Great care should be exercised in manipulation lest the table be disturbed.

3. *Parallax.*—Move the eyeglass until the cross hairs are perfectly distinct, and then direct the telescope to some distant well-defined object. If the contact remains 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 eyeglasses. 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. *The line of collimation perpendicular to the axis of revolution of the telescope.*—Point the intersection of the vertical and the middle horizontal lines of the diaphragm on some well-defined distant object; revolve the telescope in its collar 180° and again observe the object. If the intersection covers it, the adjustment is perfect; if not, one half the error must be corrected by moving the diaphragm, by means of the adjusting screws, and the other half with the tangent screw of the table. This operation should be repeated until the adjustment is complete.

5. *Axis of revolution.*—Since the bearings of the axis are unchangeable, the axis of revolution is assumed to remain parallel to the plane of the rule.

6. *Middle horizontal line of diaphragm to the plane of the horizon.*—(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 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 levels on the ruler 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 obser-

vations 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.

*The stadia rod** (Pl. 3), as used in the Coast and Geodetic Survey, is simply a scale of equal parts painted upon a wooden rod about 10 feet long, 5 inches wide, and 1¼ inches thick, so graduated that the number of divisions upon it, as seen between the upper and lower horizontal wires of the telescope, is equal to the number of units in the distance between the instrument and the rod held at right angles to the line of sight.

Graduation.—In all cases the rod should be graduated experimentally for the particular instrument, and, if the best results are to be obtained, to suit the eye of the observer.

In practice the alidade is mounted on a stand, and its centre (corresponding to the standard) is plumbed over one end of a hundred-metre base, measured on level ground. A line, representing the zero of the graduation, having been drawn about 5 inches from

* It has been decided to adopt the word "stadia" instead of "telemeter" to accord with the almost universal usage of civil engineers and surveyors. In spite of its faulty derivation the former word is now imbedded in the literature relating to measurements made according to this method, while the latter is gradually but surely disappearing. For further details of the theory of stadia measurements see: Elemente der Vermessungs-Kunde, Bauernfeind, 1873, p. 322; Handbuch der Vermessungs-Kunde, Jordan, 1888, p. 554; Theory and Practice of Surveying, Johnson, 1898, p. 238; Gillespie's Higher Surveying, Staley, 1897, p. 311; Experimental Study of Field Methods, Smith, Bulletin of University of Wisconsin, Engineering series, Vol. I, No. 5.

one end of the rod, the latter is held vertical at the other end of the base, zero mark upward. The observer at the alidade then makes the upper horizontal line of the diaphragm coincide with the zero and directs the rodsman by signals where to draw a line which coincides with the lower horizontal line. This intercepted space on the rod is now subdivided into the smaller parts of the adopted scale and the graduation continued to within a short distance of the bottom.

This graduation is represented by the equation

$$d=\frac{f}{i}s+(f+c),$$

where d = the distance from the centre of instrument to rod (in this case 100 metres);

f = the focal length of the telescope (which is 35^{cm} for the average alidade);

i = the distance between the upper and lower wires of the diaphragm (4^{mm});

s = the length of the intercepted portion of the rod ($1{\cdot}185^{m}$);

c = the distance from object glass to center of instrument $\left(=\frac{f}{2}=\frac{35^{cm}}{2}\text{ generally}\right)$

As indicated in the preceding equation, the readings of a rod graduated in this manner are not quite true for distances above or below 100 metres, since the vertices of the constant and similar angles (one subtending the chord represented by the intercepted space on the rod and the other by the space between the upper and lower wires) do not lie at the centre of the instrument, but at a distance beyond the object glass equal to the focal length of the telescope, and therefore the intercept on the rod will not be proportional for all distances from the centre of the instrument. To have it so the instrument should be mounted at a distance back from the end of the base equal to one and a half times the focal length of the telescope ($f+c$). To all readings of a rod graduated according to this last method the constant quantity $f+c$ must be added.

The correction for the first method is small and can be ignored for mapping on a scale of 1–10 000 or smaller.

The formula for the correction is:

$$K=(C+F)\left(1\frac{-B}{B'}\right)$$

Where K = correction in meters,

B = distance read on rod in meters,

B' = length of base, in meters, for which the rod was graduated.

The corrections for 50, 200, 300, and 400 meters are $+0{\cdot}262$, $-0{\cdot}525$, $-1{\cdot}050$, $-1{\cdot}575$ meters, respectively.

Inclined sights.—The foregoing applies only to horizontal sights. When the rod is held at a point above or below the instrument, the line of sight is inclined at an angle with the horizon, and a correction has to be applied to the reading to obtain the horizontal distance. Some observers prefer to have the rod held perpendicular to the line of sight, the reduction then being simply the cosine of the angle of inclination into the rod reading; the small correction for the difference in horizontal distance between the point where the line of sight cuts the rod and the foot of the rod, being ignored.

The latter correction is:

Vertical angle :	50 m :	100 m :	200 m.
5°	: +0·23 :	+0·21 :	+0·15
10°	: +0·48 :	+0·43 :	+0·33

For the reduction of the hypothenuse to the base, the following table is given:

Table for reduction of hypothenuse to base.

Angle.	Hypothenuse.				
	100 meters.	200 meters.	300 meters.	400 meters.	500 meters.
5°	99·62	199·24	298·86	398·48	498·10
10°	98·48	196·96	295·44	393·92	492·40
15°	96·59	193·19	289·78	386·37	482·96
20°	93·97	187·94	281·91	375·88	469·85
25°	90·63	181·26	271·89	362·52	453·15
30°	86·60	173·21	259·81	346·41	433·01
35°	81·92	163·83	245·75	327·66	409·58
40°	76·60	153·21	229·81	306·42	383·02
45°	70·71	141·42	212·13	282·84	353·55

With the preceding method a sight must be attached to the rod, or the amount of inclination left to the judgment of the rodsman. An objection to it becomes evident when it is necessary to measure the vertical angles of the back and foresight, since the rod changes its inclination with each new position of the instrument.

A second method is one where the rod is always held vertical. Here besides the correction to reduce the inclined distance to a horizontal one, an additional one must be applied for the oblique view of the rod.

The equation for reducing the readings is:

$$\text{Horizontal distance} = r \cos^2 v + (c+f) \cos v$$

Where r=reading of vertical rod;

v=angle of elevation or depression;

c=distance of object glass to center of instrument;

f=focal length of telescope.

The following table gives the coefficient of reduction by which the rod reading is to be multiplied. It is based on the assumption that $c+f$ is to be added to the result to obtain the distance to the center of the instrument.

Example: Given an angle of elevation or depression 8° 10′ and the reading of the inclined sight on vertical rod=173·1 meters.

From the table:

Factor for 1 metre for 8° 10′ multiplied by 100=97·98 meters.
" " 7 " " " " " " 10=68·59 "
" " 3 " " " " .....= 2·94 "
" " 0·1 " " " " .....= ·09 "

Horizontal distance ..... 169·60 "

To which $c+f$ is to be added.

*Table of coefficients for reducing readings of inclined sights on vertical rod to horizontal distance.**

Angle of inclination	Horizontal projection of:								
	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m
0° 10′	·99999	1·99998	2·99997	3·99997	4·99996	5·99994	6·99994	7·99993	8·99993
20′	·99997	1·99993	2·99990	3·99986	4·99983	5·99980	6·99977	7·99973	8·99970
30′	·99992	1·99984	2·99977	3·99969	4·99962	5·99954	6·99946	7·99939	8·99932
40′	·99986	1·99973	2·99959	3·99946	4·99932	5·99919	6·99905	7·99892	8·99878
50′	·99979	1·99957	2·99936	3·99915	4·99894	5·99873	6·99852	7·99831	8·99810
1° 00′	·99970	1·99939	2·99909	3·99878	4·99848	5·99817	6·99787	7·99757	8·99726
10′	·99959	1·99917	2·99875	3·99834	4·99793	5·99752	6·99711	7·99669	8·99628
20′	·99946	1·99891	2·99838	3·99783	4·99729	5·99676	6·99622	7·99568	8·99514
30′	·99932	1·99863	2·99794	3·99725	4·99657	5·99589	6·99520	7·99452	8·99384
40′	·99915	1·99831	2·99746	3·99659	4·99572	5·99489	6·99406	7·99323	8·99239
50′	·99908	1·99801	2·99693	3·99590	4·99488	5·99386	6·99284	7·99182	8·99080
2° 00′	·99878	1·99756	2·99635	3·99513	4·99391	5·99269	6·99147	7·99025	8·98904
10′	·99857	1·99714	2·99571	3·99428	4·99285	5·99142	6·99000	7·98857	8·98714
20′	·99834	1·99669	2·99503	3·99337	4·99171	5·99006	6·98840	7·98675	8·98509
30′	·99810	1·99620	2·99429	3·99239	4·99049	5·98859	6·98669	7·98479	8·98289
40′	·99784	1·99568	2·99351	3·99135	4·98918	5·98702	6·98485	7·98268	8·98053
50′	·99756	1·99511	2·99267	3·99023	4·98778	5·98534	6·98290	7·98046	8·97802
3° 00′	·99726	1·99452	2·99178	3·98904	4·98630	5·98357	6·98083	7·97809	8·97635
10′	·99695	1·99390	2·99085	3·98780	4·98474	5·98169	6·97865	7·97560	8·97255
20′	·99662	1·99324	2·98986	3·98648	4·98309	5·97972	6·97634	7·97296	8·96958
30′	·99627	1·99255	2·98882	3·98509	4·98136	5·97764	6·97391	7·97019	8·96646
40′	·99591	1·99182	2·98773	3·98364	4·97955	5·97546	6·97137	7·96728	8·96319
50′	·99553	1·99106	2·98659	3·98212	4·97765	5·97318	6·96871	7·96424	8·95978
4° 00′	·99513	1·99027	2·98540	3·98054	4·97567	5·97081	6·96595	7·96108	8·95621
10′	·99472	1·98944	2·98416	3·97888	4·97360	5·96832	6·96304	7·95776	8·95249
20′	·99429	1·98858	2·98287	3·97716	4·97145	5·96574	6·96003	7·95432	8·94862
30′	·99384	1·98769	2·98153	3·97537	4·96922	5·96306	6·95691	7·95075	8·94460
40′	·99338	1·98676	2·98014	3·97352	4·96690	5·96028	6·95366	7·94704	8·94043
50′	·99290	1·98580	2·97870	3·97160	4·96450	5·95740	6·95030	7·94320	8·93611
5° 00′	·99240	1·98481	2·97721	3·96961	4·96202	5·95443	6·94683	7·93923	8·93164
10′	·99189	1·98378	2·97567	3·96756	4·95945	5·95134	6·94323	7·93512	8·92702
20′	·99136	1·98272	2·97408	3·96544	4·95680	5·94816	6·93952	7·93088	8·92224
30′	·99081	1·98163	2·97244	3·96326	4·95407	5·94489	6·93570	7·92652	8·91733
40′	·99025	1·98050	2·97075	3·96100	4·95125	5·94150	6·93175	7·92200	8·91225
50′	·98967	1·97934	2·96901	3·95868	4·94835	5·93802	6·92769	7·91736	8·90703
6° 00′	·98907	1·97814	2·96722	3·95630	4·94537	5·93445	6·92358	7·91260	8·90167
10′	·98846	1·97692	2·96538	3·95384	4·94230	5·93077	6·91923	7·90769	8·89615
20′	·98783	1·97566	2·96349	3·95132	4·93915	5·92698	6·91481	7·90264	8·89048
30′	·98718	1·97436	2·96155	3·94873	4·93591	5·92310	6·91029	7·89748	8·88467
40′	·98652	1·97304	2·95956	3·94609	4·93261	5·91913	6·90566	7·89218	8·87870
50′	·98584	1·97169	2·95753	3·94337	4·92921	5·91506	6·90090	7·88674	8·87259
7° 00′	·98515	1·97030	2·95544	3·94059	4·92574	5·91089	6·89604	7·88119	8·86634

* Furnished by J. A. Flemer, Assistant, Coast and Geodetic Survey.

Table of coefficients for reducing readings of inclined sights on vertical rod to horizontal distance—Continued.

Angle of inclination.	Horizontal projection of:								
	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m
10′	·98444	1·96888	2·95331	3·93775	4·92218	5·90662	6·89105	7·87549	8·85993
20′	·98371	1·96742	2·95112	3·93483	4·91854	5·90225	6·88596	7·86967	8·85337
30′	·98296	1·96592	2·94889	3·93185	4·91481	5·89777	6·88073	7·86370	8·84667
40′	·98220	1·96441	2·94661	3·92881	4·91101	5·89322	6·87542	7·85762	8·83982
50′	·98142	1·96285	2·94427	3·92570	4·90712	5·88855	6·86997	7·85140	8·83282
8° 00′	·98063	1·96126	2·94189	3·92252	4·90315	5·88378	6·86441	7·84504	8·82568
10′	·97982	1·95964	2·93946	3·91928	4·89910	5·87892	6·85874	7·83856	8·81839
20′	·97899	1·95798	2·93698	3·91598	4·89497	5·87396	6·85296	7·83196	8·81096
30′	·97815	1·95630	2·93446	3·91261	4·89076	5·86891	6·84707	7·82522	8·80337
40′	·97729	1·95459	2·93188	3·90918	4·88647	5·86377	6·84106	7·81836	8·79565
50′	·97642	1·95284	2·92926	3·90568	4·88209	5·85851	6·83493	7·81134	8·78777
9° 00′	·97553	1·95106	2·92658	3·90211	4·87764	5·85317	6·82870	7·80423	8·77975
10′	·97462	1·94924	2·92386	3·89848	4·87310	5·84772	6·82234	7·79696	8·77159
20′	·97370	1·94740	2·92110	3·89480	4·86849	5·84219	6·81589	7·78959	8·76328
30′	·97276	1·94552	2·91828	3·89104	4·86379	5·83655	6·80931	7·78207	8·75483
40′	·97180	1·94361	2·91542	3·88722	4·85902	5·83083	6·80263	7·77444	8·74624
50′	·97083	1·94166	2·91250	3·88333	4·85416	5·82499	6·79583	7·76667	8·73750
10° 00′	·96985	1·93970	2·90954	3·87938	4·84923	5·81907	6·78892	7·75876	8·72861
10′	·96884	1·93769	2·90653	3·87537	4·84421	5·81306	6·78190	7·75074	8·71959
20′	·96782	1·93565	2·90347	3·87129	4·83912	5·80695	6·77477	7·74259	8·71042
30′	·96679	1·93358	2·90037	3·86716	4·83395	5·80074	6·76753	7·73432	8·70111
40′	·96574	1·93148	2·89721	3·86295	4·82869	5·79443	6·76017	7·72591	8·69165
50′	·96467	1·92934	2·89402	3·85869	4·82336	5·78803	6·75271	7·71738	8·68206
11° 00′	·96359	1·92718	2·89077	3·85436	4·81795	5·78154	6·74513	7·70872	8·67232
10′	·96249	1·92498	2·88748	3·84997	4·81247	5·77496	6·73746	7·69995	8·66245
20′	·96138	1·92276	2·88414	3·84552	4·80690	5·76828	6·72966	7·69104	8·65242
30′	·96025	1·92051	2·88076	3.84101	4·80126	5·76152	6·72177	7·68202	8·64227
40′	·95911	1·91822	2·87732	3·83643	4·79553	5·75464	6·71375	7·67286	8·63196
50′	·95795	1·91590	2·87385	3·83180	4·78974	5·74769	6·70564	7·66358	8·62153
12° 00′	·95677	1·91355	2·87032	3·82709	4·78386	5·74063	6·69741	7·65418	8·61095
10′	·95558	1·91116	2·86674	3·82232	4·77790	5·73348	6·68906	7·64464	8·60023
20′	·95438	1·90876	2·86313	3·81750	4·77187	5·72625	6·68062	7.63500	8·58938
30′	·95315	1·90631	2·85946	3·81261	4·76576	5·71892	6·67207	7·62522	8·57838
40′	·95192	1·90384	2·85575	3·80766	4·75958	5·71150	6·66341	7·61533	8·56724
50′	·95066	1·90132	2·85199	3·80265	4·75332	5·70399	6·65465	7·60532	8·55598
13° 00′	·94940	1·89880	2·84820	3·79759	4·74698	5·69638	6·64577	7·59516	8·54456
10′	·94811	1·89623	2·84434	3·79245	4·74056	5·68868	6·63679	7·58491	8·53302
20′	·94682	1·89364	2·84045	3·78726	4·73407	5·68088	6·62770	7·57452	8·52133
30′	·94550	1·89101	2·83651	3·78201	4·72751	5·67301	6·61852	7·56402	8·50952
40′	·94417	1·88835	2·83252	3·77669	4·72087	5·66505	6·60922	7·55339	8·49757
50′	·94283	1·88566	2·82849	3·77132	4·71415	5·65698	6·59981	7·54264	8·48548
14° 00′	·94147	1·88295	2·82442	3·76589	4·70736	5·64884	6·59031	7·53179	8·47326

Table of coefficients for reducing readings of inclined sights on vertical rod to horizontal distance—Continued.

Angle of inclination.	Horizontal projection of:								
	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m
10′	·94010	1·88020	2·82030	3·76040	4·70050	5·64060	6·58070	7·52080	8·46090
20′	·93871	1·87742	2·81613	3·75484	4·69355	5·63226	6·57097	7·50968	8·44840
30′	·93731	1·87462	2·81192	3·74923	4·68654	5.62385	6·56115	7·49846	8·43578
40′	·93589	1·87178	2·80767	3·74356	4·67945	5·61534	6·55123	7·48712	8·42302
50′	·93446	1·86892	2·80338	3·73784	4·67229	5·60675	6·54121	7·47567	8·41013
15° 00′	·93301	1·86602	2·79903	3·73204	4·66505	5·59806	6·53107	7·46408	8·39710
16° 00′	·92402	1·84805	2·77208	3·69610	4·62011	5·54414	6·46816	7·39218	8·31620
17° 00′	·91452	1·82904	2.74355	3·65806	4·57258	5·48710	6·40161	7·31613	8·23065
18° 00′	·90451	1·80902	2·71352	3·61803	4·52253	5·42704	6·33154	7·23605	8·14056
19° 00′	·89400	1·78800	2·68201	3·57600	4·47001	5·36402*	6·25802	7·15203	8·04603
20° 00′	·88302	1·76604	2·64906	3·53208	4·41510	5·29812	6·18114	7·06416	7·94718

Micrometer eyepiece.—Where a micrometer eyepiece is used in place of the stadia lines, a rod about 3·7 meters in length is employed, attached to which are two targets. A base is measured on level ground and the instrument either plumbed over one end or back of it a distance equal to $f + c$, depending upon the manner the rod is to be held for an inclined sight. The rod is then taken to one of the subdivisions of the base, consisting of an even multiple of the unit adopted; say 100, 200, or 300 meters, and the upper target being fixed, the lower target is set and fixed so that the angular measure of the interval by the micrometer will consist of an even multiple of turns of the micrometer screw. The rod is now held at the other subdivision of the base, and the readings tabulated. A distance table is then prepared, by interpolation, for the intermediate distances.

Plane-table sheet.—From the standpoint of efficiency the plane-table sheet is the least satisfactory portion of the plane table equipment. Owing to its hygrometric nature it is very susceptible to atmospheric changes; expanding and contracting unceasingly. This would be but an insignificant source of error or annoyance if it were equal in all directions. The map or plan would then simply change its scale, for which an allowance could readily be made. But the objectionable feature arises from the unequal expansion and contraction which changes the relative distance and directions of the points. It has been determined by experiment that strips cut longitudinally from drawing paper varied from 10 to 25 per cent more than strips cut transversely from the same paper.

Various substitutes* have been tried, but none have proved entirely satisfactory. The United States Geological Survey, to eliminate this distorton, employs two sheets of paragon paper, the size of the plane-table board, mounted with the grain at right angles, and with cloth between them.

* Celluloid sheets are frequently used in Alaska. The pencil lines are neither washed out nor blurred by water accumulating on the sheet.

This method is applicable to small scale surveys where a sheet the size of the table board covers a large area of country, or on the other hand, to large scale cadastral surveys where the great amount of detail makes the rate of progress slow. But for intermediate scales and an area containing a moderate amount of detail, a longer sheet is much more economical, because a smaller number of points are needed to inclose the work within the control of the triangulation than would be required if it was limited to the size of the table. A certain amount of overlapping work, of which there is more or less at the junction of the two sheets, would also be avoided.

The plane-table sheet of the United States Coast and Geodetic Survey consists of a sheet of Whatman's cold-pressed hand-made antiquarian paper, 52 by 30 inches. It is backed with muslin, which extends about 1 inch beyond the edge of the paper to protect it from fraying.

To reduce the distortion to a minimum a sheet should be thoroughly seasoned before it is taken to the field or a projection laid down on it. This is effected by exposing it alternately to a very damp and a very dry atmosphere. On testing a sheet after a week of such exposure it will be found to have much less tendency to expand or contract unequally.

Paper stored away, piled up in stacks, does not properly season.

Scale.—The selection of the scale to be employed depends so much on the character of the country to be surveyed, the amount of detail to be included, and the uses to which the completed map will be put, that no general rule can be given for guidance. It must be remembered, however, that nothing is gained, either in economy or rapidity, by the use of small scales when the details to be shown are plentiful. The minute drawing involved proves a tax on the topographer and is a great time consumer.

The scale adopted by the Coast and Geodetic Survey for the coast line from Maine to Delaware Bay is 1–10 000; from Delaware Bay southward, 1–20 000. Special surveys have been made on a scale as large as 1–1 200.

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 frequently 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 areas 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.

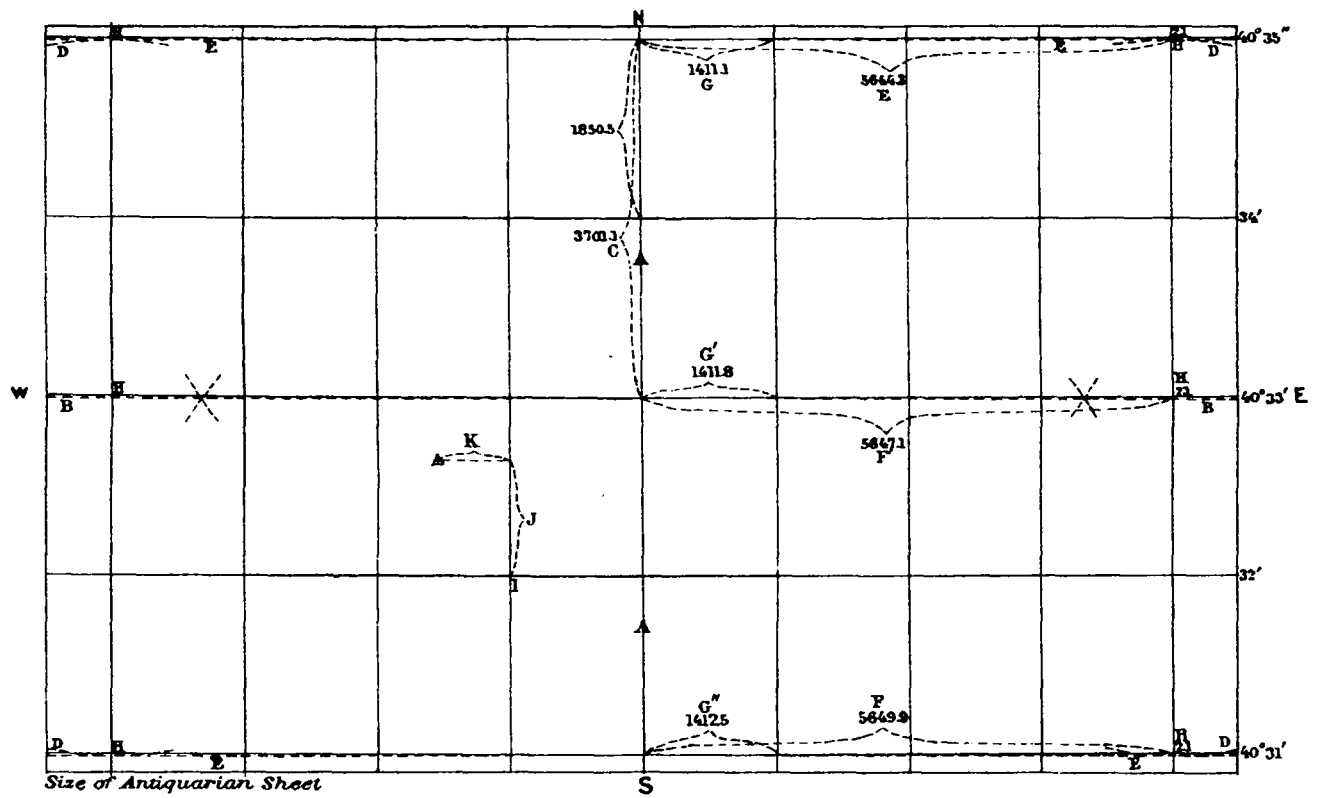


Diagram illustrating the mode of constructing the Polyconic Projection for Plane Table Work, Scale $\frac{1}{10000}$

Scale of Diagram, $\frac{1}{80000}$

THE HORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

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 ax, 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 sheets 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 familar 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 consequently 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 can not 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 draftsman will be materially assisted in laying out the limits of the projection by drawing on a piece of tracing vellum a plan of the sheet, corresponding in size to the scale of the triangulation sketch. Take, for example, a sheet 52 inches in length by 30 in width, on which a projection on a scale of 1–10 000 is to be drawn, the triangulation sketch being on a scale of 1–100 000. The dimensions of the plan will then be one-tenth those of the sheet, viz, 5.2 by 3.0 inches. Placing the pattern over the sketch and shifting its position about over the locality to be surveyed, the limits which include the most favorable conditions for the projection will soon become apparent.

*The Polyconic projection** has been adopted by the Coast and Geodetic Survey for mapping its work. The method of drawing one is as follows:

The limits of the sheet having been determined, the middle meridian A (see Pl. 5) is located and drawn; then its intersection with the most central parallel is found, and the perpendicular B erected there.

Next turn to the page of the "Polyconic projection tables" † in which is given the degree of latitude which includes the limits of the sheet. In this instance the latitude is 40°, to be found on page 223 of the tables. The number of minutes of latitude on the central meridian, above and below the central parallel, being known, take the corresponding distance from the column headed "Sums of minutes for middle latitude" 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 straightedge draw lines E E through the north and south minutes on the central meridian, and tangent to the two arcs D D to the right and left. This gives three parallel lines perpendicular to the central meridian. On the opposite page 222, from under the head of "Arcs of the parallel in meters," 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 F F′ F″ on each perpendicular, taking each distance from its appropriate latitude. Subdivide these into minutes G G′ 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 "Coordinates 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 draftsman 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

* See a Treatise on Projections, Craig, United States Coast and Geodetic Survey Bulletin, 1882. Chart and Chart Making, Pillsbury, No. 29, Proceedings United States Naval Institute.

† United States Coast and Geodetic Survey Report, 1884, Appendix No. 6.

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 become 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 sign 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.

Accessories.—The usual accessories for plane-table work are: Large umbrella for shading table, 10 or 20 meter steel tape, Lockes level, clinometer, metal scale, dividers, pencils, rubber, block of emery or sand paper, table of heights, note, and sketch book.

A metal chart case should always accompany the table to secure the sheet from sudden rain and other injury liable to occur in transportation of the sheet to and from the field and for its safe keeping when not in use. Its diameter should not be less than 3 inches, for no sheet can be rolled to a less diameter without serious rupture of the fiber of the paper. It is also advisable to have a rubber cloth for covering the table when it is carried from station to station.

Approximate weights.—Plane-table movement, 18½ pounds, boxed, 34½ pounds; plane-table board, 8¼ pounds, boxed, 26½ pounds; plane-table alidade, 7 pounds, boxed, 21¼ pounds; plane-table tripod legs, 11 pounds; 2 stadia rods, 16½ pounds. Mountain plane table, set up complete with alidade, 19¾ pounds, boxed, 36 pounds; 2 stadia rods, 12¾ pounds.

c. Field Work.

Organization of party.—In organizing a party for field work it is necessary to have one man to carry the table. His duty is to remain constantly with the instrument, never to leave it unguarded; and while the topographer is at work he holds the umbrella to shade the table from the sun and thus protect the observer's eyes from the glaring reflections from the paper and instruments. The table bearer should be taught at the beginning of the 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 it 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, in order to keep the tripod head vertical over the point and approximately horizontal, securing the latter condition by sighting over the head to the horizon. In taking up the table the two nearest 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.

Two rodsmen are needed, and the rapidity with which the work is executed largely depends upon their efficiency. When well trained they should be able to recognize the salient points of the features to be mapped, so that the topographer can draw in correctly the details from the least number of readings, and in the absence of an aid to make a sketch of the intricate portions.

The amount of assistance an aid can give to his chief is limited only by his skill and experience. The logical inference being that he is in training to become a topographer himself, he takes charge of an increasing share of the work as he becomes more and more familiar with the methods employed. This enables his chief to turn his attention in other directions, which will expedite the survey and increase the output.

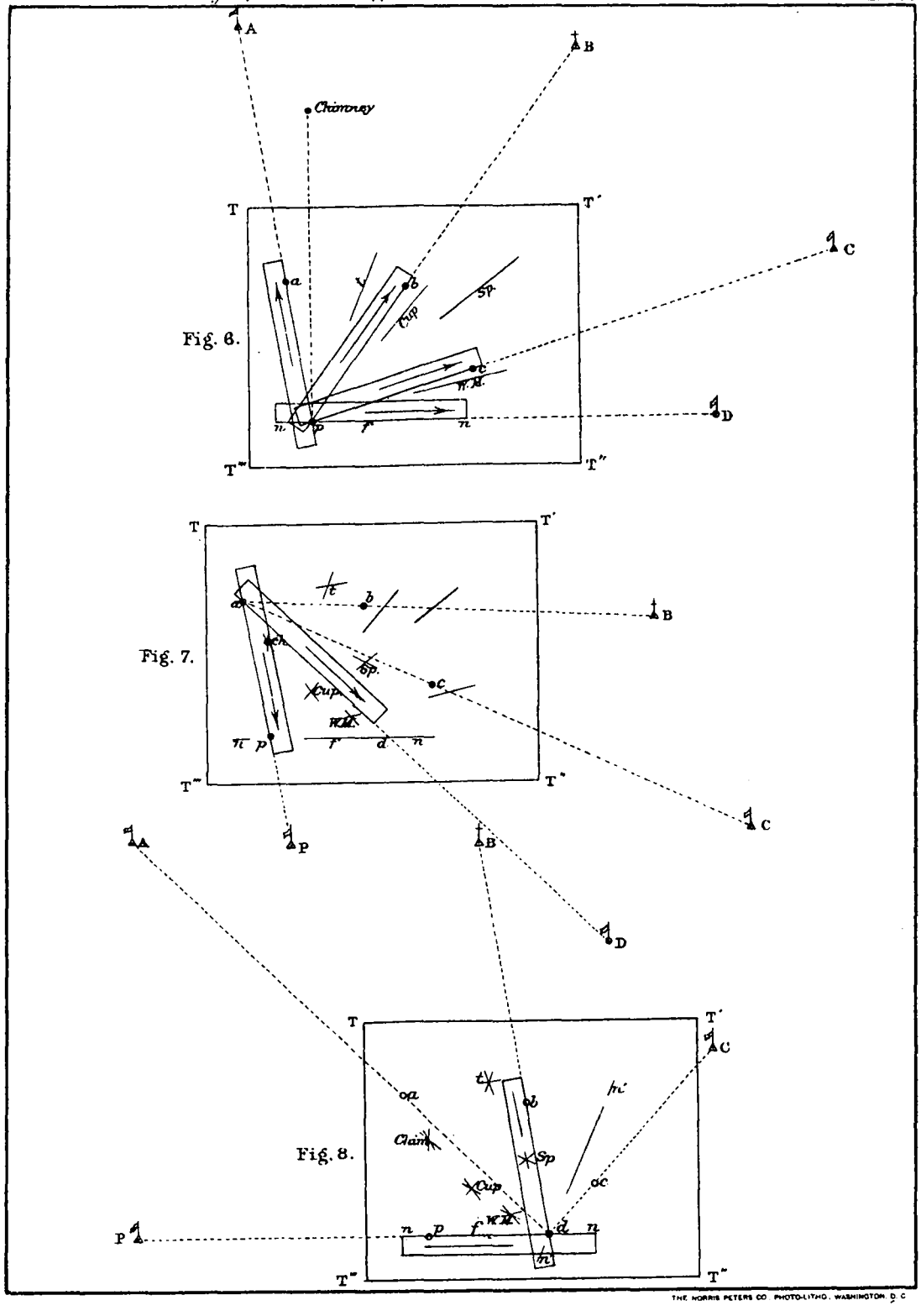
An outline, merely, of his duties can be suggested: Building signals, drawing plans of intricate details, sketching contours, selecting stations in advance, running traverse lines with auxiliary instruments, and finally in taking charge of the plane-table in the absence of his chief, who is thus afforded the opportunity of inspecting some difficult area and formulating some plan to meet the conditions found there.

The additional number of men required to complete the party will depend mainly on the means of transportation—wagon, horseback, or boat.

Preliminary reconnoissance.—Before commencing the instrumental work, a reconnoissance of the country should be made for the purpose of recovering triangulation stations and to locate signals at suitable points for subsequent determination and use. In the location of signals, either as permanent points or simply for temporary forward lines, a great deal depends upon the good judgment of the person placing them. Two purposes are to be subserved: first, the seeing of sufficient known points to give a good determination; and, second, to command a view of as great an area of country, and as many natural and artificial features for filling in the topography, as possible. It should be remarked, also, that in the course of prosecution of the regular work no favorable opportunity must be allowed to pass for locating a signal or determining a point which may at some future time be of service. Advantage should be taken of open places in the woods commanding roads or ravines. Piers or draws of bridges, or piles, giving lines up and down streams, which have precipitous and wooded banks; trees of unusual appearance in prominent positions, or bearing flags placed upon them for the purpose; points of rock, offshore or otherwise; lightning-rods, cupolas, weather-cocks, chimneys of factories, and other peculiar and marked objects come within this category. In fact, it may be set down as a rule that well-determined signals located at convenient distances over the sheet are more likely to be too few than too frequent.

Signal poles should be straight and perpendicular, and the flags upon them adapted in color to the background against which they will be seen when observed upon.

Graphic triangulation.—Signals having been erected at each triangulation station, and also on all prominent hills within the area of the sheet, where they would be useful in providing additional control; the next proceeding will be to occupy one of the former points.



THE NORRIS PETERS CO. PHOTO-LITHO., WASHINGTON, D. C.

Care should be exercised in choosing the day for this portion of the work, as it is essential to have favorable weather for a satisfactory test of the plotted points in the field and for the determination of new ones.

On arrival at the station the table is set up approximately over the center mark, and the sheet secured 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.

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‴ (Pl.6, fig. 6), 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.

In maps of large scale it is important to plumb the plotted point exactly over the station, but on the usual field scales of the Coast and Geodetic Survey (1–10000 and 1–20000) an approximation with the eye is all that is requisite. To effect it more closely a small stone is held underneath the point and then dropped to test the plumb, or a plumb-bob fastened to the table below the point serves the same purpose. Plumbing arms or forks are made and supplied by the instrument dealers.

The plotted point having been plumbed over the station as accurately as the scale of the work demands, place the alidade on 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*, consécutively, 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 failure to bisect A and C would indicate an error of plotting or an unequal change of the dimensions of the paper (distortion), which must be examined, and in case of the former corrected, and in case of the latter allowance made for, as indicated later on. (See distortion errors, page 439.)

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 the objects sighted, where details are complex; and they then 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 afterwards intersected should be drawn to such objects as it is desired to determine. 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 its intersection by a direction from some other fixed point, 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. 7.) 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. 8.) The table is placed over the point D, put in approximate position, leveled, etc., 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 inter-

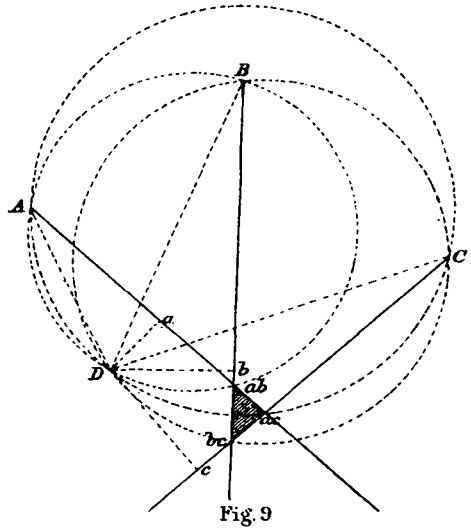


Fig. 9

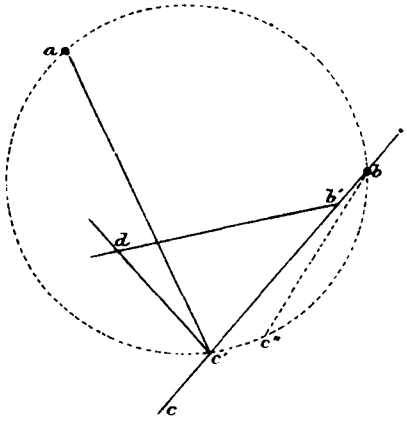


Fig. 19.

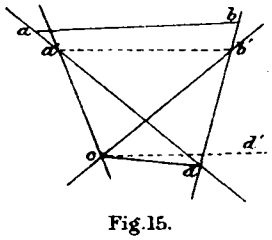


Fig. 15.

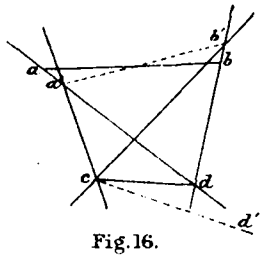


Fig. 16.

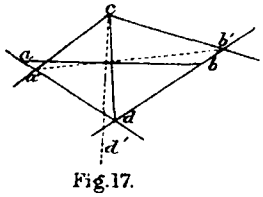


Fig. 17.

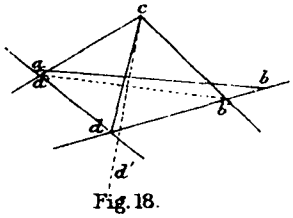


Fig. 18.

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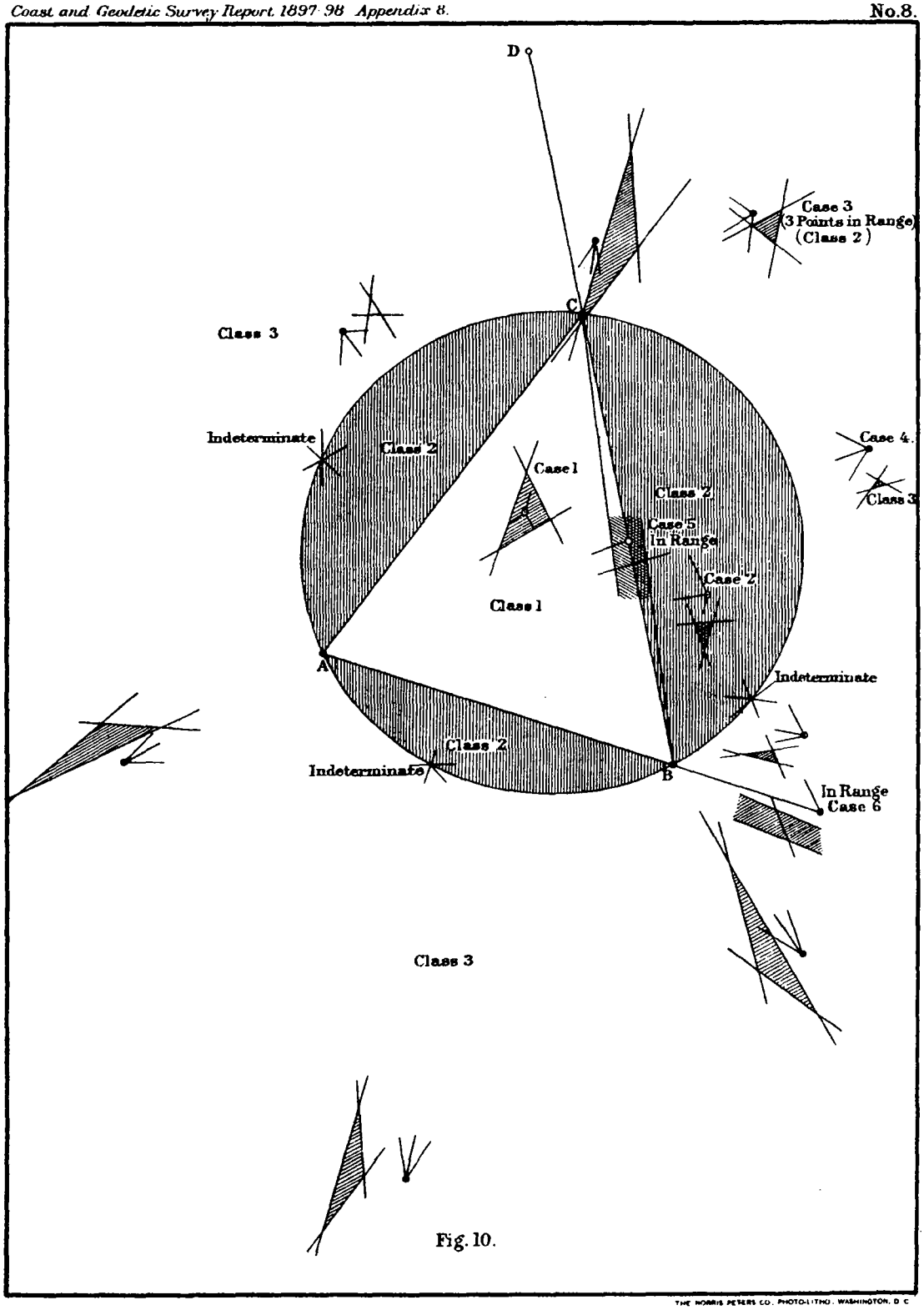

Fig. 10.

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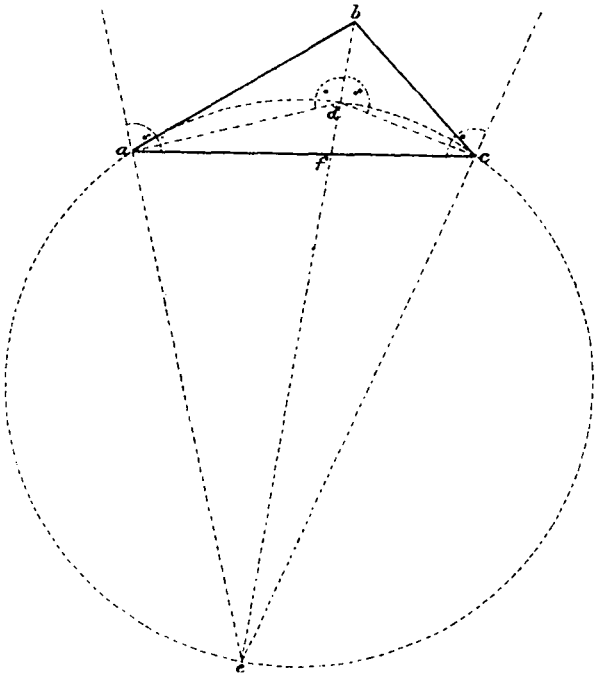

Fig. 11.

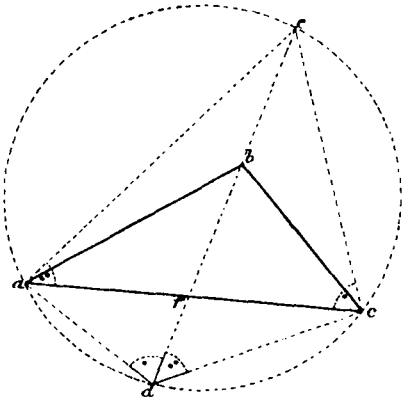

Fig. 12.

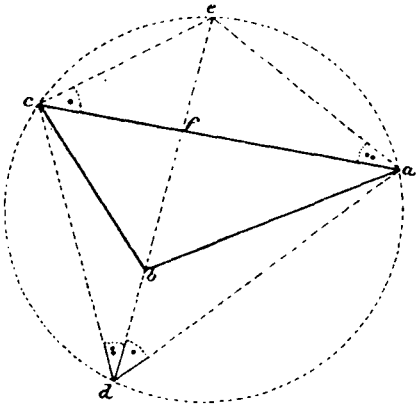

Fig. 13

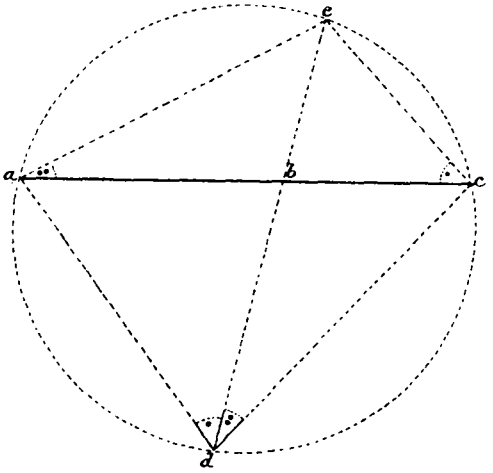

Fig. 14.

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sects 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 *chimney*, *tree*, *cupola*, *windmill*, etc.

There are occasions on occupying some station that several objects are seen whose position it is desirable to determine by prosection, but there is doubt of their being recognized from other stations. A new station is then occupied close by the first one and new lines drawn to the objects. The intersection thus obtained will necessarily be acute, but will materially assist in their identification from other localities.

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.

Amount of control.—There is no fixed ratio between the number of determined points and the number of square miles of the region to be surveyed or square inches of plane-table sheet.

The greater the number of points well distributed over the latter the less likelihood of error or annoyance due to the distortion of the paper in the future.

A large number also makes it easy for the topographer to determine by resection subordinate stations for mapping the details, and in consequence fewer traverse lines need be run.

More than sufficient for these purposes are not necessary, and it is important when carrying on a graphic triangulation not to waste valuable time and favorable weather, but to advance this part of the work as rapidly as possible before the sheet becomes affected by exposure.

The three-point problem.—A subordinate station is located at any desired place where a good view of the surrounding features can be obtained. If this place has not been previously determined it is now effected by means of the resection of lines from three fixed points.

The special advantages of the plane table as a mapping instrument are due to the rapidity with which it obtains results by the method of graphic triangulation and to the facility it affords the topographer in determining his position at an unknown point by the graphic solution of the three-point problem.

When the latter method is applicable; that is, when the country is open and signals easily seen, its superiority over a system of traverse lines is manifest. The topographer then is at liberty to choose his ground without reference to his last station or to one succeeding. He is not tied down to a backsight nor restricted by the conditions imposed by a foresight. He need not set up his instrument on an area barren of detail nor cut his way through obstacles (bushes, hedges, trees) to establish a station at a commanding point of view.

The number and situation of the stations is governed solely by the amount and location of the information to be mapped. On the other hand, traverse stations are chosen on account of their visibility, and many of them are of no service whatever beyond carrying the line forward.

Definitions.—When the table is imperfectly oriented, the lines drawn from the three projected points will not intersect at one point, except when all four are on the circumference of a circle. (See fig. 10, positions marked indeterminate.) Except in this case, two of the lines will be parallel, intersected by a third (see case 5, station on range line between two fixed points, and case 6, station on prolongation of range line), or they will form a small triangle called the *triangle of error.* (See shaded triangles, fig. 10.)

The triangle formed by the three fixed points is called the *great triangle* (Fig. 10 ABC), and the circle passing through the same points the *great circle.*

There are a number of graphic solutions of the three-point problem, but all save three are better suited to the drafting room, with its appliances, than to the conditions which exist in the field.

*Lehmann's method** of solution is the simplest, most direct, and applies under all circumstances. It is based on a fact which can be stated in the form of a rule.

Rule 1.—The true point 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.

Demonstration.—A, B, C (Pl. 7, fig. 9) 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—

$$Da : Db :: DA : DB \text{ or } Db : Dc :: DB : DC.$$

It is convenient to make the following classification, based upon the locality of the true point in relation to the three fixed points:

Class 1.—When the point sought falls within the great triangle (fig. 10, case 1), Pl. 8.

Class 2.—When the point sought falls within either of the segments of the great circle formed by the sides of the great triangle as chords. (Case 2.)

This also includes case 3 where the three fixed points (B, C, D) 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 point sought always lying in one of the segments of the great circle.

Class 3.—When the point sought falls without the great circle (Case 4).

Since it is not always easy to quickly decide where the true point should be located in reference to the triangle of error according to rule 1, three additional rules are given to serve as guides. The surveyor is assumed to be facing the signals and the directions right and left are given accordingly.

Rule 2.—The point sought is always to be found on the same side of each line drawn from the three fixed points: that is, if it is on the right side of one line it is on the right side of each of the other two; if on the left of one, it is on the left of the other two.

*See United States Coast and Geodetic Report, 1880, App. 13, for additional methods of solution.

Rule 3.—When the point sought falls within either of the three segments of the great circle formed by the sides of the great triangle, the line drawn from the middle point lies between the true point and the intersection of the other two lines (fig. 10, class 2),

Rule 4.—When the point sought is without the great circle 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 (fig. 10, class 1).

The point sought in cases of class 1 must fall within the triangle of error. No other position would satisfy the conditions of rule 2.

Its definite position is then decided upon according to rule 1, by estimating its proportional distance from each line.

Rules 3 and 4 are complementary to rule 2 and are especially useful in classes 2 and 3.

Procedure.—In practice, the position of the point sought is first determined with reference to one line by either rule 3 or 4; it then follows from rule 2 that it must be on the corresponding side of the other two lines. Rule 1 is then applied.

Example, Class 2, Case 2.—The line drawn from A, the middle point, is to the right of the intersection of the lines from B and C, therefore (rule 3) the point sought must be on its right, and also (rule 2), to the right of the line from B and C.

Example, Class 3, Case 4.—The intersection of the lines from B and C fall to the right of the line from A, the farthest point; therefore (rule 4) the point sought must be on its right, and also (rule 2) on the right of the line from B and from C.

There are two cases, 5 and 6, where no triangle of error is formed, two of the lines drawn from fixed points being parallel, intersected by a third. In practice the topographer would recognize at once that he was either on a range between two points or on the prolongation of a range line, and orienting by it there would be no deflection of the table, and consequently the lines would all intersect at one point. The examples are, however, instructive, since they indicate the treatment in cases of points which fall near a range.

Case 5.—When the point sought is on or near the range between two fixed points the true point must be between the parallel lines to satisfy the conditions of rule 2. Its position with reference to the intersecting line follows from the same rule. In the figure the point sought being between the lines from B and C, is to the right of each; therefore it is to the right of the line from A.

Case 6.—When the point sought is on or near the prolongation of a range line the true point will be outside the parallel lines and on the side of the line to the nearest fixed point of the range. If the point sought were placed on the other side, it would be impossible to satisfy the conditions of rule 1. In the figure it will be seen that the point sought must be outside the lines from A and B to satisfy rule 2, and to their right to satisfy rule 1, and also to the right of the line from C.

The preceding cases are all examples of the conditions which may occur when the table is deflected to the right. By turning the printed side of the illustration to the light and looking at the figure through the paper, it will appear reversed and the "cases" will then be examples of conditions which may occur when the table is deflected to the left.

Repetition.—When the true point has been estimated and marked on the sheet in accordance with the foregoing rules, a new orientation is made. If the lines from the

three stations now intersect at that point it proves the estimate to have been correct and the position is determined. If a new triangle of error is formed, it indicates a faulty estimate, and the operation must be repeated.

Orienting by estimation.—A small triangle of error is the result of a close orientation, which the topographer endeavors to accomplish at the first trial by taking advantage of any range that may exist either of signals or other details already platted on the sheet. It will serve the same purpose if they are near enough in line to estimate a direction on the sheet to the farthest object, and then to orient by it.

The declinatoire may be used, but it is a slow and inaccurate method of orientation.

It is employed for this purpose by placing the straight edge of the box containing the needle upon a magnetic meridian, previously traced upon the map, and revolving the table until the needle points to 0°, or north, on the graduated arc at the end of the box. The magnetic meridian is roughly determined at any well-determined station, when the table is properly oriented by the use of the declinatoire itself, the meridian line being drawn upon the sheet along the straight edge of the box when the needle points to 0°. Or the table may be oriented by making the straight edge of the box coincide with one of the meridians of the projection and then turning the board until the needle points to the right or left of the zero, according to the amount and direction of the magnetic deviation.

Bessel's method by inscribed quadrilateral is the simplest method by construction. The objection to it arises from the fact that in practice the intersection of the construction lines often falls beyond the limit of the board.

By this 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.

Pl. 9. (Figs. 11, 12, 13, and 14.) 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. 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*.

In using this method 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, and terminated by those joining the extremes with the middle point. The graphic solution can then proceed in the same manner as that described for an original triangle.

Tracing-cloth protractor.—The third method consists in laying off the angles between the three known points on tracing cloth or paper, and using this as a protractor, determine the position of the unknown point.

Fasten a sheet of tracing cloth or paper to the board, marking upon it a point to represent the unknown point. Draw through it lines toward the three known points. Then shift the tracing cloth over the sheet until each of the three lines passes through the plotted point corresponding to the point toward which it is drawn. The position of the unknown point will be at the intersection of these lines.

This method is less exact and not so convenient as the other two previously described, and is impracticable in any wind.

TWO-POINT PROBLEM.

The occasion may arise where it is desirable to place the table in position at a given point, from which only two determined points are visible. This may be done by the following methods:

The first mode possesses the virtue of making no linear measurement, and demonstrates in a very satisfactory manner the effectiveness of the table in determining position by resection.

(Plate 7, figs. 5, 6, 7, and 8.)—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, so 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. 9):

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 it 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 orient by the latter. Resect on the unknown point drawing the line anywhere on the sheet most convenient. Leave a signal at the occupied point on the range line and set up the instrument at the unknown point. Orient by the line drawn when at the station on the range line, sighting on the latter station. The table will now be in a parallel position to that when on the range line, which is the true position, and the unknown point may be determined by resection upon the two fixed points and their projections.

Deflection of long lines.—In adjusting lines of intersection upon a point or object from a series of stations, when these lines do not coincide in one point, as they are usually derived from signals at unequal distances, the error should not be divided equally among them, but in proportion to their lengths if the discrepancies are not eliminated by the rules for distortion errors given later.

It should be borne in mind that very short lines from a determined point—as, for instance, to the corners of a fenced road, where the table occupies the center of the intersection of two roads—may be taken with no apparent error when the table is deflected to some extent from its true azimuth, but that in this case a prolonged line will be considerably out at its further extremity.

A long line should never be obtained by the prolongation of a short one from a back station where there is no small check line, or some other point in that prolongation already fixed.

It will be apparent that the more nearly at right angles intersecting lines cross each other, the more clearly the point will be defined; acute intersections, as far as possible, should be avoided, and, even when they are crossed by a third line at a satisfactory angle, a fourth line, or an accurate rod reading from a well-determined point, is advisable if within reach.

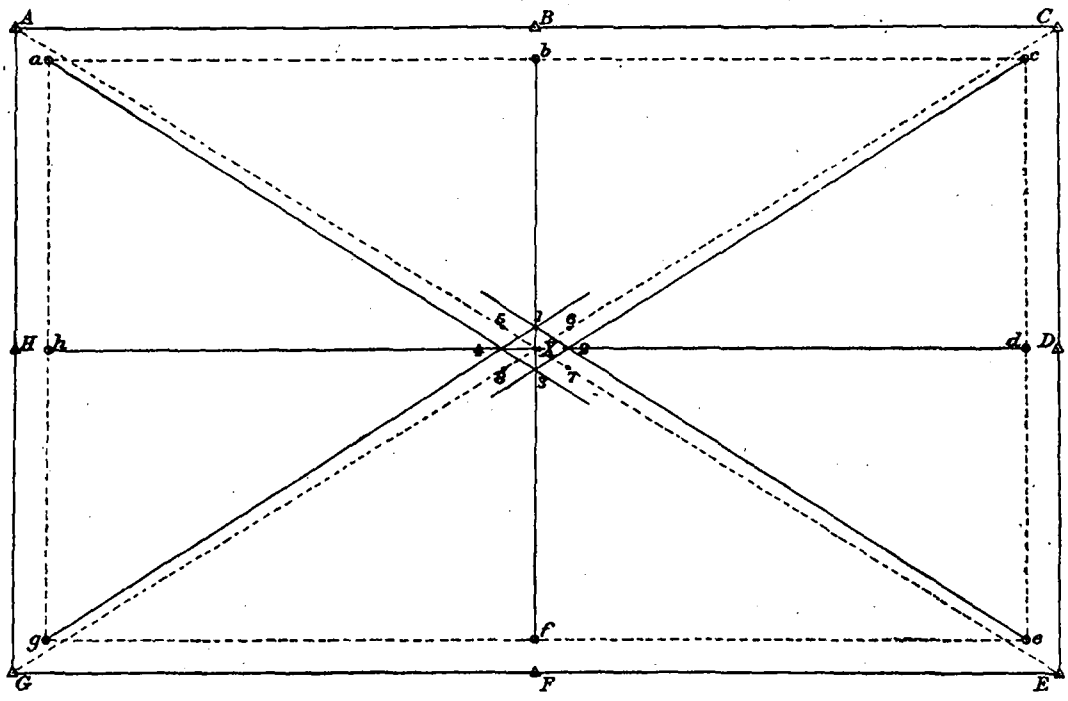
Sometimes a position is established by measuring along the estimated direction

from a nearly fixed point and then orienting by this assumed position and a distant point. This method should be used with caution, but is generally reliable for rodding the detail in the vicinity.

*Distortion errors.**—The distortion of a plane table sheet destroys the perfect proportions which exist between the fixed points and their plotted representatives on the sheet.

The diagram, Pl. 10, illustrates the effect distortion would have in the determination of a point.

No. 10



A, *B*, *C*, etc., are plotted in their true relations. After the sheet has contracted *a*, *b*, *c*, etc., represent the relations those points have assumed. The paper contracts at a uniform but different rate in each direction.

The plane table is supposed to be at *x*, the exact center of the figure, and it is required to determine the position by the distorted points *a*, *b*, *c*, etc. By reversing the telescope, we immediately ascertain that we are directly on the line *HD*. Reversal will also show that we are on the lines *AE*, *CG*, and *BF*. But the distortion is not apparent until the telescope is pointed at the signals, and the lines are drawn on the sheet. Then if we orient by the line *HD*, we shall produce the figure of the diagram, giving five determinations, 1, 2, 3, 4, and *x*, each made with four well-conditioned points. Any one of these conditions would be considered satisfactory if we had not the other points to show that something was wrong. To orient by the line *BF* will produce the same result. But if we take the diagonal *AE*, we shall have two positions at 5 and 7, formed by the intersection of the diagonal points, with the lines from the other points

*See Distortion of Plane Table Sheets, Ogden, Science, Vol. XI, No. 270.

running wild. Using the diagonal *CG* would give two points at 6 and 8, with the lines from the other points running wild as before.

Position by compromise.—There is no question that out of the nine positions developed by these settings, that at *X* is the only true compromise. When the sheet is distorted, all positions are compromises; and *X* is the true compromise in this case, for it is on the lines *CG*, *AE*, etc.: *a* below and *e* above, the line connecting *A* and *E*, by equal quantities. A line drawn through the distorted points *a* and *e* must pass through the middle point *X*. The positions 5, 6, 7, and 8 can not be true because lines forming them will not pass through the opposite points when extended, which we know to be the condition that must be filled.

Rules:

(1) A station made with three points that are on the lines of contraction, the resecting lines forming nearly right angles at their intersection, will give the true position in relation to all points in the sheet (as *h*, *b*, *d*).

(2) A similar condition of right-angular intersection at the station, but the lines forming diagonals to the lines of contraction, will give the worst possible position for the station (as *a*, *c*, and *e*).

(3) A station made with three points on one of the lines of contraction will give the correct orientation of the table (*a*, *h*, and *c*) but not the correct position.

(4) In estimating errors of the point due to distortion, those situated on the lines of contraction require no allowance, however distant.

Application.—If the change in the sheet due to contraction or expansion gives the same percentage of the units of length, both lengthwise and transverse of the sheet, the points are still in their true relative position, and the projection is practically as good as when laid on the paper, but is on a slightly altered scale. When the percentage of change in the units of length is greater in one direction than the other the sheet and projection are distorted; and to make a station by the three-point problem the change of scale in each direction must be allowed for. The difficulty in making such allowances is not great if the principal effects of distortion in the sheet are borne in mind. It would not be permissible, even were it practicable, to make new points on the sheet, as this would destroy the geographic position. It is necessary, therefore, to assume the new points by estimation, applying the percentage of change to the distances measured between the points on the lines of change—that is, on lines parallel to the edges of the sheet. If the point occupied and the point sighted to are on a line parallel, or nearly so, to one edge of the sheet, its movement from the distortion can only be along that line. When the position of the point sighted to is found situated to one side of the line parallel to the edge of the sheet, the distortion will also affect it in the direction at right angles to that edge, and the effect of the distortion will be most apparent when the angle of deflection is 45° and the position at as great a distance from the point occupied as the paper will permit. As the angle of deflection increases above 45° the effect becomes less and disappears at 90°, when the position will fall again in a line parallel to an edge of the sheet.

Referring to the diagram, Pl. 10, to make a station with the three points *a*, *b*, *c*: If the sheet were not distorted the station would be at *X*; *A*, *B*, and *C* being the true positions plotted when the projection was drawn. But the sheet having contracted, *a*, *b*, and *c* show the relative positions of these points; therefore we make such allowance

for the contraction derived from measuring the unit of length that we can place or imagine *a* and *c* to be where they belong, at *A* and *C*. *b* requires no change, as it is on a line parallel to the edge of the sheet. To locate *A* we must know the distances (approximately) *h* to *a* and *h* to *X*, which multiplied by the percentages of contraction (in this case) will give the distance of A above and to the left of *a*. The same process locates *C*.

If the station were to be made with the points *a*, *c*, and *e*, all three points would have to be imagined in a new position by the same process that *A* has been located.

Stations made in this way will be good for all local sketching within an area that the contraction of the sheet is inappreciable; but to take cuts on distant objects from such a station the orientation of the table must be changed. If an object is somewhere near the direction of *a* and the table at the compromise station *X*, the table must be oriented by *a* and *X*, the imaginary position *A* being discarded.

The same processes apply to all positions on the sheet for the station occupied.

Height of instrument.—Having obtained the horizontal position on the sheet of the occupied point, the next proceeding in the logical sequence is the determination of the height of the instrument above some datum plane, in order to locate and draw the contours of the area surrounding the station. The angle read and the distance between the occupied point and the observed point measured from the map, the height is computed by means of the following table, in which correction is made for curvation 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	23·2	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
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

Table showing the height in feet corresponding to a given angle of elevation and a given distance in meters—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.*
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.		

TABLE II.— *Table showing the height, in meters, corre-*

(Curvature and refraction

		100	200	300	400	500	600	700	800	900	1000	1100	1200
0°	1′	0·03	0·06	0·09	0·13	0·16	0·20	0·24	0·28	0·32	0·36	0·40	0·45
	2	0·06	0·12	0·18	0·24	0·31	0·37	0·44	0·51	0·58	0·65	0·72	0·79
	3	0·09	0·18	0·27	0·36	0·45	0·55	0·64	0·74	0·84	0·94	1·04	1·14
	4	0·12	0·24	0·36	0·48	0·60	0·72	0·85	0 97	1·10	1·23	1·36	1·39
	5	0·15	0·29	0·44	0·59	0·74	0·90	1·05	1·21	1·36	1·52	1·68	1·84
0°	6′	0·18	0·35	0·53	0·70	0·89	1·07	1·26	1·44	1·62	1·81	2·00	2·19
	7	0·20	0·41	0·62	0·82	1·04	1·24	1·46	1·67	1·89	2·10	2·32	2·44
	8	0·23	0·47	0·70	0·94	1·18	1·42	1·66	1·90	2·16	2·39	2·64	2·89
	9	0·26	0·53	0·79	1·06	1·33	1·59	1·87	2·14	2·41	2·68	2·96	3·24
	10	0·29	0·58	0·88	1·18	1·47	1·77	2·07	2·37	2·68	2·98	3·28	3·59
0°	11′	0·32	0·64	0·97	1·29	1·62	1·94	2·27	2·60	2·93	3·27	3·60	3·74
	12	0·35	·70	1·05	1·41	1·76	2·12	2·48	2·84	3·20	3·56	3·92	4·29
	13	0·38	0·76	1·14	1·52	1·91	2·29	2·68	3·07	3·46	3·85	4·24	4·63
	14	0·41	0·82	1·23	1·64	2·05	2·47	2·88	3·30	3·72	4·14	4·56	4·98
	15	0·44	0·88	1·32	1·76	2·20	2·64	3·08	3·53	3·98	4·43	4·88	5·33
0°	16′	0·47	0·93	1·40	1·87	2·34	2·82	3·29	3·77	4·24	4·72	5·20	5·68
	17	0·50	0·99	1·49	1·99	2·49	2·99	3·49	3·90	4·50	5·01	5·52	6·03
	18	0·52	1·05	1·58	2·10	2·64	3·17	3·70	4·23	4·77	5·30	5·84	6·38
	19	0·55	1·11	1·66	2·22	2·78	3·34	3·90	4·46	5·03	5·59	6·16	6·63
	20	0·58	1·17	1·75	2·34	2·93	3·51	4·11	4·70	5·29	5·88	6·48	7·08
0°	21′	0·61	1·23	1·84	2·45	3·07	3·69	4·31	4·93	5·55	6·17	6·80	7·43
	22	0·64	1·28	1·93	2·57	3·22	3·86	4·51	5·16	5·81	6·47	7·12	7·78
	23	0·67	1·34	2·01	2·69	3·36	4·04	4·72	5·40	6·08	6·76	7·44	8·12
	24	0·70	1·40	2·10	2·80	3·50	4·21	4·92	5·63	6·34	7·05	7·76	8·47
	25	0·73	1·46	2·19	2·92	3·65	4·39	5·12	5·88	6·60	7·34	8·08	8·82
0°	26′	0·76	1·52	2·28	3·04	3·80	4·56	5·33	6·09	6·86	7·63	8·40	9·17
	27	0·79	1·57	2·36	3·15	3·95	4·74	5·53	6·33	7·12	7·92	8·72	9·52
	28	0·82	1·63	2·45	3·27	4·09	4·91	5·74	6·56	7·38	8·21	9·04	9·87
	29	0·84	1·69	2·54	3·38	4·24	5·08	5·94	6·79	7·65	8·50	9·36	10·22
	30	0·87	1·75	2·62	3·50	4·38	5·26	6·14	7·02	7·91	8·79	9·68	10·57
0°	40′	1·16	2·33	3·50	4·66	5·84	7·00	8·18	9·35	10·53	11·70	12·88	14·06
	50	1·45	2·91	4·37	5·83	7·29	8·75	10·22	11·68	13·14	14·62	16·08	17·55
1	00	1·75	3·49	5·24	6·99	8·74	10·50	12·25	14·01	15·76	17·52	19·28	21·04
1	10	2·04	4·08	6·12	8·16	10·20	12·24	14·29	16·33	18·38	20·43	22·48	24·53
1	20	2·33	4·66	6·99	9·32	11·66	13·99	16·33	18·66	21·00	23·34	25·68	28·03
1°	30′	2·62	5·24	7·86	10·48	13·11	15·73	18·36	20·99	23·62	26·25	28·88	31·52
1	40	2·91	5·82	8·74	11·65	14·56	17·48	20·40	23·32	26·24	29·16	32·09	35·01
1	50	3·20	6·40	9·61	12·82	16·02	19·23	22·44	25·65	28·86	32·08	35·29	38·51
2	00	3·49	6·99	10·48	13·98	17·49	20·98	24·48	27·98	31·48	34·99	38·49	42·00
2°	30′	4·37	8·74	13·11	17·28	21·85	26·22	30·60	34·97	39·35	43·73	48·11	52·49
3	00	5·24	10·48	15·73	20·97	26·22	31·47	36·72	41·97	47·22	52·47	57·73	62·99
3	30	6·12	12·24	18·36	24·48	30·60	36·72	42·85	44·97	55·10	61·23	67·36	73·49
4	00	6·99	13·99	20·98	27·98	34·98	41·98	48·98	55·98	62·99	69·99	77·00	84·01
		100	200	300	400	500	600	700	800	900	1000	1100	1200

sponding to given angles of elevation and distances in meters.

taken into account.)

1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500		
0·49	0·54	0·59	0·64	0·69	0·74	0·80	0·85	0·90	0·96	1·02	1·08	1·14	0°	1′
0·87	0·95	1·02	1·10	1·18	1·26	1·35	1·43	1·52	1·60	1·69	1·78	1·87		2
1·25	1·35	1·46	1·57	1·68	1·79	1·90	2·01	2·13	2·24	2·36	2·48	2·60		3
1·63	1·76	1·90	2·03	2·17	2·31	2·45	2·59	2·74	2·88	3·03	3·18	3·33		4
2·00	2·17	2·33	2·50	2·67	2·83	3·00	3·18	3·35	3·52	3·70	3·88	4·05		5
2·38	2·57	2·77	2·96	3·16	3·35	3·56	3·76	3·96	4·16	4·37	4·57	4·78	0°	6′
2·76	2·98	3·20	3·43	3·66	3·88	4·11	4·34	4·57	4·80	5·04	5·27	5·51		7
3·14	3·39	3·64	3·89	4·15	4·50	4·66	4·92	5·18	5·44	5·70	5·97	6·24		8
3·52	3·80	4·08	4·36	4·64	4·93	5·22	5·50	5·79	6·08	6·37	6·67	6·96		9
3·90	4·20	4·51	4·82	5·14	5·45	5·77	6·08	6·40	6·72	7·04	7·36	7·69		10
4·27	4·61	4·95	5·29	5·63	5·98	6·32	6·67	7·01	7·36	7·71	8·06	8·42	0°	11′
4·65	5·02	5·39	5·76	6·13	6·50	6·87	7·25	7·62	8·00	8·38	8·76	9·14		12
5·03	5·42	5·82	6·22	6·62	7·02	7·43	7·83	8·24	8·64	9·05	9·46	9·87		13
5·41	5·83	6·26	6·69	7·12	7·55	7·98	8·41	8·85	9·28	9·72	10·16	10·60		14
5·78	6·24	6·70	7·15	7·62	8·07	8·53	8·99	9·46	9·92	10·39	10·86	11·32		15
6·16	6·65	7·13	7·62	8·11	8·59	9·08	9·58	10·07	10·56	11·06	11·55	12·05	0°	16′
6·54	7·05	7·56	8·08	8·60	9·12	9·64	10·16	10·68	11·20	11·73	12·25	12·78		17
6·92	7·46	8·00	8·55	9·09	9·64	10·19	10·74	11·29	11·84	12·40	12·95	13·51		18
7·30	7·87	8·44	9·01	9·59	10·16	10·74	11·32	11·90	12·48	13·06	13·65	14·23		19
7·68	8·28	8·88	9·48	10·08	10·69	11·30	11·90	12·51	13·12	13·73	14·35	14·96		20
8·05	8·68	9·31	9·94	10·58	11·21	11·85	12·48	13·12	13·76	14·40	15·04	15·69	0°	21′
8·43	9·09	9·75	10·41	11·07	11·74	12·40	13·07	13·73	14·40	15·07	15·74	16·42		22
8·81	9·50	10·19	10·88	11·57	12·26	12·95	13·65	14·34	15·04	15·74	16·44	17·14		23
9·19	9·90	10·62	11·34	12·06	12·78	13·51	14·23	14·96	15·68	16·41	17·14	17·87		24
9·57	10·31	11·06	11·81	12·56	13·31	14·06	14·81	15·57	16·32	17·08	17·84	18·60		25
9·94	10·72	11·50	12·27	13·05	13·83	14·61	15·39	16·18	16·96	17·75	18·54	19·32	0°	26′
10·32	11·13	11·93	12·74	13·55	14·35	15·16	15·98	16·79	17·60	18·42	19·23	20·05		27
10·70	11·53	12·37	13·20	14·04	14·88	15·72	16·56	17·40	18·24	19·09	19·93	20·78		28
11·08	11·94	12·80	13·67	14·53	15·40	16·27	17·14	18·01	18·88	19·76	20·63	21·51		29
11·46	12·35	13·24	14·13	15·03	15·93	16·82	17·72	18·62	19·52	20·42	21·33	22·23		30
15·24	16·42	17·60	18·79	19·97	21·16	22·35	23·54	24·73	25·82	27·12	28·31	29·50	0°	40′
19·02	20·49	21·97	23·44	24·92	26·40	27·88	29·36	30·84	32·32	33·81	35·29	36·78		50
22·81	24·57	26·33	28·10	29·87	31·64	33·41	35·18	36·95	38·72	40·50	42·28	44·06	1	00
26·59	28·64	30·70	32·75	34·81	36·87	38·94	41·00	43·06	45·13	47·19	49·26	51·33	1	10
30·37	32·72	35·06	37·41	39·76	42·10	44·46	46·82	49·17	51·53	53·89	56·25	58·61	1	20
34·16	36·79	39·43	42·07	44·71	47·35	49·99	52·64	55·28	57·93	60·58	63·23	65·88	1°	30′
37·94	40·87	43·80	46·73	49·66	52·59	55·52	58·46	61·40	64·34	67·28	70·22	73·16	1	40
41·72	44·94	48·16	51·38	54·61	57·83	61·06	64·28	67·51	70·74	73·97	77·21	80·44	1	50
45·50	49·02	52·53	56·04	59·56	63·07	66·59	70·10	73·63	77·15	80·67	84·20	87·72	2	00
56·87	61·26	65·64	70·03	74·42	78·81	83·20	87·59	91·98	96·38	100·78	105·17	109·57	2°	30′
68·24	73·51	78·76	84·02	89·29	94·55	99·82	105·10	110·35	115·62	120·89	126·16	131·44	3	00
79·63	85·76	91·89	98·03	104·18	110·31	116·45	122·59	128·74	134·88	141·03	147·18	153·33	3	30
91·02	98·03	105·04	112·06	117·07	126·09	133·10	140·12	147·14	154·18	161·19	168·21	175·24	4	00
1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500		

Pl. 32 is a diagram showing the method of constructing a scale for taking off the heights corresponding to a given angle and distance.

*Table of factors for computing differences in elevation.**

To obtain the difference in elevation in feet multiply the horizontal distance in meters by the factor in this table corresponding to the observed angle of elevation or depression. The factors are given for each ten minutes, but the value for the nearest minute may be interpolated, using the column of differences for one minute. The result is still to be corrected where necessary for the effect of curvature and refraction.

TABLE III.

Angle.	0′	10′	20′	30′	40′	50′	60′	Difference for 1 minute (fourth decimal place).
0	0·0000	0·0095	0·0191	0·0286	0·0382	0·0477	0·0573	9·5
1	0·0573	0·0668	0·0764	0·0859	0·0955	0·1050	0·1146	9·6
2	0·1146	0·1241	0·1337	0·1432	0·1528	0·1624	0·1719	9·6
3	0·1719	0·1815	0·1911	0·2007	0·2102	0·2198	0·2294	9·6
4	0·2294	0·2390	0·2486	0·2582	0·2678	0·2774	0·2870	9·6
5	0·2870	0·2967	0·3063	0·3159	0·3255	0·3352	0·3448	9·6
6	0·3448	0·3545	0·3641	0·3738	0·3835	0·3932	0·4028	9·7
7	0·4028	0·4125	0·4222	0·4319	0·4416	0·4514	0·4611	9·7
8	0·4611	0·4708	0·4806	0·4903	0·5001	0·5098	0·5196	9·8
9	0·5196	0·5294	0·5392	0·5490	0·5588	0·5687	0·5785	9·8
10	0·5785	0·5884	0·5982	0·6081	0·6179	0·6278	0·6377	9·9
11	0·6377	0·6476	0·6576	0·6675	0·6774	0·6874	0·6974	9·9
12	0·6974	0·7073	0·7173	0·7273	0·7374	0·7474	0·7574	10·0
13	0·7574	0·7675	0·7776	0·7877	0·7978	0·8079	0·8180	10·1
14	0·8180	0·8282	0·8383	0·8485	0·8587	0·8689	0·8791	10·2
15	0·8791	0·8893	0·8996	0·9099	0·9201	0·9304	0·9408	10·3
16	0·9408	0·9511	0·9615	0·9718	0·9822	0·9926	1·0031	10·4
17	1·0031	1·0135	1·0240	1·0344	1·0449	1·0555	1·0660	10·5
18	1·0660	1·0766	1·0872	1·0978	1·1084	1·1190	1·1297	10·6
19	1·1297	1·1404	1·1511	1·1618	1·1726	1·1833	1·1941	10·7
20	1·1941	1·2050	1·2158	1·2266	1·2375	1·2485	1·2594	10·9
21	1·2594	1·2704	1·2813	1·2924	1·3034	1·3144	1·3255	11·0
22	1·3255	1·3367	1·3478	1·3590	1·3702	1·3814	1·3926	11·2
23	1·3926	1·4039	1·4152	1·4266	1·4379	1·4493	1·4607	11·4
24	1·4607	1·4722	1·4836	1·4952	1·5067	1·5183	1·5299	11·5
25	1·5299	1·5415	1·5532	1·5649	1·5766	1·5884	1·6002	11·7
26	1·6002	1·6120	1·6239	1·6358	1·6477	1·6597	1·6717	11·9
27	1·6717	1·6837	1·6958	1·7079	1·7200	1·7322	1·7444	12·1
28	1·7444	1·7567	1·7690	1·7814	1·7937	1·8061	1·8186	12·4
29	1·8186	1·8311	1·8436	1·8562	1·8688	1·8815	1·8942	12·6
30	1·8942	1·9069	1·9197	1·9326	1·9454	1·9584	1·9713	12·9
31	1·9713	1·9843	1·9974	2·0105	2·0236	2·0368	2·0501	13·1
32	2·0501	2·0634	2·0767	2·0901	2·1036	2·1171	2·1306	13·4
33	2·1306	2·1442	2·1578	2·1715	2·1853	2·1991	2·2130	13·7
34	2·2130	2·2269	2·2408	2·2548	2·2689	2·2831	2·2973	14·0
35	2·2973	2·3115	2·3258	2·3402	2·3546	2·3691	2·3837	14·4
36	2·3837	2·3983	2·4130	2·4277	2·4425	2·4574	2·4723	14·8
37	2·4723	2·4873	2·5023	2·5175	2·5327	2·5479	2·5633	15·2
38	2·5633	2·5787	2·5942	2·6097	2·6253	2·6410	2·6568	15·6
39	2·6568	2·6726	2·6885	2·7045	2·7206	2·7367	2·7530	16·0
40	2·7530	2·7692	2·7856	2·8021	2·8186	2·8353	2·8520	16·5
41	2·8520	2·8688	2·8857	2·9026	2·9197	2·9368	2·9541	17·0
42	2·9541	2·9714	2·9888	3·0063	3·0239	3·0416	3·0594	17·6
43	3·0594	3·0773	3·0953	3·1134	3·1316	3·1499	3·1683	18·1
44	3·1683	3·1868	3·2054	3·2241	3·2429	3·2618	3·2808	18·8

* Furnished by G. R. Putnam, Assistant, Coast and Geodetic Survey.

*Table of corrections for curvature and refraction.**

The correction in feet for the combined effect of curvature and refraction is given for each 100 meters' distance, the thousands of meters being given in the column to the left and the hundreds in the upper line. The correction is to be added to the *difference* of elevation for angles of *elevation* and *subtracted* for angles of *depression*, or it is always to be added to the uncorrected *elevation* of the point to be determined from point of observation.

Example: At a station whose elevation is 1 000 feet (at telescope), angle to signal = 3° elevation, horizontal distance = 5 000 meters. From Table III factor is 0·1719, which multiplied by 5 000 = 859·5 feet. From Table IV correction is 5·5 feet. Corrected difference of elevation = 859·5 + 5·5 = 865 feet, which added to 1 000 = 1 865 feet for elevation of signal. If the above angle to signal be 3° depression, then corrected difference of elevation = 859·5 — 5·5 = 854·0 feet, which makes height of signal = 1 000 — 854·0 = 146·0 feet.

TABLE IV.

Distance in meters.	0	100	200	300	400	500	600	700	800	900	1 000
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
0	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·2	0·2
1 000	0·2	0·3	0·3	0·4	0·4	0·5	0·6	0·6	0·7	0·8	0·9
2 000	0·9	1.0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·9	2·0
3 000	2·0	2·1	2·3	2·4	2·6	2·7	2·9	3·0	3·2	3·4	3·5
4 000	3·5	3·7	3·9	4·1	4·3	4·5	4·7	4·9	5·1	5·3	5·5
5 000	5·5	5·8	6·0	6·2	6·5	6·7	7·0	7·2	7·4	7·7	8·0
6 000	8·0	8·2	8·5	8·8	9·1	9·4	9·7	10·0	10·2	10·6	10·9
7 000	10·9	11·2	11·5	11·8	12·1	12·5	12·8	13·1	13·5	13·8	14·2
8 000	14·2	14·5	14·9	15·3	15·6	16·0	16·4	16·8	17·2	17·6	18·0
9 000	18·0	18·4	18·8	19·2	19·6	20·0	20·4	20·8	21·3	21·7	22·2
10 000	22·2	22·6	23·0	23·5	24·0	24·4	24·9	25·4	25·8	26·3	26·8
11 000	26·8	27·3	27·8	28·3	28·8	29·3	29·8	30·3	30·8	31·4	31·9
12 000	31·9	32·4	33·0	33·5	34·1	34·6	35·2	35·7	36·3	36·9	37·4
13 000	37·4	38·0	38·6	39·2	39·8	40·4	41·0	41·6	42·2	42·8	43·4
14 000	43·4	44·1	44·7	45·3	46·0	46·6	47·2	47·9	48·5	49·2	49·8
15 000	49·8	50·5	51·2	51·9	52·5	53·2	53·9	54·6	55·3	56·0	56·7
16 000	56·7	57·4	58·2	58·9	59·6	60·3	61·0	61·8	62·5	63·3	64·0
17 000	64·0	64·8	65·6	66·3	67·1	67·9	68·6	69·4	70·2	71·0	71·8
18 000	71·8	72·6	73·4	74·2	75·0	75·8	76·7	77·5	78·3	79·1	80·0
19 000	80·0	80·8	81·7	82·5	83·4	84·2	85·1	86·0	86·9	87·7	88·6

* Furnished by G. R. Putnam, Assistant, Coast and Geodetic Survey.

Table of factors for computing differences in elevation.

To obtain the difference in elevation in *meters* multiply the horizontal distance in meters by the factor in this table corresponding to the observed angle of elevation or depression. The factors are given for each ten minutes, but the value of the nearest minute may be interpolated, using the column of differences for one minute. The result is still to be corrected where necessary for the effect of curvature and refraction.

TABLE V.

Angle	0′	10′	20′	30′	40′	50′	60′	Difference for 1 minute (4th dec. place)
°								
0	0·0000	0·0029	0·0058	0·0087	0·0116	0·0145	0·0175	2·9
1	·0175	·0204	·0233	·0262	·0291	·0320	·0349	2·9
2	·0349	·0378	·0407	·0437	·0466	·0495	·0524	2·9
3	·0524	·0553	·0582	·0612	·0641	·0670	·0699	2·9
4	·0699	·0729	·0758	·0787	·0816	·0846	·0875	2·9
5	·0875	·0904	·0934	·0963	·0992	·1022	·1051	2·9
6	·1051	·1080	·1110	·1139	·1169	·1198	·1228	2·9
7	·1228	·1257	·1287	·1317	·1346	·1376	·1405	2·9
8	·1405	·1435	·1465	·1495	·1524	·1554	·1584	3·0
9	·1584	·1614	·1644	·1673	·1703	·1733	·1763	3·0
10	·1763	·1793	·1823	·1853	·1883	·1914	·1944	3·0
11	·1944	·1974	·2004	·2035	·2065	·2095	·2126	3·0
12	·2126	·2156	·2186	·2217	·2247	·2278	·2309	3·0
13	·2309	·2339	·2370	·2401	·2432	·2462	·2493	3·1
14	·2493	·2524	·2555	·2586	·2617	·2648	·2679	3·1
15	·2679	·2711	·2742	·2773	·2805	·2836	·2867	3·1
16	·2867	·2899	·2931	·2962	·2994	·3026	·3057	3·2
17	·3057	·3089	·3121	·3153	·3185	·3217	·3249	3·2
18	·3249	·3281	·3314	·3346	·3378	·3411	·3443	3·2
19	·3443	·3476	·3508	·3541	·3574	·3607	·3640	3·3
20	·3640	·3673	·3706	·3739	·3772	·3805	·3839	3·3
21	·3839	·3872	·3906	·3939	·3973	·4006	·4040	3·3
22	·4040	·4074	·4108	·4142	·4176	·4210	·4245	3·4
23	·4245	·4279	·4314	·4348	·4383	·4417	·4452	3·4
24	·4452	·4487	·4522	·4557	·4592	·4628	·4663	3·5
25	·4663	·4699	·4734	·4770	·4806	·4841	·4877	3·5
26	·4877	·4913	·4950	·4986	·5022	·5059	·5095	3·6
27	·5095	·5132	·5169	·5206	·5243	·5280	·5317	3·7
28	·5317	·5354	·5392	·5430	·5467	·5505	·5543	3·8
29	·5543	·5581	·5619	·5658	·5696	·5735	·5774	3·8
30	·5774	·5812	·5851	·5890	·5930	·5969	·6009	3·9
31	·6009	·6048	·6088	·6128	·6168	·6208	·6249	4·0
32	·6249	·6289	·6330	·6371	·6412	·6453	·6494	4·1
33	·6494	·6536	·6577	·6619	·6661	·6703	·6745	4·2
34	·6745	·6787	·6830	·6873	·6916	·6959	·7002	4·3
35	·7002	·7046	·7089	·7133	·7177	·7221	·7265	4·4
36	·7265	·7310	·7355	·7400	·7445	·7490	·7536	4·5
37	·7536	·7581	·7627	·7673	·7720	·7766	·7813	4·6
38	·7813	·7860	·7907	·7954	·8002	·8050	·8098	4·7
39	·8098	·8146	·8195	·8243	·8292	·8342	·8391	4·9
40	·8391	·8441	·8491	·8541	·8591	·8642	·8693	5·0
41	·8693	·8744	·8796	·8847	·8899	·8952	·9004	5·2
42	·9004	·9057	·9110	·9163	·9217	·9271	·9325	5·4
43	·9325	·9380	·9435	·9490	·9545	·9601	·9657	5·6
44	·9657	·9713	·9770	·9827	·9884	·9942	1·0000	5·7

Table of corrections for curvature and refraction.

The correction in *meters* for the combined effect of curvature and refraction is given for each 100 meters distance, the thousands of meters being given in the column to the left and the hundreds in the upper line. The correction is to be added to the *difference* of elevation for angles of *elevation* and substracted for angles of *depression*, or it is always to be added to the uncorrected *elevation* of the point to be determined from point of observation.

Example: At a station whose elevation is 304·80 meters (at telescope), angle to signal 3° elevation, horizontal distance 5 000 meters. From Table V factor is 0·0524, which multiplied by 5 000 = 262·00. From Table VI correction is 1·67 meters. Corrected difference of elevation = 262·00 + 1·67 = 263·67 meters, which added to 304·80 = 568·47 meters for elevation of signal. If the above angle to signal be 3° depression, then corrected difference of elevation 262·00 — 1·67 = 260·33 meters, which makes height of signal = 304·80 — 260·33 = 44·47 meters.

TABLE VI.

Distance in meters	0	100	200	300	400	500	600	700	800	900	1 000
0	0·00	0·00	0·00	0·01	0·01	0·02	0·02	0·03	0·04	0·05	0·07
1 000	0·07	0·08	0·10	0·11	0·13	0·15	0·17	0·19	0·22	0·24	0·27
2 000	0·27	0·29	0·32	0·35	0·38	0·42	0·45	0·49	0·52	0·56	0·60
3 000	0·60	0·64	0·68	0·73	0·77	0·82	0·86	0·91	0·96	1·01	1·07
4 000	1·07	1·12	1·18	1·23	1·29	1·35	1·41	1·47	1·54	1·60	1·67
5 000	1·67	1·74	1·80	1·87	1·94	2·02	2·09	2·17	2·24	2·32	2·40
6 000	2·40	2·48	2·56	2·65	2·73	2·82	2·91	3·00	3·09	3·18	3·27
7 000	3·27	3·36	3·46	3·55	3·65	3·75	3·85	3·96	4·06	4·16	4·27
8 000	4·27	4·38	4·49	4·60	4·71	4·82	4·93	5·05	5·16	5·28	5·40
9 000	5·40	5·52	5·65	5·77	5·89	6·02	6·15	6·28	6·41	6·54	6·67
10 000	6·67	6·80	6·94	7·08	7·22	7·36	7·50	7·64	7·78	7·93	8·07
11 000	8·07	8·22	8·37	8·52	8·67	8·82	8·98	9·13	9·29	9·45	9·61
12 000	9·61	9·77	9·93	10·09	10·26	10·42	10·59	10·76	10·92	11·10	11·27
13 000	11·27	11·45	11·62	11·80	11·98	12·16	12·34	12·52	12·71	12·89	13·08
14 000	13·08	13·26	13·45	13·64	13·83	14·03	14·22	14·42	14·61	14·81	15·01
15 000	15·01	15·21	15·41	15·62	15·82	16·03	16·24	16·44	16·65	16·87	17·08
16 000	17·08	17·30	17·51	17·73	17·95	18·17	18·39	18·61	18·83	19·05	19·28
17 000	19·28	19·51	19·73	19·96	20·19	20·43	20·66	20·89	21·13	21·37	21·61
18 000	21·61	21·86	22·10	22·34	22·58	22·83	23·08	23·33	23·58	23·83	24·08
19 000	24·08	24·34	24·60	24·85	25·11	25·37	25·63	25·89	26·15	26·42	26·68

Comparison of feet and meters.

[1 meter = 3.280869 feet.]

Meters.	Feet.	Feet.	Meters.
1	3·2808	1	0·3048
2	6·5617	2	0·6096
3	9·8425	3	0·9144
4	13·1233	4	1·2192
5	16·4042	5	1·5240
6	19·6850	6	1·8288
7	22·9658	7	2·1336
8	26·2467	8	2·4384
9	29·5275	9	2·7432

Relief.—There are two methods of representing it—by hill shading and by contours.

Hill shading is generally effected by a system of lines, called hachures, drawn in the direction of the slope. When it is steep, the hachures are thick and closely spaced. On the other hand, a gentle incline will be indicated by fine lines widely separated.

*Contours** or horizontal curves are the outlines of horizontal sections of ground at different elevations with designated equal intervals between their planes, delineated in their true positions relatively to each other and to the rest of the map, and conforming to the scale of the map itself; or, briefly, a contour is the curve produced by the intersection of the horizontal plane with the surface of the ground. They may also be described as imaginary shore lines formed at stated or regular elevations, by water which is supposed to rise successively to these elevations over the face of the country.

Profile.—As each curve has equal vertical ordinates at all points, the elevation or profile of a hill, as well as a model in relief, can be constructed from the map, when it is accurately executed on a large scale, without further field measurements.

A profile of a hill is the outline or trace formed with its surface by a vertical plane cutting the hill in any direction.

Pl. 11 shows the profile through the line A′ B′ of the hill H, as represented on a topographical map. The full parallel lines upon the profile represent the successive heights or sections of the hill of 20 feet, and the broken or intermediate lines x x x those of 10 feet. A reference to the letters of the diagram is all that is necessary to a full understanding of the subject: *a* is the shore line or high-water line upon the map, x x x are the auxiliary 10-foot curves; *f′* the coincidence of curves upon the chart at the perpendicular face of the hill f, upon the section. This is the only case where contours of different heights run into each other upon a topographic plan. D′ D′ are depressions in the face of the hill, represented on the profile by D D. *d′* is a barranca or dry broken gulley, and *c′* c′ a water course.

It will be plain that if we were to suppose the water to rise to a height of 20 feet above the high-water line, to *h* on the profile, the 20-foot curve upon the map would become the shore line and the depression D′ would fill up and become a pond of water; and if the water were to rise to a height of 30 feet, the dotted broken line would form a shore line, and the knoll G would become an island.

Advantages and disadvantages of hill shading and contours.—In a mountainous country the method of hill shading presents a picture which expresses more forcibly to the eye the configuration of the country than a system of contours. But the objection to its sole use arises from the fact that although one ridge is perceived to be higher than another, there is no guide for stating in terms of some linear unit this difference in elevation. It also obscures the symbols representing other details on the surface.

A system of contours furnishes a convenient means for obtaining the heights on any part of a map, but does not adapt itself to the representation of the small but important accidents of the ground, such as gullies, ledges, rocks, etc.; nor does it satisfactorily delineate such features as cliffs, bluffs, quarries, railroad cuts, and embankments.

For these reasons the United States Coast and Geodetic Survey has adopted both methods; employing hachures for the smaller features and where the steepness of the slope would make the contour lines approach together so closely that individual lines would become indistinguishable, and relying on the contours to delineate less precipitous ground.

The two systems can be seen combined when it is necessary to indicate a rocky and broken mountain face. (Pls. 12 and 13.)

* For interesting articles on the diagrammatic properties of the contour line see: On Contour and Slope Lines, Cayley, London & Ed. Mag., 1859, pp. 264-268; On Hills and Dales, Clerk Maxwell, ibid, 1870, pp. 421-426; Properties of Matter, Tait, 1890, pp. 70-81.

Diagram illustrating the mode of constructing Profile from Plan

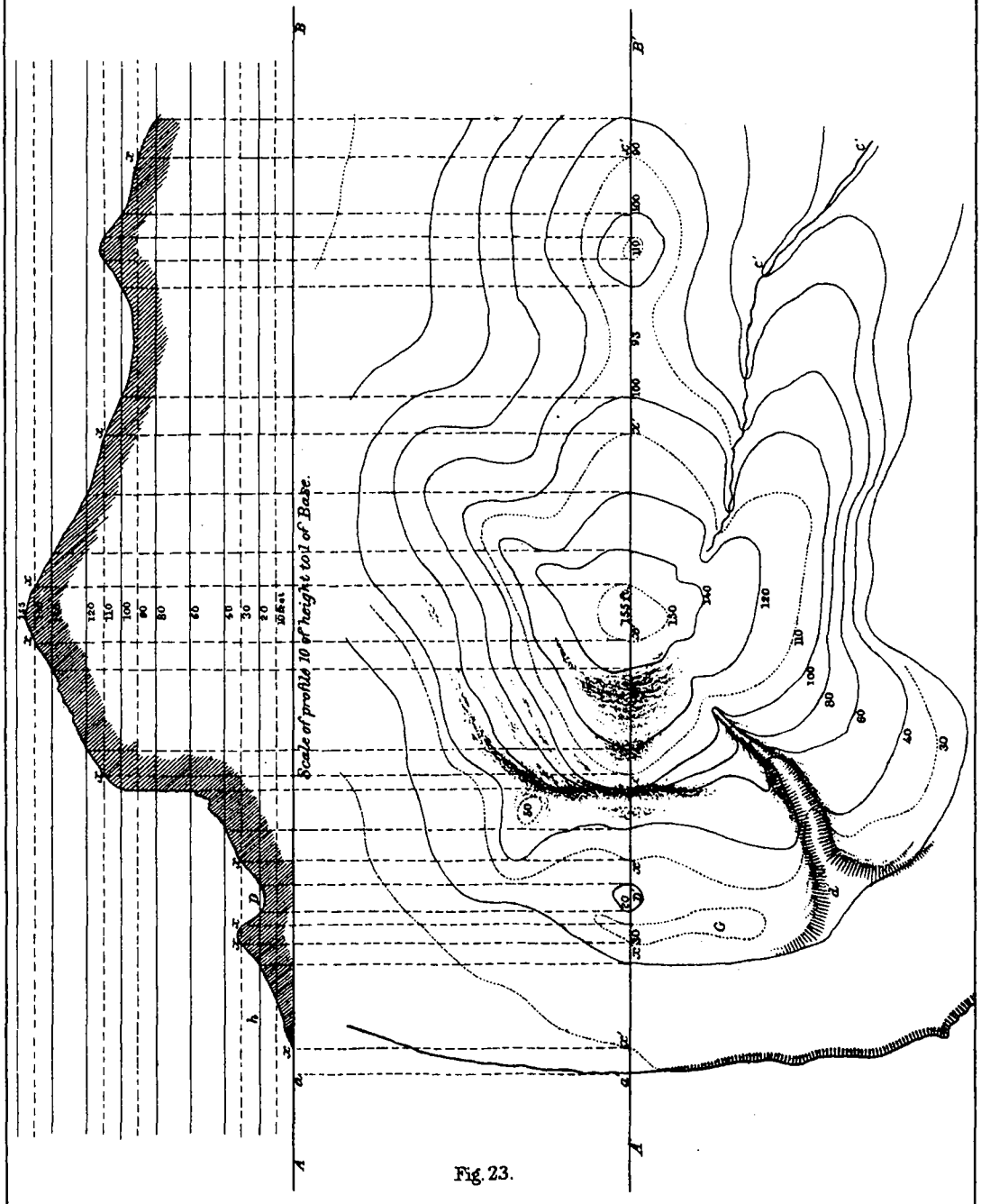


Fig. 23.

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The contour interval customarily used on the Coast and Geodetic Survey field sheets is 20 feet. When, however, the contour runs very near to some remarkable accident of ground, as a prominent spur or indentation, a slight deviation above or below its true plane is admissible to include this feature, although it is preferable to avoid doing so, if possible, by the introduction of an auxiliary curve.

In abruptly mountainous and comparatively inaccessible regions, where sketching must be relied upon, 100-foot curves may suffice to develop all necessary features.

Datum plane.—Probably the best plane of reference for heights of points on the earth's surface is the mean level of the sea, since the mean of the rise and fall of the tides is approximately this level. In practice, however, mean high water is usually taken, as it includes all land not covered by the tide range, and is the line dividing land and water.

Reference signal.—It is advisable in commencing the survey of a region bordering on tide water to locate one or more signals 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 upon for heights from points occupied during the progress of the graphic triangulation. As the heights of other points are determined in the course of the survey and verified from observations from two or three other points, these in turn may be used for the same purpose.

Regular and irregular methods of contouring.—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 rod 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.

Station routine.—The topographer having determined his position on the sheet, and also the height of the instrument, he proceeds to map the natural and artificial details of the area surrounding the station. For this purpose the direction of each detail is obtained by pointing the telescope upon it, the edge of the rule cutting the station point; its distance by reading the stadia rod held there for the purpose. This distance is then taken off the metal scale with a pair of dividers and plotted along the edge of the rule.

While this is in progress, the alidade is used both as a level for the observation of objects of the same height as the instrument, and for measuring angles of elevation and depression to such of the plotted details, whose position at critical points of the contours would materially assist the topographer in tracing them.

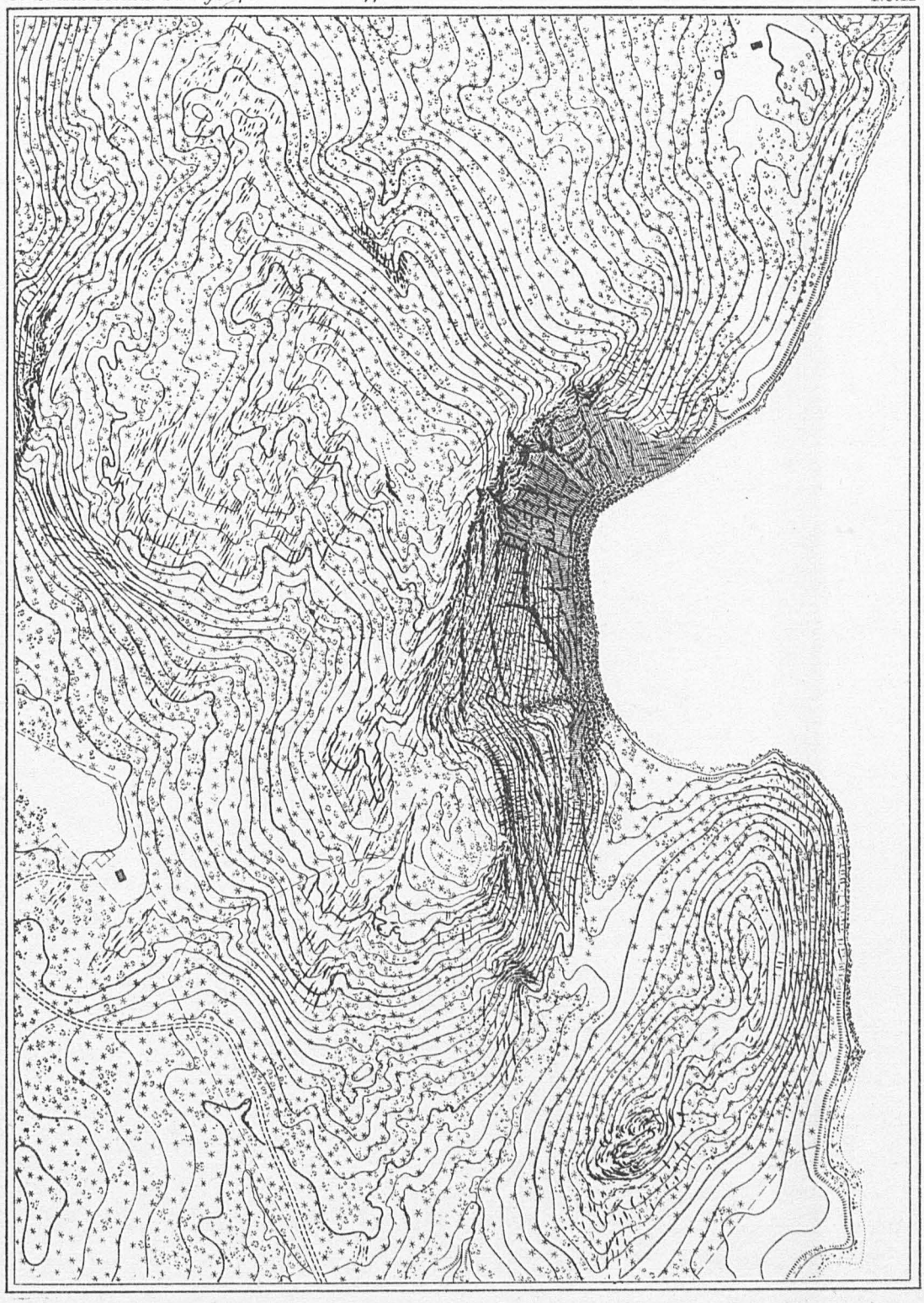
Number of elevations to be determined.—No rule can be laid down as to the number of elevations that should in this manner be determined from each plane table station or for a given area. It will depend on the skill of the topographer and the modeling of the ground. The number will be adequate when he is confident of tracing by their aid the contours with an accuracy sufficient for the scale and the purpose of the survey.

It would indicate careless and slovenly work if the contours were found on examination to deviate frequently from their true position on the sheet by more than half an interval for a slope of less than 5° in an open country. When the slope is steeper, or in wooded regions, a greater latitude is permissible, but even here in representing the crests of ridges, prominent hill tops, and valley floors, this limit of half an interval should not be departed from for good work.*

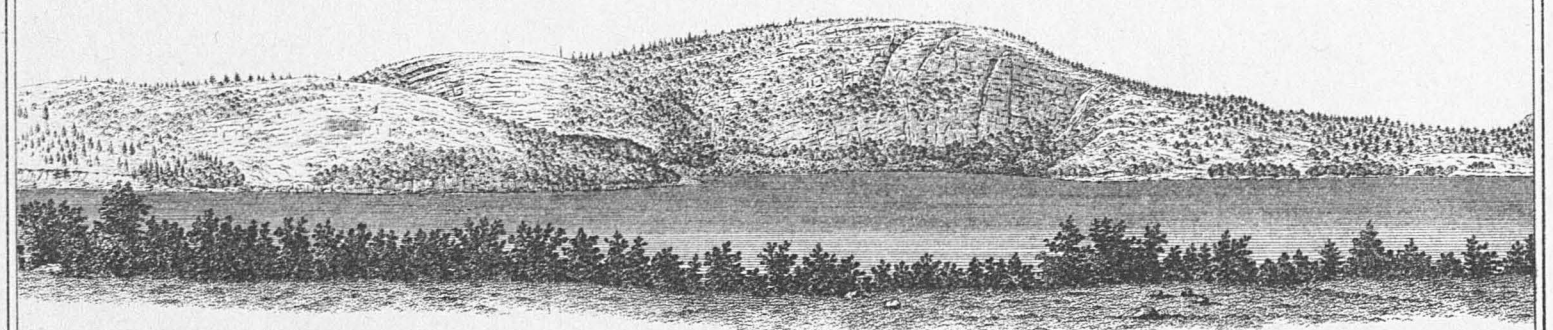
Contour sketching.—The topographer will be assisted in sketching contours, where the modeling is intricate, by lightly drawing a skeleton composed of the ridge lines and thalweg lines (lowest lines of valleys) in their proper positions around the station. On the ridge lines will be found the extreme outward or convex bends of the contours, and on the thalweg lines the extreme inward or concave bends.

It can be readily imagined that if each spur and each small depression was represented by its appropriate line, and on each of them were located, either by observation

*For some pertinent remarks on this subject see Bulletin of the University of Wisconsin, Eng. Series, Vol. 1, No. 10, Topographical Surveys. Their methods and values, J. F. Van Ornum, pp. 360-361.



Crest, Face and Talus of a Granite Cliff. (Eagle Cliff, Mt. Desert I.)



Eagle Cliff, Mt. Desert Id. (Looking West.)

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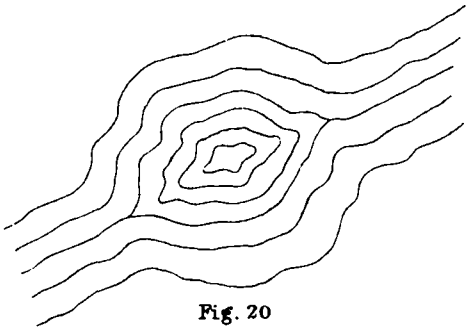

Fig. 20

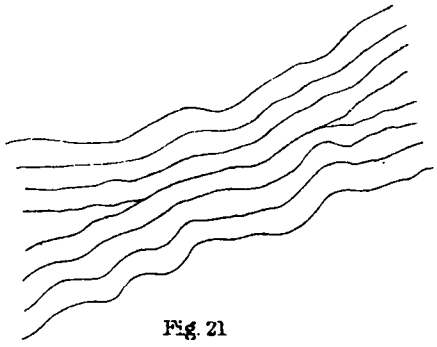

Fig. 21



Fig. 22

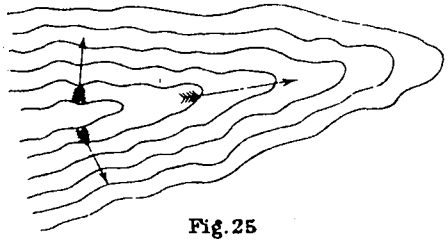

Fig. 25

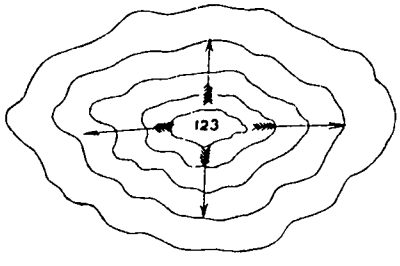

Fig. 23

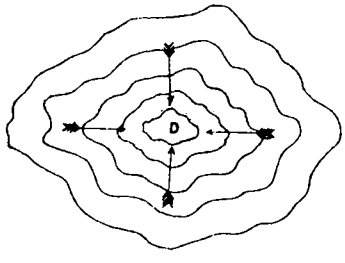

Fig. 24

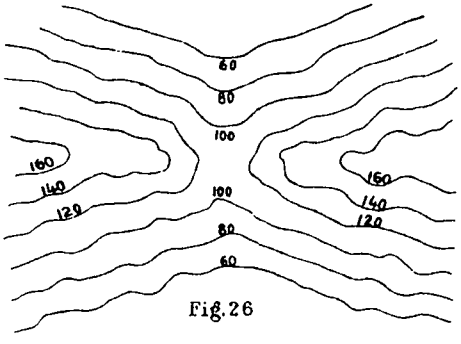

Fig. 26

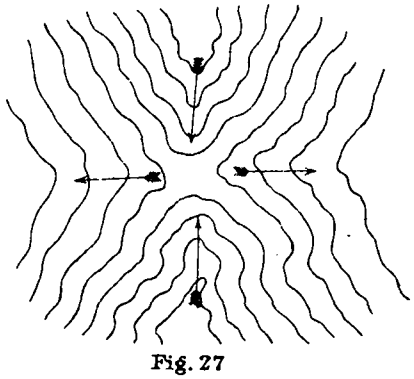

Fig. 27

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Typical Contour Groups

or estimation, points having elevations equal to some multiple of the contour interval, it would be only necessary to connect those points having the same elevation with a smooth curve to have a correct plan of the contours.

It will simplify the sketching at a station to draw the highest, lowest, and middle contours first, as they will then serve as guides for estimating the position of the others.

It should be remembered that a contour never splits, as shown in Pl. 14, fig. 20; nor do two contours run into one, as shown at fig. 21; nor cross each other, except in the rare instance of an overhanging cliff, as shown in fig. 22.

When an auxiliary contour is introduced, no more of it is drawn than is sufficient to delineate the special feature which makes it necessary. A principal contour, on the other hand, can not have an end within the map; if it commences at one edge it must terminate at another.

Typical contour groups.—A closed contour encircled by one or more closed contours is either a hill, as shown in fig. 23, Pl. 14, or a depression, as shown at fig. 24; the arrows showing the direction in which water would run. The summits of all the hills of importance should have their elevations determined and marked on the map. All depressions without an outlet and which do not contain a pond or lake should be marked with a D at their lowest point.

A series of contours, as shown in fig. 25, is either a croupe (the end of a ridge or promontory) or a valley. If a croupe, the contours will have their concave sides toward the higher ground; if a valley, the contours will have their concave sides toward the lower ground.

A combination of four sets, like fig. 26, with convex sides turned toward each other, represents a dip in a ridge, or the junction of two ridges, and is called a saddle.

A pass in a mountain range generally takes the form shown in fig. 27.

Order of development of contours.—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 Pl. 30.)

Filling in.—Having completed the work at a given station, the topographer proceeds with his party and instruments to an adjoining locality, where he selects a new station from which he can gather the details of an area bordering upon the one last surveyed. In this manner, by successively occupying stations over the whole expanse of the sheet, the skeleton map is filled in.

Traverse lines.—In a wooded country, where it is impossible to find open space with range sufficient to see enough points for determination of position by resection, it is

necessary to run traverses along the roads, 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. The levels, when necessary, are carried along with the line by observing the vertical angles with the alidade upon some mark on the rod, taking back and fore sights at alternate stations.

Main traverse.—The standard table is used on main roads and whenever the details are important and numerous.

The traverse line is started by occupying some point previously determined and sending the telemeter rod ahead to a place selected for its advantageous position, in reference either to the surrounding features, or facility in obtaining a new section of the traverse.

Having sighted to this point, read and plotted the distance, short guide lines should be drawn along the edge of the ruler at both ends and numbered or lettered, so they may be identified from others of like character. The table is then moved to the forward station, approximately oriented with the eye, and the plotted point carefully plumbed over the one on the ground.

The alidade is now placed on the table, and the table oriented by bringing the edge of the ruler close up to the guide lines; then revolving the table until the vertical wire bisects the rod or signal left for that purpose at the last station.

The same processes which were employed at the initial station are now repeated; the detail mapped and the new station in advance occupied in turn; the line progressing in this manner by successive steps.

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 which might arise from the inclination of the signal poles.

Subordinate traverse.—When the line is unimportant and few features present themselves to be noted, an auxiliary plane-table oriented by a declinatoire or a transit, fitted with stadia wires, may be employed.

When this method is pursued with a second table the forward rod station is not occupied, but another is chosen in advance of it, from which it can be seen where the instrument is set up and oriented with the declinatoire. Sighting the alidade to what is now the back station, the distance is read and plotted along the edge of the ruler, and the point so determined represents the one occupied by the table.

The pivot on which the declinatoire needle rests should be examined frequently, the least roughness as to its point will cause the needle to drag and introduces serious deflections in azimuth.

All traverse lines should start and end at well-determined points. This will serve to check the accuracy of the work. If the closing error is not too large, the line should be adjusted by distributing it throughout its length. The line is run on a spare sheet when an auxiliary table is used; then traced, "swung in," and adjusted between the two fixed points.

Determinations for hydrography.—Where the topography surveyed includes the shoreline of a body of water, the hydrographic survey of which is intended to follow the topographical work, as in the Coast Survey, it is the duty of the topographer to locate and determine the shore signals, and it is only necessary to state that they should be so placed

as to furnish the hydrographic party with as many points as is desirable for the determination of positions on the water.

Natural or artificial objects along the shore, or in plain sight from the water, such as fence ends, rocks, prominent houses, etc., should be determined and marked upon the sheet.

Lines to buoys and other permanent floating objects should be, as far as practicable, taken at the same stage of the tide, or direction of current.

The delineation of the ordinary mean low-water mark should be aimed at, and when it is beyond the reach of the plane-table, and presents no marked points for determination, or is of a character that will not admit of putting up and working the instrument—as along the swampy shores of the south, where the muddy shoals extend far seaward, and among the shifting quicksands of our great estuaries and bays—it may be left to be traced by the soundings and tidal reductions of the hydrographic parties. The channels through mud flats of this character should be indicated, however, if only approximately, by cuts and tangents, or the determination of stakes at the turning points. Where the fall of the tide exposes rocks and ledges, shingle beaches, etc., their character and extent should be delineated and distinguished from the sandy beaches, as these are features most difficult and laborious for the hydrographic survey to represent.

High-water and storm-water line.—In tracing the shore line on an exposed sandy coast care should be taken to discriminate between the average high-water line and the storm-water line.

Determination of inaccessible points.—On a precipitous coast, where the shore line is inaccessible and can not be determined by ordinary methods, the salient features are located, when occupying commanding stations, by observing the vertical angles upon them, and drawing direction lines to them. Then using the elevation of each station as a base the distance to each feature is computed and plotted.

The same method applies to outlying rocks, and is often employed where there is any doubt of their being identified from different places.

Large scale surveys.—As has been previously stated, 1–10 000 and 1–20 000 are the scales customarily used in the execution of the topographical work of the United States Coast and Geodetic Survey, as they are the ones best suited for the charting of the coast line and harbors of the United States.

Other surveys for special purposes have been made from time to time on scales both larger and smaller, and the field practice has been modified according to the requirements of the scale used.

A topographical survey of the District of Columbia outside the thickly populated limits of the City of Washington was made between the years of 1880 and 1891 on a scale of 1–4 800.

The methods pursued are here described, as they are typical of other surveys on a large scale.

Based on a sufficiently minute triangulation, the plane-table and stadia, wye level, and rod were used for all determinations of details. The relief was elaborately indicated by contour intervals of 5 feet. The datum plane is the same as used by the engineer department of the District, on which is based all the levels used for grades of streets and sewers in the city of Washington, the survey being made for the purpose of extending streets and avenues beyond the city limits.

From this datum, along all roads, avenues, and railroads, and where roads were infrequent, across country, lines of level were run, and after careful checking in the usual manner bench marks were placed in position convenient to all parts of the field.

The plane-table stations were established so as to easily overlook every part of the field and so close together that each was surrounded by the others within the range of a single reading of the stadia rod.

The mode of procedure was as follows:

The plane-table was placed in position by a graphic solution of the three-point problem. At the same time the height of the level was determined above some near bench mark and the target of the level rod fixed, so that when it was in the line of sight of the level the bottom of the rod would rest on the ground where the elevation corresponded to that of some contour. The level rodsman then began his journey along this imaginary horizontal line, holding the rod for the observation of the levelman at each noticeable change in the configuration of the ground. The levelman directed the rodsman by signals at each point until the rod was in position on the contour line, when the stadia rod was substituted and its distance read and plotted on the plane-table sheet. Both rodsmen followed the contour line in both directions from the table as far as the stadia rod could be conveniently read. Generally two and sometimes three contours were run from one level station, and on their completion a turning point was fixed and the level shifted to a higher or lower ground, as the circumstances required.

A survey of Craney Island, Virginia, was made in the same manner on a scale of 1–1 200.

RAPID SURVEYS.

Military reconnoissance.—In almost every field of operations, from the commencement of the civil war to its close, the plane-table was used.

Until this time very little was known, save in theory, of the value of the plane table as a reconnoitering instrument, and it is the testimony of all the officers of these parties, as the result of their labors, that for rapidity and accuracy in the execution of military reconnoissance it is more effective than any other instrument.

The usual system adopted, in default of triangulation, was the measurement of a base with an ordinary chain and triangulating with the plane table.

In detailed surveys for the Army, where a topographer averages from 1 to 3 square miles a day, on large scales a chained base of from one-half to three-quarters of a mile for the survey of an area of 25 square miles is found sufficient.

At Chattanooga, from two different bases of about half a mile each, platted on separate sheets, and measured once carefully with the common 20-meter chain, the same chain being used for both measurements, after considerable intermediate plane-table triangulation carried on by two officers, two objects were determined 2½ miles apart, common to both sheets, which were on a scale of $\frac{1}{10000}$, and the discrepancy was but about 15 meters. Many other points of junction indicated this to be the maximum error. In this case the leaves were mostly off the trees and the hills afforded good points. The sheets covered about 20 square miles each. At Nashville there was a discrepancy of about 10 meters in 2 miles.

At other times, when the character of the country or the pressure of time did not admit of the measurement of a preliminary base and topographical triangulation, the

work was commenced by starting from a single point and prosecuted by linear measurement with the chain or stadia, intersections from the ends of the chained lines being taken to determine objects, which, as the work progressed, could also be used as checks upon the chaining. Where circumstances permitted, an occasional return with the chain to a back point, either to close a series of lines upon it or to start afresh, was resorted to. This work was generally carried on over roads and the interior filled in by sketching and intersection as far as practicable. Some of the tests in this latter work, where the operations of two officers joined, were remarkably close.

A very efficient topographical officer estimates that with the usual number of hands and a good sketcher for aid, in a country of average variety of detail, in which all the houses, prominent barns and outbuildings, streams, roads, general outline of woods, and approximate curves are to be shown, on a scale of $\frac{1}{10560}$, an area of between 2 and 3 square miles can be filled in daily, with not only sufficient accuracy for military purposes, but so that an accustomed eye with "the map in hand would not discover any marked discrepancy."

This rapidity of work, however, could not be expected in or near towns or populous districts. It is doubtful if the average work would reach more than one-half this amount.

In some thickly wooded sections and where time is limited, it has been found advisable to run the main roads with the plane table and fill up with the compass, which is more rapid but less accurate than where the entire work is done with the plane table alone. The usual method employed where these methods were combined, was as follows: Where the army was stationary, or moving leisurally, one main road was run with the plane table, the operator being accompanied by assistants well practiced in the use of the compass. Upon arriving at any important road or water course an assistant was sent to the right and left, starting from a plane-table point, determined by the chaining, and running as far as was requisite and then returning to the main road again to repeat the operation, the compass notes, of course, being kept in a book prepared for the purpose. Prominent points determined by the plane table were used as checks in the compass work. The intervening topography, where no compass or plane-table work had been done, was sketched in by the chief of the party, in which accurate pacing became of great value.

With compass and notebook.—Plane-table methods can be utilized to advantage when compass, pencil, notebook, and ruler are the substitutes for an instrumental outfit. The book serves as the sheet and board combined, and the ruler, as it was in the early days of the art, becomes the alidade.*

Photogrammetry.†—In the topographical reconnoissance made for the Alaska Boundary Survey by the Coast and Geodetic Survey, the camera with constant focal length has been used as an adjunct to the small mountain plane table. The latter was used to plat the shore line and adjacent topography, also to determine as many peaks of the interior country as possible by the intersection of lines of direction. All camera stations were determined geographically and hypsometrically, and platted upon the

* See "Sketching without instruments," in Topography, Drawing, and Sketching, by Lieut. Henry A. Reed, U. S. A., 1886.

† See United States Coast and Geodetic Survey Report, 1893, App., 3, and Report for 1897. Photo-Topographic Methods and Instruments, Flemer.

plane-table sheet. The topographical details beyond the reach of the plane table were added to the map in the Office by the photogrammetric methods.

The rugged mountains of southeast Alaska appear particularly well adapted for this mode of procedure, as identical points can be readily picked out from different panorama views, owing to the characteristic shapes of the mountain peaks, snow fields, glaciers, etc.

Periods of fair weather are also very short and of rare occurrence in that locality, and a great deal of topographical material can be gathered photographically in a short time, which when platted will cover a large territory if a sufficient number of reference points on the views have been located instrumentally.

The platting proper can be carried out to any degree of minuteness and detail; the only requirement is that a sufficient number of camera stations shall have been occupied to fully cover the territory in question, so that every topographical feature of prominence has been seen or photographed from at least two stations—better more.

By this application of photogrammetry the plane-table methods of determining topographical details are extended to the Office, inasmuch as the same features are selected from the panorama views and platted geographically which would have been located by the plane table. But the actual time spent in the field is reduced at the expense of the time needed for office work.

Survey in advance of triangulation.—Where it is necessary to make a topographical survey in advance of the determination of points by triangulation, a reconnoissance 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 a standard at a fixed tension, and to one end of which is attached a spring balance to secure the same tension during measurement. The successive lengths are marked by lines cut on copper tacks driven in wooden stubs firmly set in the ground. The temperature is noted at frequent intervals as the work progresses, and the corrections are applied to the length of the base when completed.

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.

OFFICE WORK.

All the drawing of the topographical features of a survey upon the chart should be penciled in the field, while they are still under the eye. Sketching and plotting in the office from notes, unless the country be near at hand for ready reference in case of doubt or a defective sketch, is objectionable. Where this is unavoidable, the sketch should be transferred to the sheet as soon as possible after having been taken, while it is fresh in the mind of the person by whom it was made, and by whom, also, if possible, it should be plotted. Days which, from inclemency of the weather, are unfavorable for out-of-door work should be allotted to this purpose, and advantage should be taken of them, also, for retouching any details of the sheet which may have become indistinct, as it is very important that they should not be left indefinite or become obliterated; for when the inking is done, as it generally is, at a distance from the field of operations, the necessity for this care is obvious. Nos. 4 and 5 pencils are good for this purpose, for which very hard or very soft and black pencils are equally unsuited.

In the inking of a topographical sheet three requisites to its proper appearance when finished should be borne in mind: clearness, neatness, and uniformity.

The lines and objects should be clean and sharply defined, nothing being left obscure or doubtful; the paper should be kept unsoiled, and erasures avoided as far as possible, and the style and strength of the drawing should be the same throughout. It is an important matter that an easy and natural appearance should be given to the map, for, as before remarked, a mere rigid adherence to conventional signs is not all that is necessary; while there should be no deviation in this respect, at the same time the draftsman should strive to *represent the country*. There is a great difference with regard to this among topographers. Two perfectly correct charts of the same section of ground, executed by different persons, may be inked, and while one will have a stiff and ungraceful look, the other will appear artistic and natural, giving at once the impression of a sincere representation of the country surveyed.

Office work should not be commenced until the topography is entirely completed, as no inked or partially inked chart should ever be used in the field. Sometimes, for the special examination of old work, or for the insertion of some recent artificial or natural changes, this becomes necessary. There is always a risk of injuring an inked map by exposure to the weather or by using it upon a plane table.

The inking should commence with the shore lines, high and low water. The high water, or shore line proper, should, in all cases, be full and black, the heaviest lines on

the sheet, and in this, as in all the rest of the ink work, the lines of the survey should be strictly adhered to.

The topography as drawn in the field is supposed to be correct when the chart is finished, and no office amendments or changes are admissible. The low-water line is next drawn, not so full as the former, but clear, black, and uniform, consisting of a dotted line for sand and mud and the conventional sign where it is formed by shells, rocks, or coral reefs.

Grass upon flats, or shoals covered at high tide, have no distinct continuous line to mark their limits, each being represented in its proper form and within its area by its conventional sign only, but the shape should be well and correctly defined. All objects between high and low water, covered at full tide, should be represented less boldly than the rest of the map, but not faintly or indefinitely.

The roads should next be inked plainly and evenly, and their sides parallel, except where the survey shows a deviation from the general width. Main thoroughfares when fenced are drawn with a full line, subordinate roads where fenced should be shown by the usual sign, and where there is no inclosure a line of dashes should indicate the road-side, and then should follow the fences and houses. In drawing the latter care must be taken that the corners and angles exhibit a sharp, clear outline, which adds much to the appearance of the map.

The general skeleton of the survey being now completed, the contours are drawn with a bold, uniform, plain red line, without break, over all the other work, following accurately the full range of level of each of the contours on the sheet.

After this comes the general filling in, by conventional signs, of sand, marsh, grass, cultivation, orchards, rocks, hachures, etc. Some practice is needed to execute the sand work regularly and neatly. It should never be hurriedly done, though of course rapidity in this respect follows practice. The lines representing marsh, and the delineation of grass on the fast land, should always run in the same direction over the whole sheet and be parallel to the top of the sheet and the title. The appended drawings, Pls. 15, 16, 17, and 18, give the conventional signs as adopted by and now used in the Coast Survey.

The most difficult part of the inking for a beginner is the lettering, which now follows, and for which samples are given (Pl. 19). It is expected that every topographer shall have learned to draw sufficiently well to ink his sheet in a clear and distinct manner and letter it with some regard to neatness and graphic effect, as the appearance of an otherwise well-inked sheet is sometimes marred by careless or indifferent lettering.

The location of the names upon the sheet should be such as not to cover or obliterate any detail or feature of the survey, and the letters should be put in neatly and gracefully, and in point of size and form according to the specimens furnished. The title should finally follow, with such notes as may be necessary to explain any peculiarity of the sheet or survey. This title and lettering should, as far as practicable, be so placed, that when the sheet is held with the top (usually the north or east end of the map) from you it can be easily read; in other words, as nearly parallel to the top or upper end of the sheet as the nature of the work will admit. All names well established and recognized in a neighborhood, both general and local, should be collected during the survey, and their correct orthography ascertained, and in case of any doubtful or disputed orthography a report should be given of any traditions or any authorities which may

bear upon the subject. No illuminated or German text, old English, or what is known as "fancy printing," should be indulged in, a strict adherence to simplicity being the greatest ornament.

The minutes of the parallels of latitude and meridians of longitude should be marked in figures at the upper and right-hand ends, respectively, the degrees on the center parallel and center meridian only.

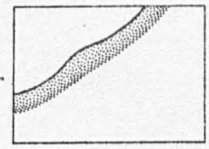
Where the buoys are determined by the topographer, and their names, colors, numbers, or kind are known, they should be lettered upon the map.

The triangulation points should also be lettered, first being surrounded by a small red triangle. Barns, houses, prominent trees, and other objects determined by the plane-table that may be used as points of reference in making additions to the sheet subsequent to the survey should be indicated by a small blue circle.

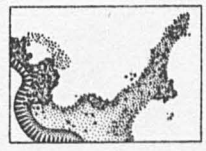
NOTE.

Plates No. 20 to No. 29 were selected from a collection prepared by the late Assistant E. Hergesheimer to illustrate the topographical features in various portions of the United States. The full collection is to be found in Appendix 14, United States Coast and Geodetic Survey Report, 1883.

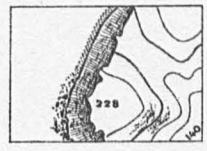
Shoreline Low Water



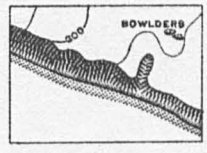
Rocky Ledges



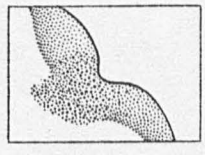
Rocky Bluff



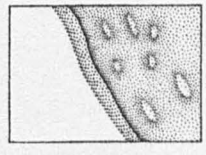
Eroded Bank



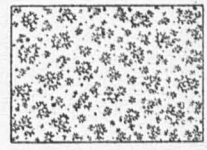
Sand and Shingle



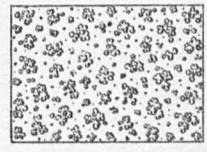
Sand Dunes



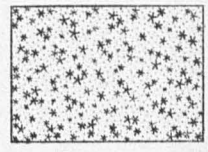
Oak



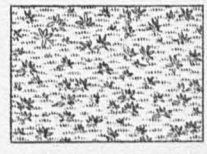
Deciduous and Undergrowth



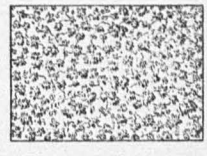
Pine



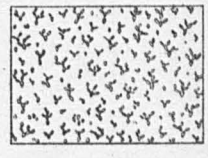
Palmetto



Mangroves



Cacti



Topographical Symbols

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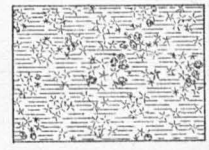
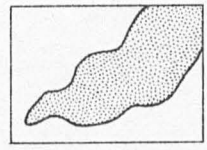
Salt Marsh



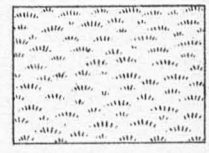
Cypress Swamp



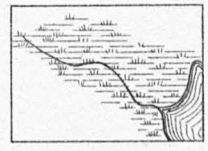
Salt Pond



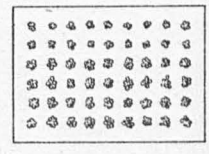
Grass



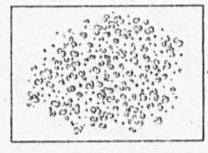
Fresh Marsh and Fresh Pond



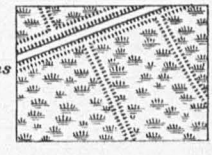
Orchard



Oyster Bed



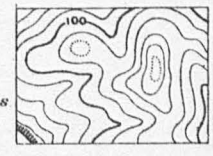
Rice Dikes & Ditches



Wooded Marsh



Curves of equal elevation and intermediate curves

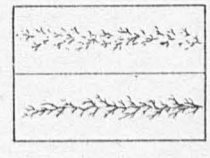


Submerged Marsh



Eel Grass

Kelp



Topographical Symbols

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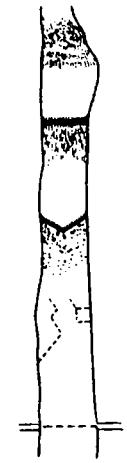

Rapids

Falls

Dam

Fish Weirs
(proper location)

Ferry

Topographical Station

Triangulation Point

Dwelling House

Barn

Shed and Pen

Ruins

Windmill

Church

Cemetery

Fence

Public Road

Road fenced on one side

Telegraph Road

Topographical Symbols

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Railroad (each track)	
Railroad (large Scale)	
Road not fenced	
Path or Trail	
Stone Wall	
Hedge	
Embankment	
Canal and Lock	
Known Altitude	420 ft.
*Approx " *	(approx) 420 ft.
Lighthouse (rays red)	
Light-ship (" ")	
Buoys (Can, Nun, Spar and Bell)	
Red and Green	
Black	
Horizontal Stripes	
Perpendicular Stripes	
Whistling	
Lighted	
Mooring	
Beacon (Lighted, rays red)	
Spindle or Stake	
Anchorage	
Wreck	
Rock awash	
Sunken Rock	+

Topographical Symbols

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DECIMILLIMETRES						
60	ENGRAVING			*ENGRAVING*		
55	DIVISION			*DIVISION*		
50	CAPITOL			*CAPITOL*		
45	HARBOR			*HARBOR*		
40	ISLANDS			*ISLANDS*		
35	RIVERS			*RIVERS*		
30	SOUNDINGS			*SOUNDINGS*		
25	DIRECTIONS			*DIRECTIONS*		
20	POINTS	*POINTS*	Points	*Points*	POINTS	*POINTS*
15	CREEKS	*CREEKS*	Creeks	*Creeks*	CREEKS	*CREEKS*
12	CHANNELS	*CHANNELS*	Channels	*Channels*	CHANNELS	*CHANNELS*
10	SHOALS	*SHOALS*	Shoals	*Shoals*	SHOALS	*SHOALS*

ABCDEFGHIJKLMNOPQRSTUVWXYZ

ABCDEFGHIJKLMNOPQRSTUVWXYZ

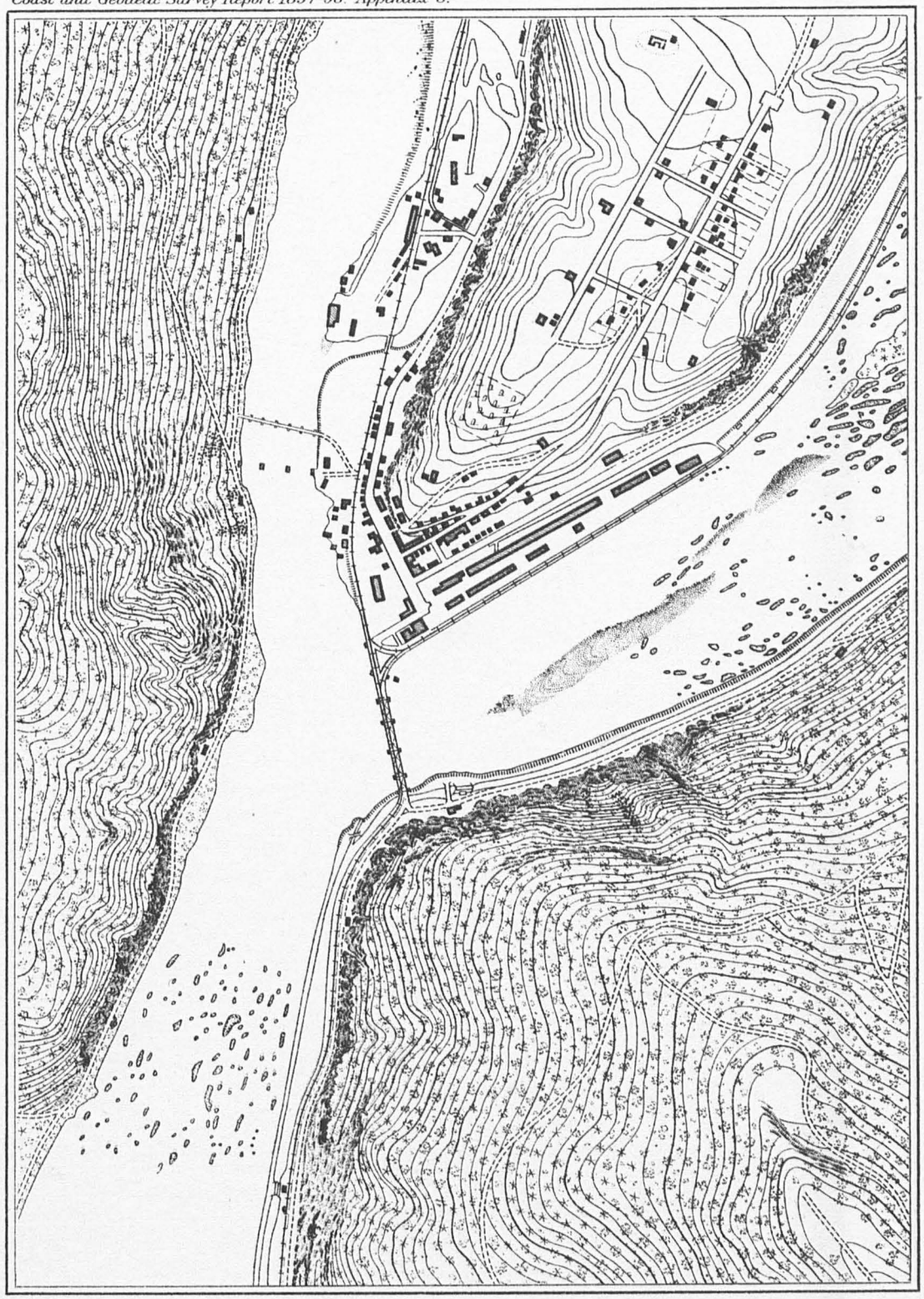
Specimens of Lettering

THE W. H. & O. PETERS CO. PHOTO-LITHO. WASHINGTON, D. C.



Sparsely settled Town, Salt Marsh, Pine Woods, Ditches, Fences, and Undefined Roads (Brunswick, Ga.)

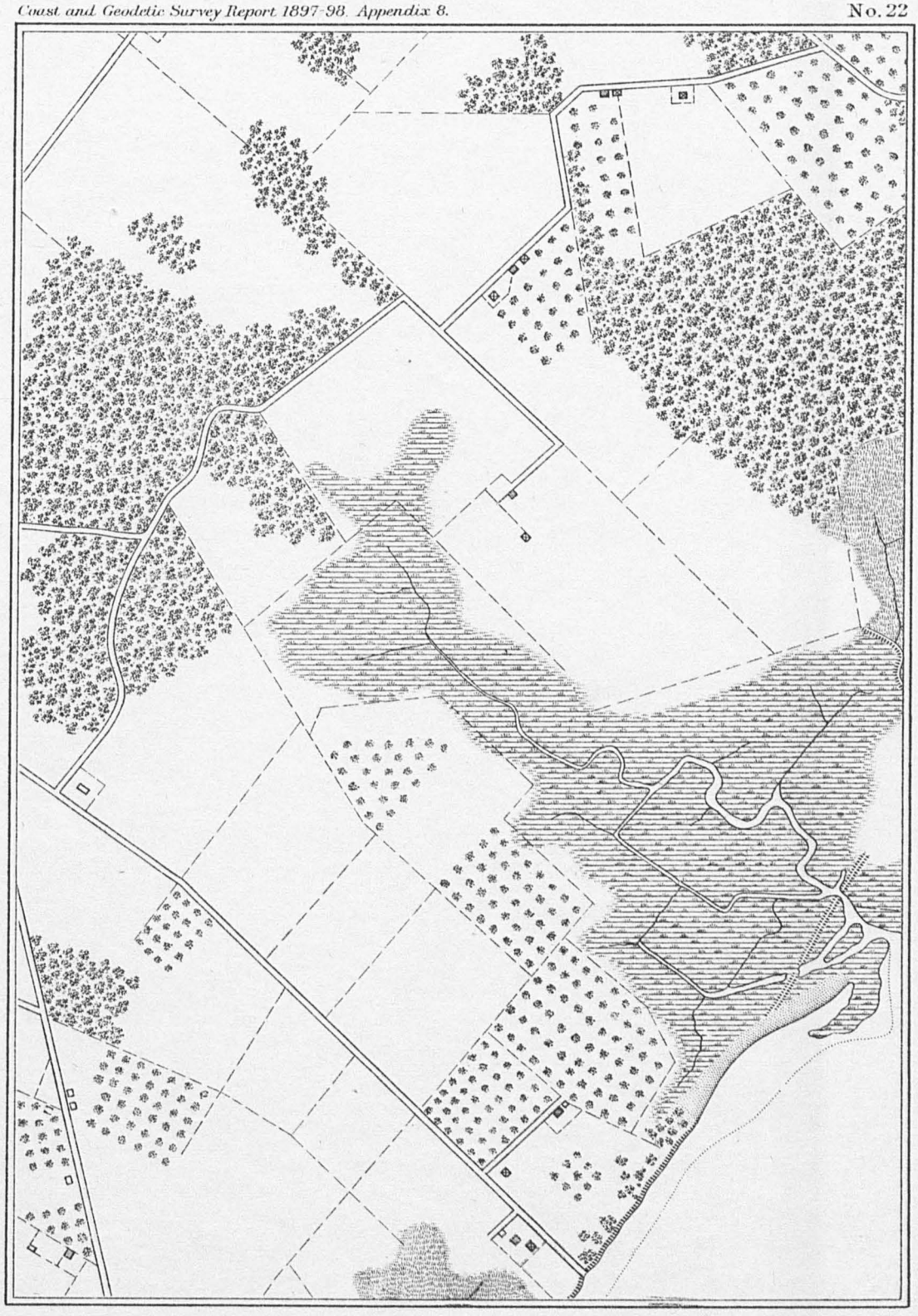
THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Railroads, Canals, Iron Bridges, Rocky Cliffs, Mid-river drift, Water-worn rocks Mixed woods over hill curves.

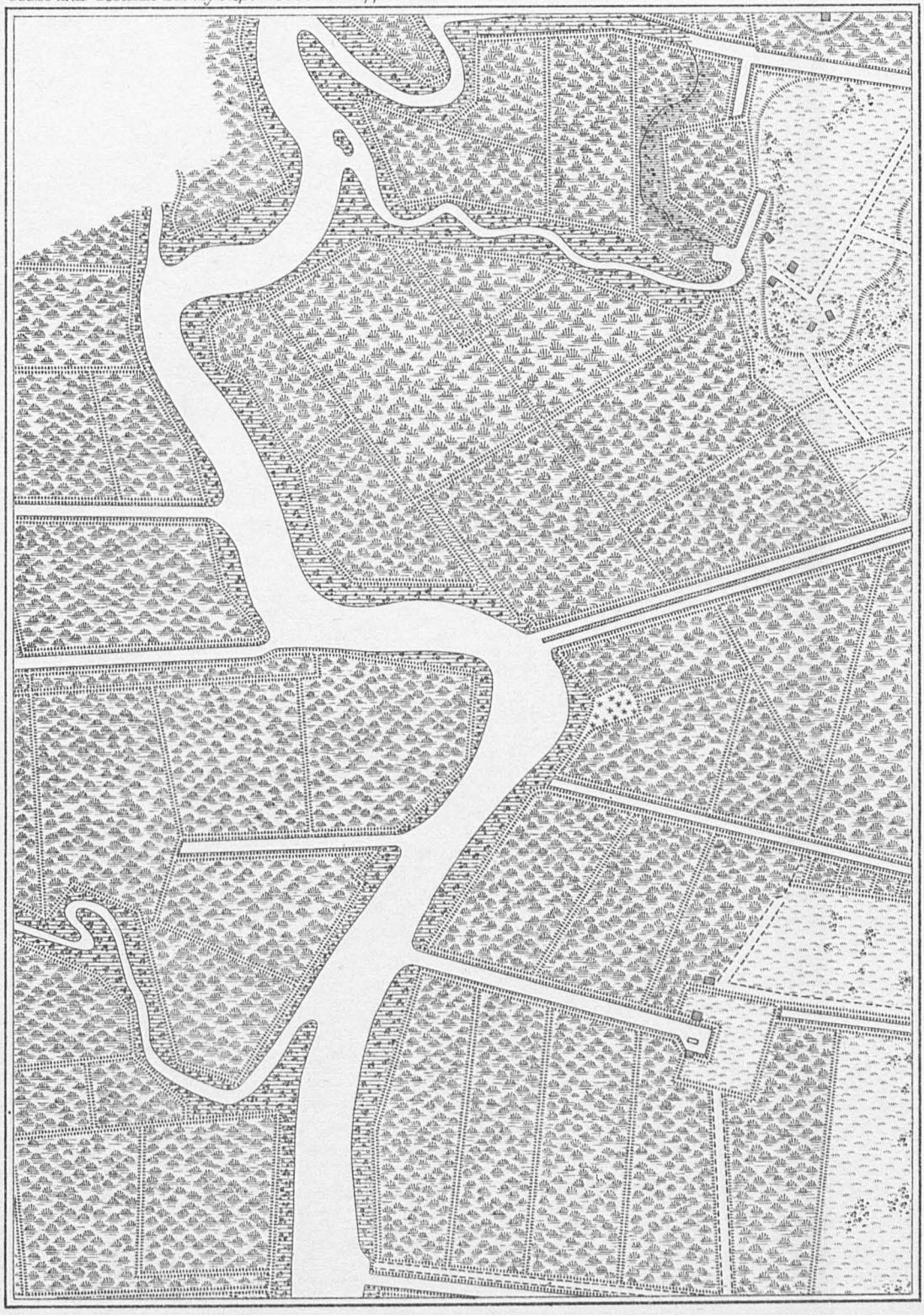
(Harpers Ferry)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Heavy Oak Woods, Reclaimed Marsh and Orchards (Delaware River)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Rice, Dykes and Ditches. (Santee River)

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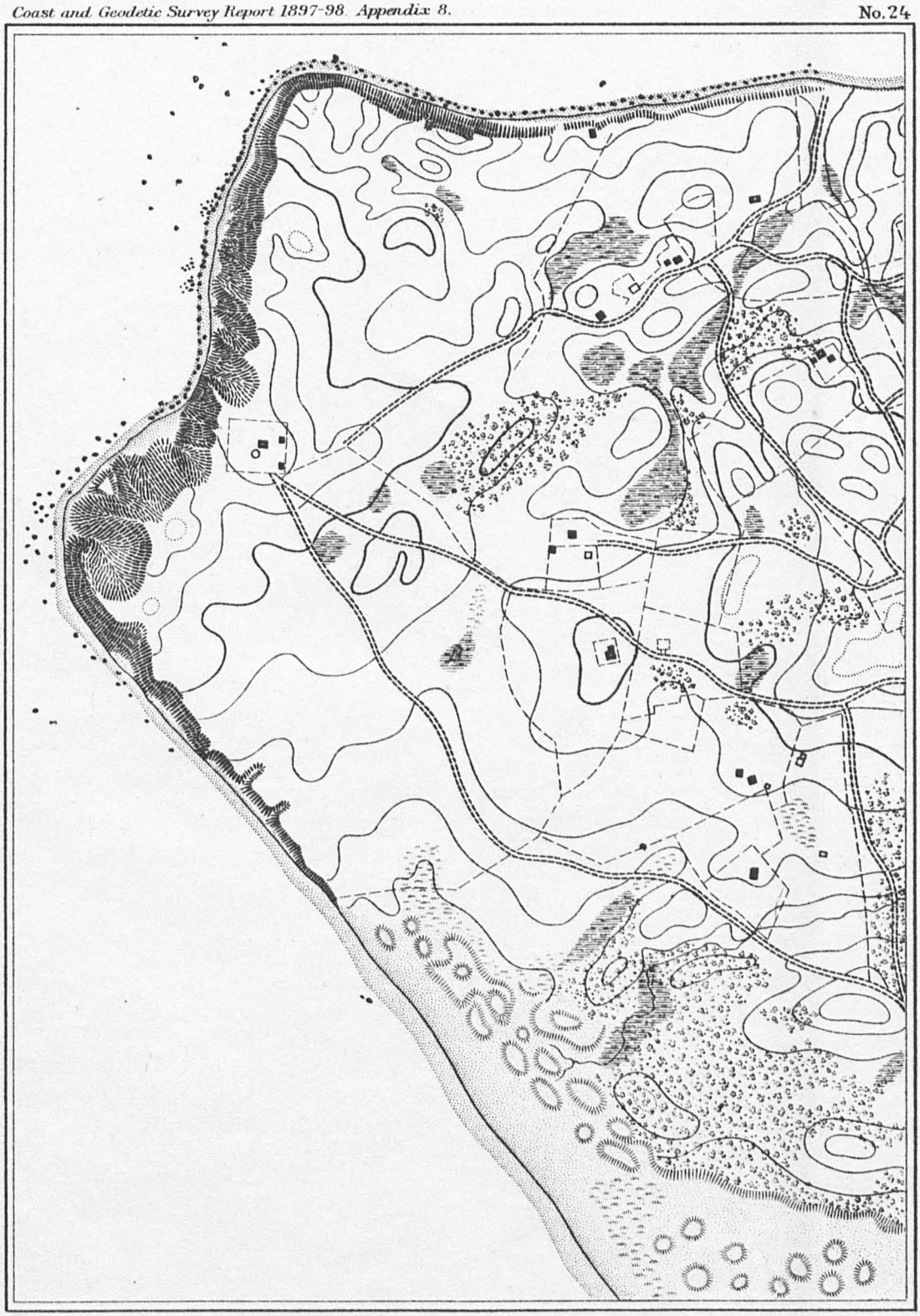
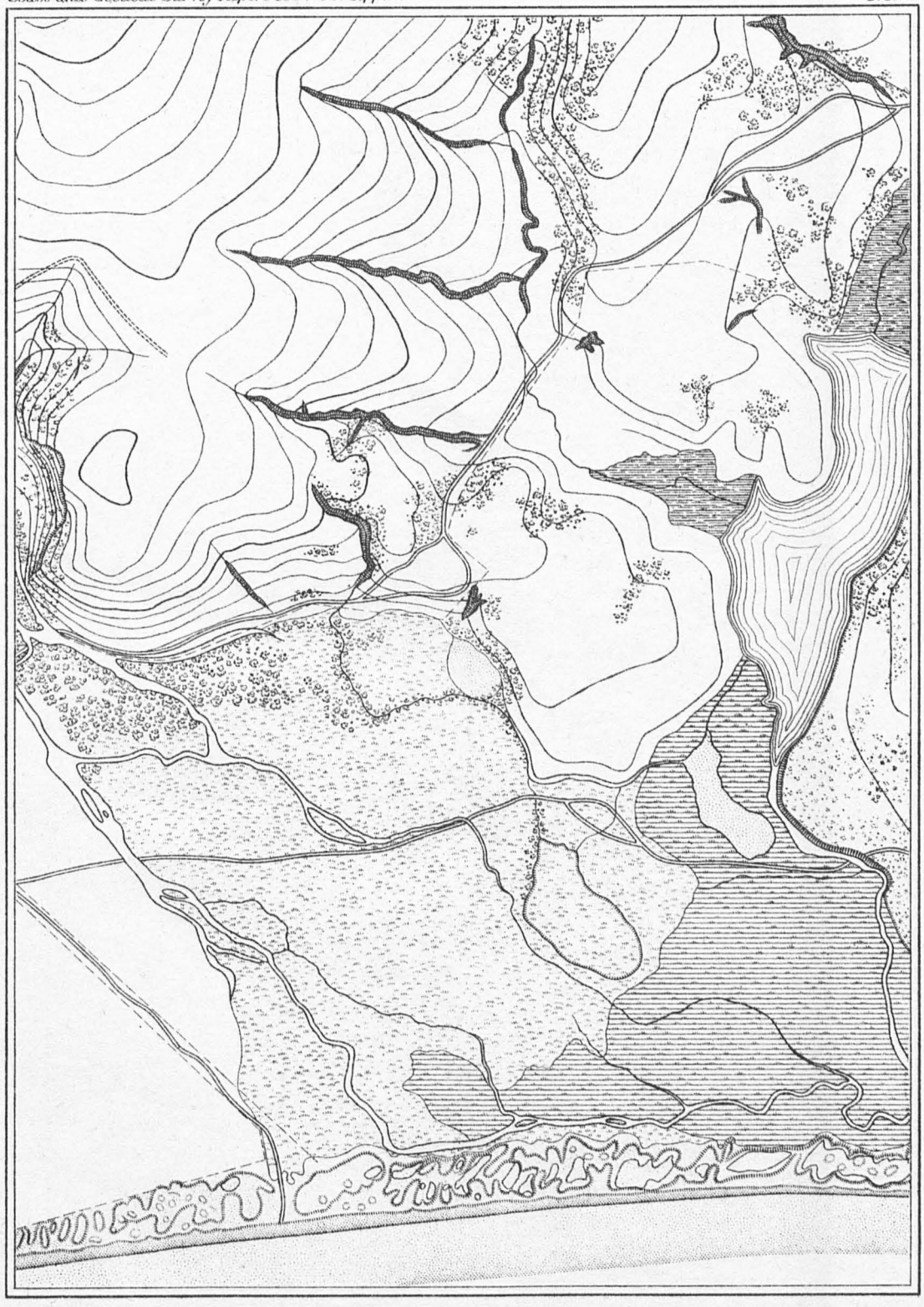


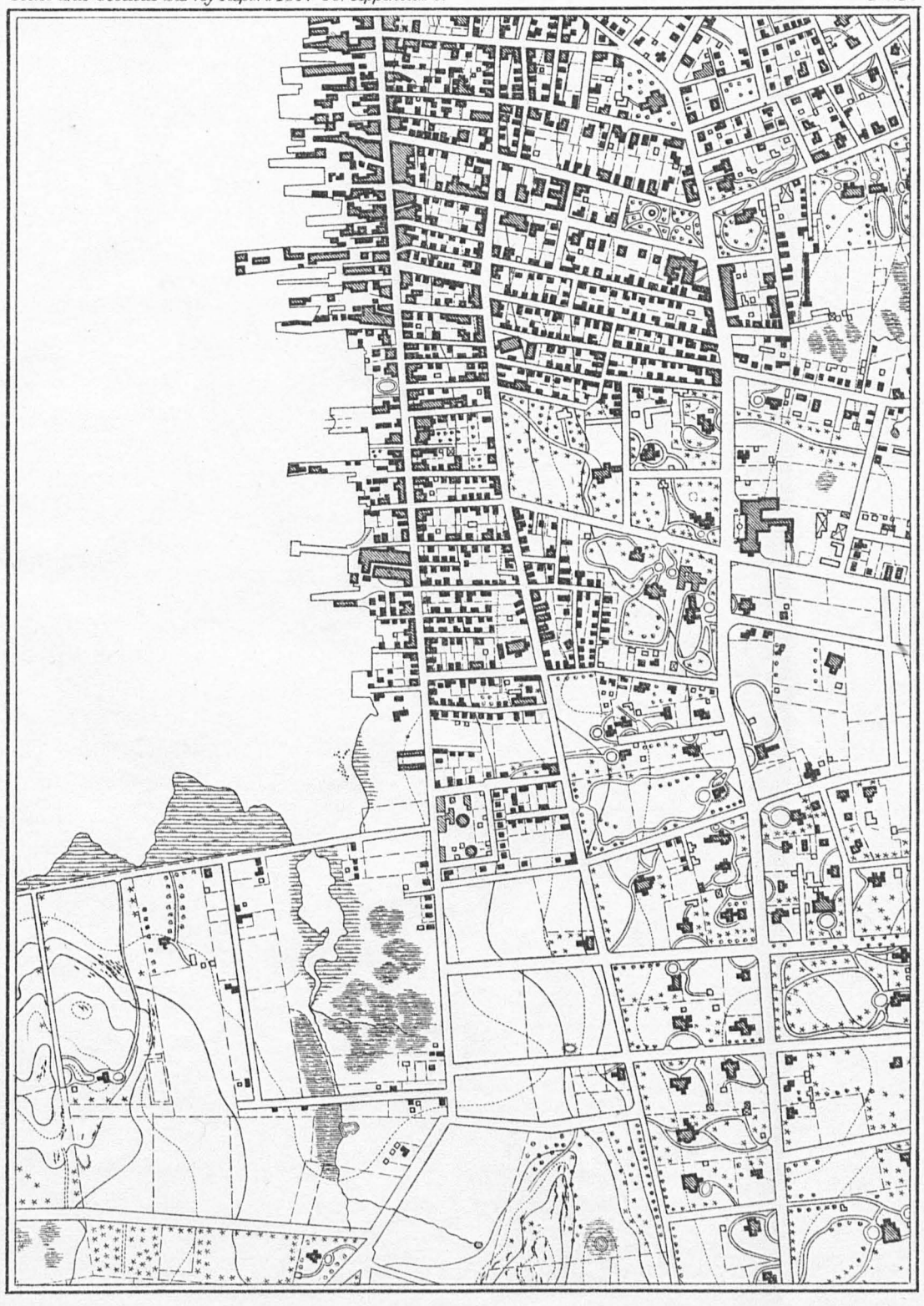
Eroded drift banks, with boulders set free; and scrub deciduous woods. (Gay Head)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



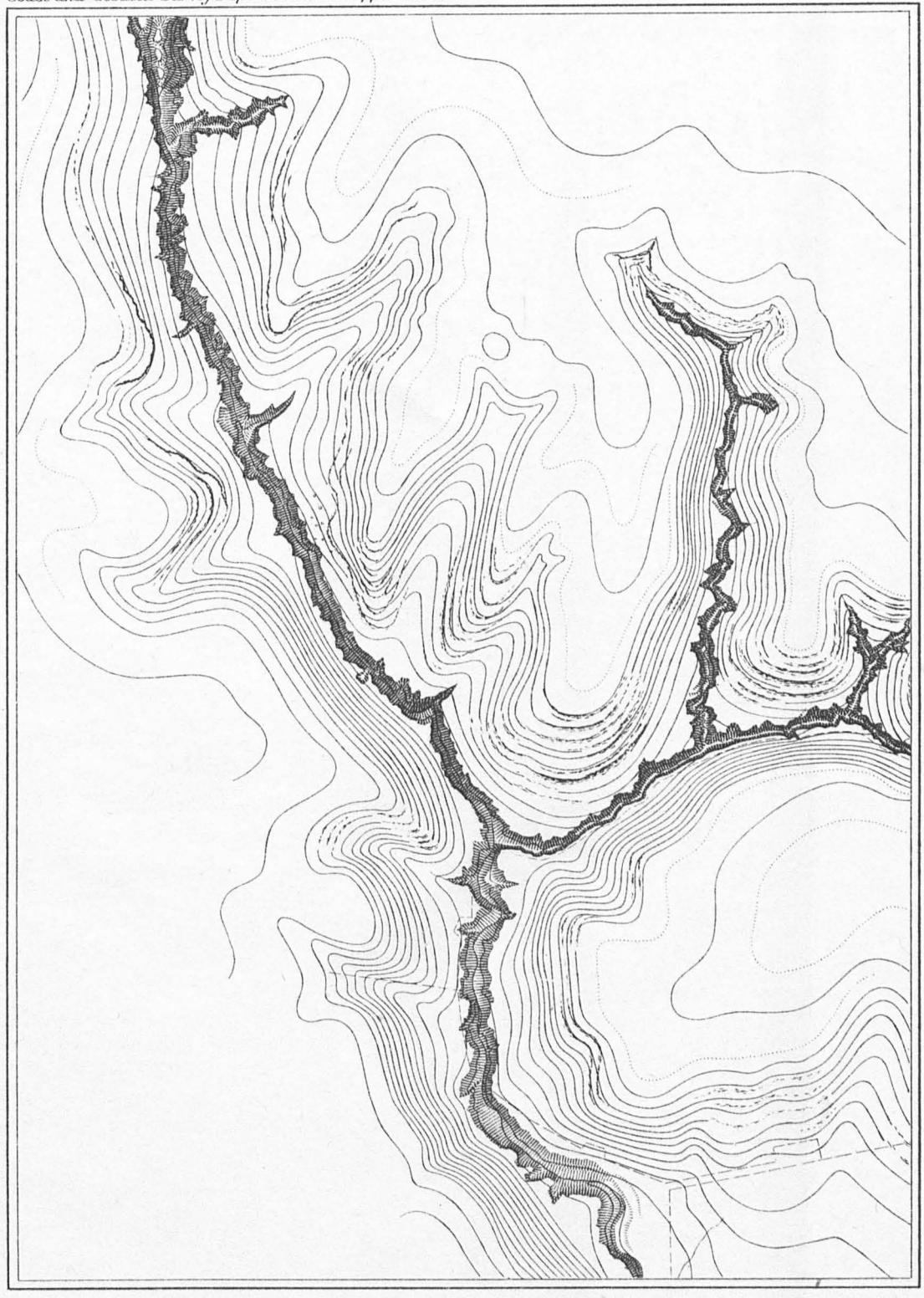
Sand Beach with Low Dunes, Fresh Water Pond, Meadow Grass, Sage Brush and Arroyos
(S. Coast of California)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



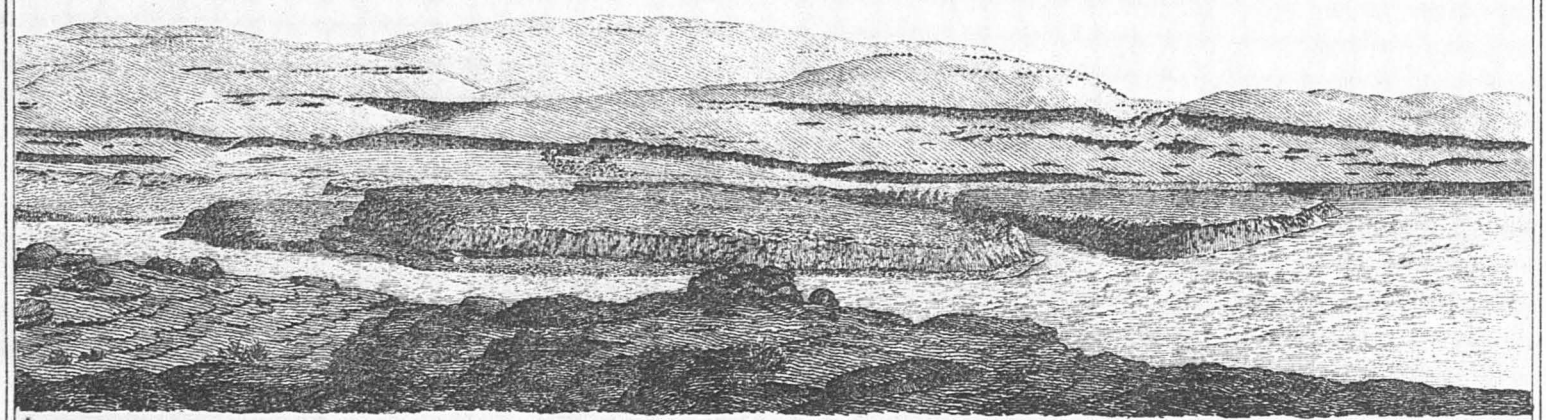
Blocking of Cities, Large Buildings, Suburban Villas and Grounds, Fresh Marsh. (Newport, R.I.)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Erosion of Soft Stratified Rock and Gulch. (Santa Cruz, Cal.)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Engraved by J.R.Barker

The Dalles, Columbia River, Looking South-Easterly.

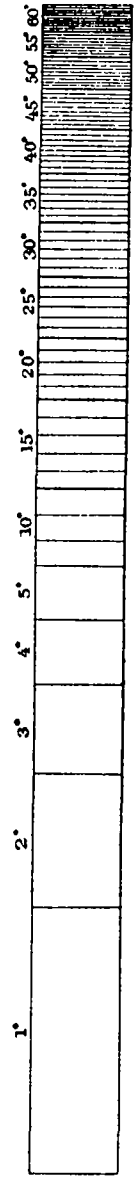
THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



Erosion of Eruptive Rocks, Basaltic Escarpments and River Torrent. (The Dalles, Columbia River)

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Hill Curves for every 20 feet difference of level. Scale ~~1/10,000~~



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

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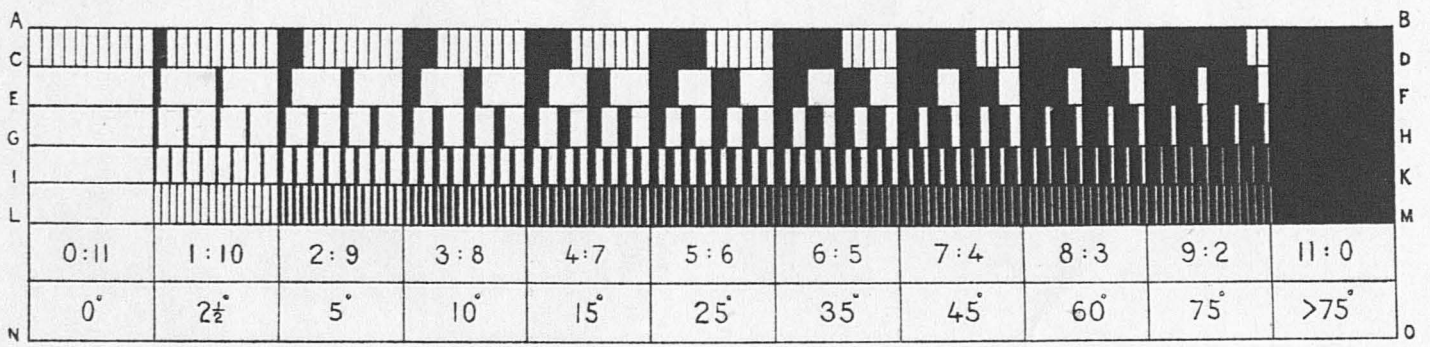
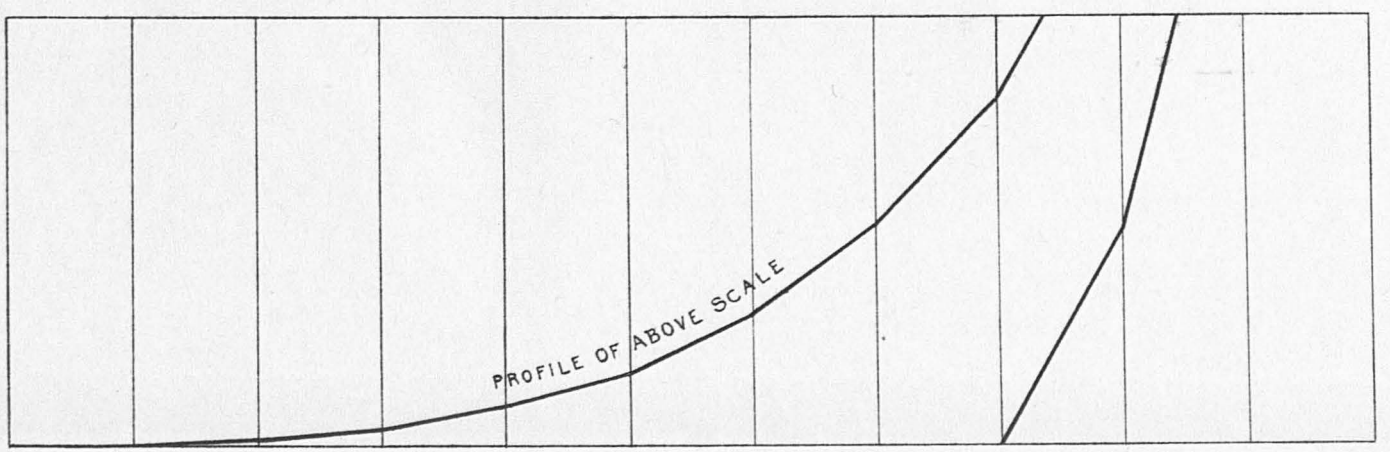
Fig. 75, U. S. C. AND G. SURVEY SCALE OF SHADE.





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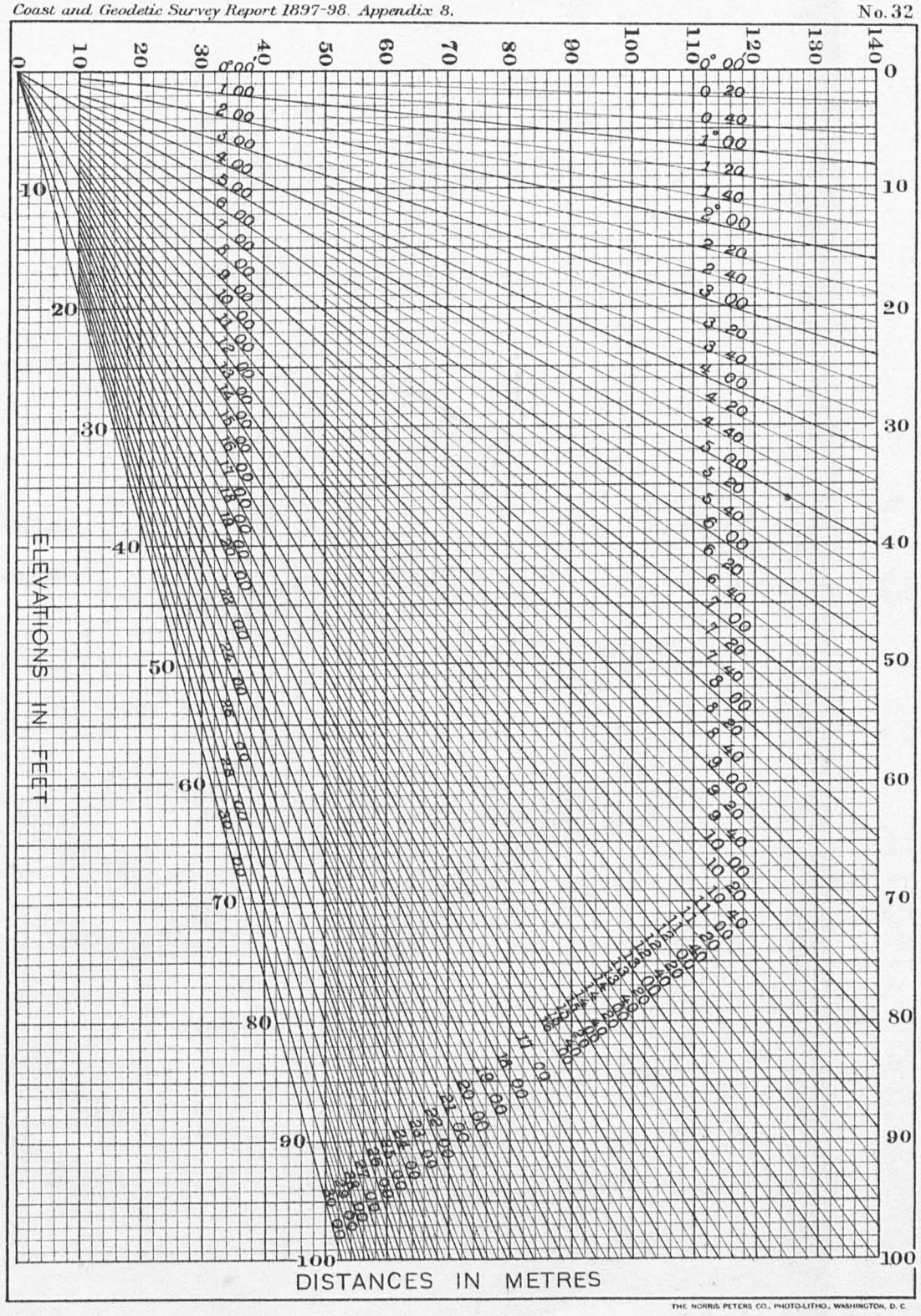

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APPENDIX No. 9—1897-98.

PROBLEMS IN PHYSIOGRAPHY.

SALINITY AND TEMPERATURE OF THE PACIFIC OCEAN.

By A. LINDENKOHL, U. S. Coast and Geodetic Survey.

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APPENDIX No. 9—1897-98.

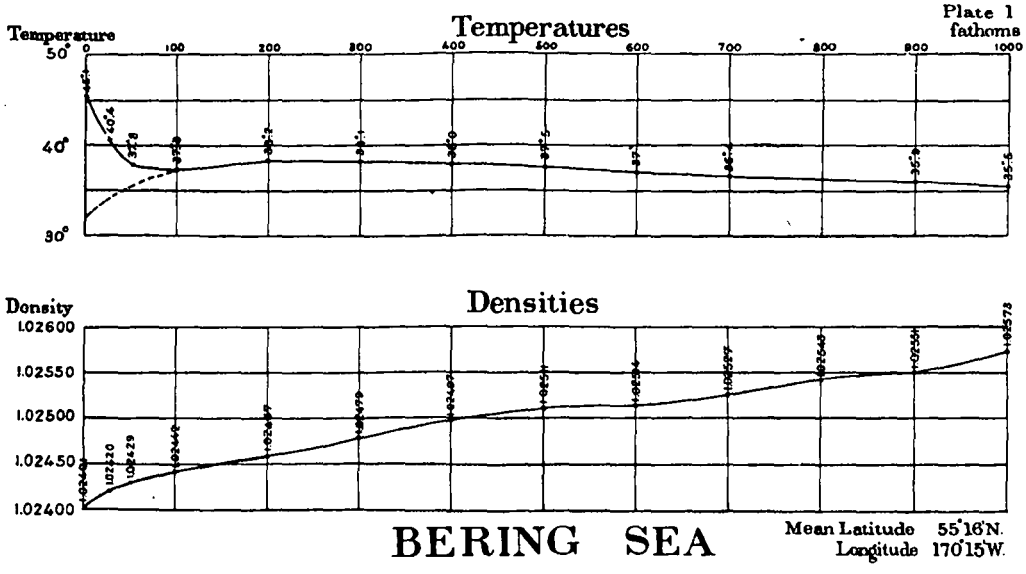
PROBLEMS OF PHYSIOGRAPHY, CONCERNING SALINITY AND TEMPERATURE OF THE PACIFIC OCEAN.

By A. LINDENKOHL, *U. S. Coast and Geodetic Survey*,

a. BERING SEA.

The subjoined diagram, plate 1, gives the mean result of the temperature and density observations by the U. S. Fish Commission steamer *Albatross* in the years 1890 and 1895, at eight different stations in the deeper part of Bering Sea south of the Pribilof Islands.

In the curve of densities we see a continuous increase from 1·0241 at the surface to 1·0257 at the depth of 1 000 fathoms, and according to a single observation this increase



continues to the bottom of the sea, where 1·0261 was reached at 1 998 fathoms. This distribution of densities leads us to suspect the existence of causes tending to reduce

NOTE.—On plates 2 and 3 for "Appendix 10" read "Appendix 9."

the densities of the surface and which we find in a copious precipitation and the discharge of several large rivers, notably the Yukon. The steadiness of density existing under these conditions may be accounted for by assuming the presence of an undercurrent which proceeds from an adjoining part of the ocean and carries a supply of salt into Bering Sea. The western part of the North Pacific is the only adjoining region which can furnish such a supply, the Arctic Sea and eastern part of the North Pacific each possessing but a scant store of salt. The Kuro Siwo, the great carrier of salt and heat in the North Pacific, according to Makaroff, extends only to latitude 40° as a surface current, or according to Kümmel to latitude 42°, and its further passage northward is an undercurrent. It constantly loses heat and salt by contact with colder and fresher water, the result being that its density is increased by reduction of temperature more than it is diminished by the loss of salt. It will therefore continue to sink until in the noted accumulation of salt in the deeper parts of Bering Sea we find the last traces of that warm and briny current. The mean specific gravity of the greater depths of the North Pacific, according to Makaroff, is 1·0258; hence we find that the waters at the bottom of Bering Sea contain at least as much, if not more, salt than the ocean in lower latitudes. We may admit that the great depth of 3 117 fathoms, which Lieutenant-Commander Moser in 1897 found between Kamchatka and Bering Island, where less than 500 fathoms were supposed to exist, and also that of 1 996 fathoms between the Commandorski and Aleutian Islands greatly facilitates the ingress of the water from the Pacific. On the other hand, we are not justified in denying the possibility of Bering Sea deriving a supply of salt either from the eastern part of the North Pacific or from the Artic Ocean on account of the limited depth of the channel through the Aleutian Islands or Bering Strait. In the matter of transfer of salt from one sea to another a high degree of salinity is more essential than great depth of the connecting channel. In the case of the Mediterranean Sea and the Atlantic Ocean the moderate depth of 170 fathoms in the Strait of Gibraltar does not prevent the warm and salty waters of the Mediterranean from entering the Atlantic by an undercurrent, which, by spreading and sinking, reaches beyond the middle of the ocean and to depths greater than 1 500 fathoms.

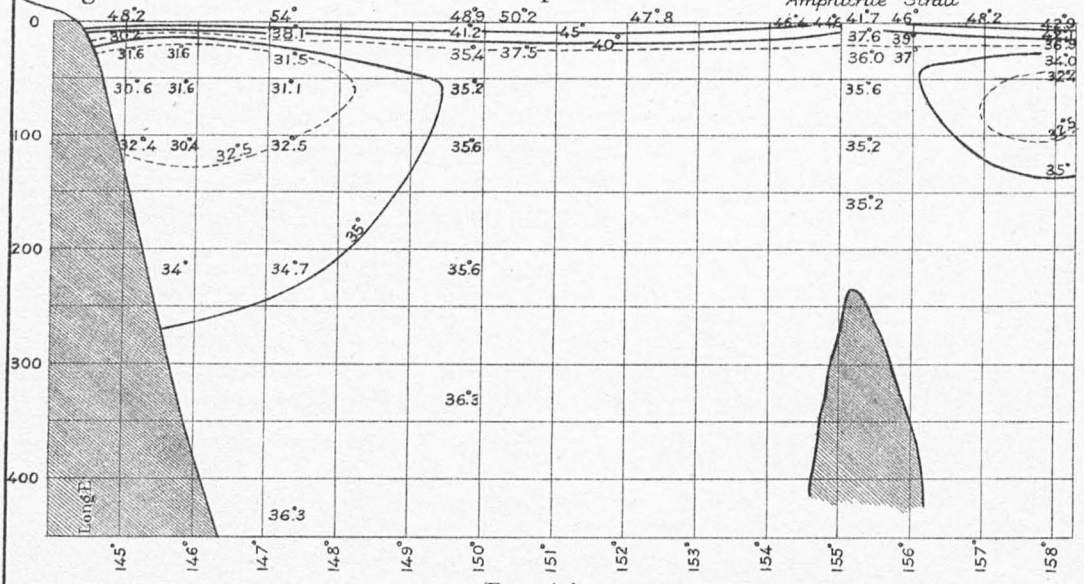
The temperature shows a rapid decrease from 45°·1 at the surface to 37°·3 in 100 fathoms, where we find a minimum. It rises to 38°·2 at 200 fathoms, remains nearly stationary at 38° to 400 fathoms, whence it slowly sinks to 35°·5 at 1 000 fathoms and to 35° at the bottom, which in the southwestern part of the Bering Sea is usually found at depths slightly exceeding 2 000 fathoms. There are no indications of the existence of a constant temperature from a certain level downward to the bottom as we find it in the Gulf of Mexico, where the temperature of 39°·5 prevails at all depths beyond 700 fathoms. All observations were made about the middle of August, when it is probable that the surface temperature had nearly attained its annual maximum. From the existence of a minimum of temperature at 100 fathoms at this season of the year we conclude that no heat finds its way from the surface to below this depth, either by radiation or convection; that whatever heat we find here is brought along by the same undercurrent which supplies Bering Sea with salt. The presumable conditions about the time of the lowest temperatures, toward the end of February, are indicated by a broken line on the diagram. The surface temperature is supposed to remain then near the freezing point of fresh water; the winter's cold is assumed to penetrate to the depth of about 200 fathoms, where the maximum of temperature, 38°·2, is found.

Saghalin Id.

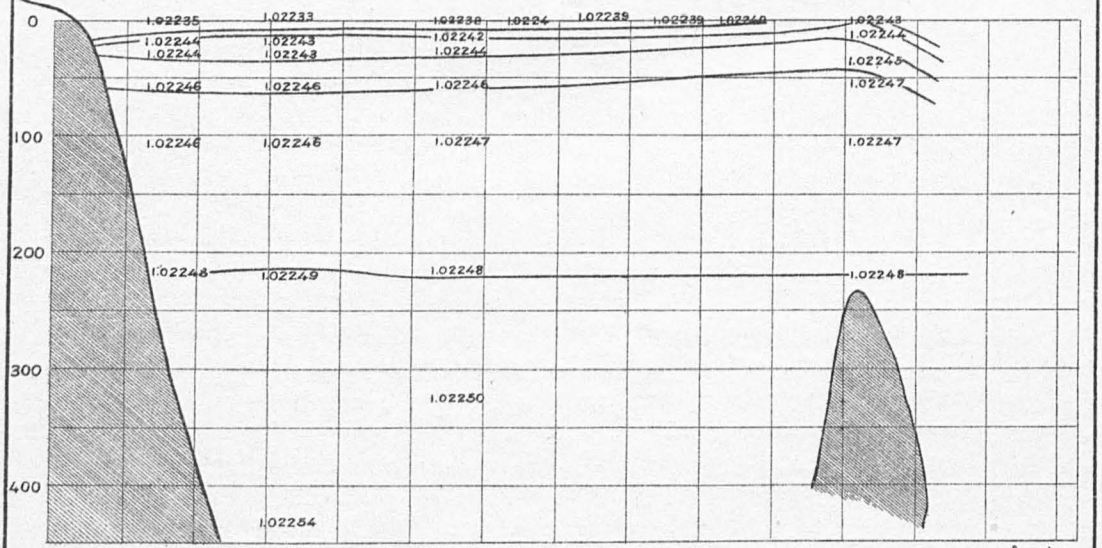
Temperatures

PACIFIC OCEAN

Amphitrite Strait



Densities



Mean Latitude 49°45'N.

OKHOTSK SEA

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Below 200 fathoms no appreciable difference between the summer and winter temperatures is supposed to exist.

b The Okhotsk Sea.

The accompanying diagram, plate 2, represents an east and west section through Okhotsk Sea, from Amphitrite Strait to Saghalin Island, based upon observations by the Russian Admiral Makaroff on the corvette *Vitiaz* in the early part of September, 1887.

According to the soundings by Lieut. Commander J. F. Moser in the *Albatross* in 1896, the basin of Okhotsk Sea has the shape of a trough, descending from the Kuril Islands by a steep slope and ascending by a more gentle one toward Saghalin Island. The depth of the basin was found to be 1 843 fathoms in lat. 47° 50′, long. 149° 42′, and 1 744 fathoms in lat. 45° 21′, long. 146° 27′.

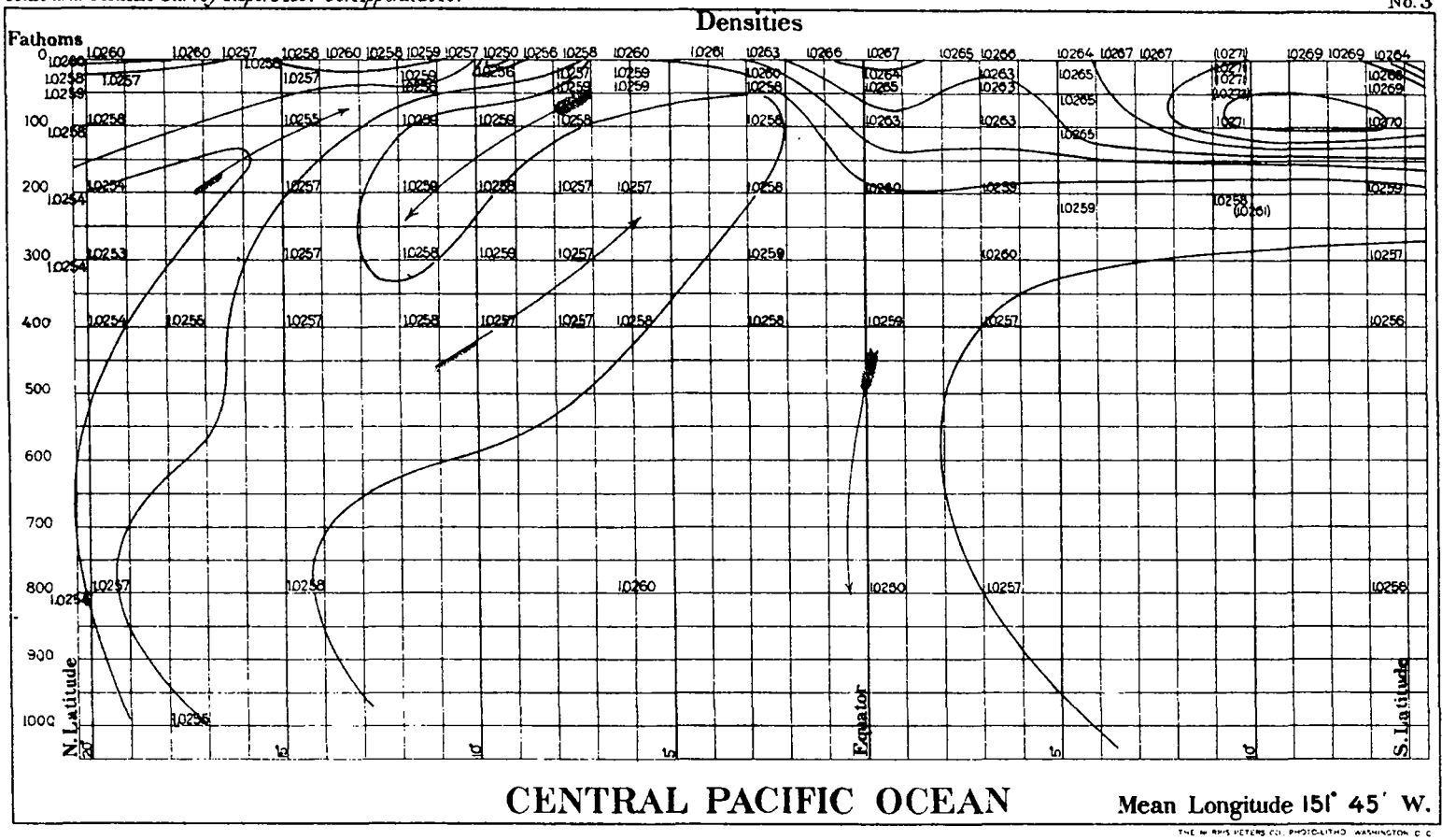
Along the east coast of Saghalin Island, extending about 120 miles to the eastward, we find a body of water with a temperature below 32° and a density of 1·0244 to 1·0246, reaching to the depth of about 100 fathoms, overlaid by the stratum of warm water of a temperature between 48° and 54° and a density ranging between 1·0222 and 1·0238. These conditions are contrary to our usual experience of finding densities keeping pace with temperatures, and seem to call for an explanation. During winter, which here is exceedingly rigorous, the whole of Okhotsk Sea is covered with ice, but congelation does not take place until the temperature has been reduced below 29°. In freezing much of the salt is liberated and tends to increase the density of the underlying strata. During the summer months the surface waters, consisting of melted ice, receive large additions of warm, fresh water from neighboring streams, and also, according to Makaroff, from the Amur River, whose waters, after rounding the northern shore of Saghalin Island, pass along its eastern shore to the southward. This superficial sheet of warm water does not appear to impart any considerable part of its heat to the underlying body of cold water, probably on account of the absence of currents and for the reason that the low specific gravity keeps the surface waters from sinking to any great depth in consequence of evaporation.

We have only surface observations of temperature and density for the eastern part of Okhotsk Sea, and can form only conjectures concerning its thermic conditions. Freezing probably sets in at a later date, but otherwise very little difference is supposed to exist between the eastern and western part in regard to temperature during the winter months. During the summer months, however, we have reason to believe that a warm current passes through the eastern part, and that the lowest temperature Makaroff found in the Amphitrite Strait, which was 35°·2 at the depths of 109 and 164 fathoms, is probably the lowest which we may expect to find in the eastern part during the warm season. For the greater depths we note a slight increase of temperature, 36°·3 being recorded at 328 and 437 fathoms. Moser's observations seem to indicate a uniform temperature of 36° for all the great depths in the trough. The densities increase from 1·0222–1·0240 at the surface to 1·0246 at 55 fathoms, 1·0248 at 219, and 1·0254 at 437 fathoms. These relations of temperature and densities teach us that the Okhotsk Sea, like Bering Sea, receives its supply of salt and heat through an undercurrent, and suggests the question, "Whence does the Okhotsk Sea receive its supply of salt and heat; from the Pacific or Japan Sea?" Makaroff has no decided answer to this question, although all of his arguments are in favor of the Japan Sea. To arrive at a conclusion in this matter we

have to examine carefully the condition which Makaroff found to exist in La Pérouse Strait, where the waters of the Japan Sea meet the Siberian waters, those of the Okhotsk Sea. What we observe there does not look like a friendly greeting on either side.

Makaroff found in the month of August three kinds of water, each of a distinct type in regard to physical characteristics. In the southern part, skirting the Island of Yezo, the water has a density of 1·0252, with a temperature of 66°. In these properties we recognize water from the Japan Sea on its way northward. In the northern part of the strait, in Aniwa Bay, adjoining Cape Crillon, the surface water has a density of 1·0237 and temperature of 61°. From the resemblance of the water to that which we found at the surface farther north, to the eastward of Saghalin Island, we conclude that it likewise consists of melted ice and water from the Amur and other Siberian rivers, and has drifted to its present position by flowing southward, following the eastern shore of Saghalin Island. With the exception of this thin layer of warm and light surface water, the whole northern part of the strait is occupied by waters of the density of 1·0248 and of a very low temperature. This is the same kind of water which in a higher latitude we found off Saghalin Island between the approximate depths of 25 and 250 fathoms. It is believed that no warm undercurrents reach the western part of Okhotsk Sea within these depths, and that the low winter temperatures are not greatly modified by the heat of the summer. Where this water meets that from the Japan Sea it rises to the surface in a long narrow band stretching from Cape Crillon in a southeasterly direction for a distance of 40 miles, thus effectually barring the access of the latter to the western part of Okhotsk Sea and forcing it to seek a passage in the eastern part along the Kuril chain. Moser's observations in August and September, 1896, enable us to trace the further progress of the current. He crossed the sea thrice, and each time found the greatest surface density near the Kuril Islands, and the lowest near Saghalin Island, viz, 1·0247 in latitude 45° 16′ near Iturup Island, 1·0245 in latitude 46° 18′, and 1·0244 in latitude 47° 32′ near Unishir Island, and as low as 1·0221 near Robben Island, an islet near Saghalin. If we consider these observations in connection with those made by Makaroff, giving 1·0240 in latitude 49° 53′ near Paramushir Island, and compare the figures, we find that the current of dense water follows the inner edge of the Kuril Islands, and that in its progress to the northeast it is gradually overlapped by the lighter waters to its left, and in about 50° latitude sink below the surface. This is in entire accordance with the views concerning the waters of the Sea of Okhotsk, which Makaroff expresses in his work, "Le Vitiaz et L'Océan Pacifique"—namely, that Okhotsk Sea obtains its supply of salt and heat from the Japan Sea; that the warm current which passes through La Pérouse Strait to the northward deflects to the eastward, and that the warm and saline waters on reaching Okhotsk Sea commence to sink and finally occupy all the deeper parts of this sea.

Concerning the depths of the channels which connect Okhotsk Sea with the Japan Sea and the Pacific, La Pérouse Strait has but 35 fathoms. Little is known of the depth in the passages through the Kurils, but they are assumed to be much deeper. Makaroff gives 235 fathoms for the depth of Amphitrite Strait in latitude 50°. From the circumstance that the deeper parts of Okhotsk Sea show a constant temperature of 36° and that this temperature corresponds to the depth of about 800 fathoms in the Pacific, we infer that this depth indicates approximately the limit of the greatest depth in the passages through the Kurils. If these conjectures are true, the Okhotsk Sea is more


Densities
Fathoms
0
100
200
300
400
500
600
700
800
900
1000
N. Latitude
Equator
S. Latitude
CENTRAL PACIFIC OCEAN
Mean Longitude 151° 45′ W.

accessible to the waters of the Pacific than to those of the Japan Sea, and we can ascribe the fact of its receiving its supply of salt and heat from the latter only to the circumstance that the adjoining waters of the Pacific do not possess these qualities in sufficient degree.

The serial temperature observations by Belknap and Makaroff show the existence of a well-defined minimum of temperature in the Pacific off the Kuril Islands and Kamchatka, at a depth of about 50 fathoms; Belknap records 32°·4 off the Kurils in latitude 49° 41′, and Makaroff found 30°·7 between Kamchatka and Bering Island. This tends to prove that no warm currents pass near these shores. The zone of the low temperatures which exists along the Kuril Islands was formerly attributed to the effect of cold currents which were supposed to come from the direction of Kamchatka and sweep along these islands toward Japan. Makaroff has correctly interpreted it as being produced by an intermingling of the water from the lower strata with the surface water. There are instances where cold water rises to the surface and causes the appearance of "cold zones" in the open ocean, such as the one off the west coast of South America at the equator, where the rising is entirely the result of conditions of density and temperature; but in the present instance an inspection of the diagram shows that it is confined to a stratum not exceeding 25 fathoms in depth, and that it must be attributed to the obstacles which islands and reefs offer to the passage of a formidable tidal current which sweeps through the passages four times a day.

THE CENTRAL PACIFIC OCEAN.

The annexed diagram, plate 3, represents a section of the Pacific Ocean a short distance to the eastward of the Hawaiian Islands, along the meridian of 151° 45′ west, from latitude 20° 18′ north to 13° 28′ south, based on observations by the *Challenger* in August and September, 1875.

The surface densities in this section and as a rule in the South Pacific are higher than the North Pacific. This is due mainly to the fact that no rivers draining extensive continental areas empty their waters into the South Pacific. The maximum of density in the South Pacific is reached in the latitude of the Society Islands, about 20° south, where 1·0276 is obtained; that of the North Pacific, in the longitude of the section, in about 30° north latitude, where 1·0266 is recorded. But farther to the westward, in longitude 163° 16′ east, Makaroff in 1887 found in latitude 23° 50′ a density of 1·0276, and Moser in 1896 in about latitude 28° north and longitude 167° east one of 1·0271. This would make the maximum of the North Pacific equal to that of the South Pacific; but even if this should be the case, there is no doubt of the proposition that in the lower latitudes the South Pacific is more saline than the North. The lowest surface density in the section (1·0250) is found in latitude 9° 28′ north, or near the southern edge of the north equatorial current.

As a rule, the densities decrease from the surface to the depth of about 300 fathoms, where from 1·0254 to 1·0257 is found; thence there is a very gradual increase extending to the bottom, where 1·0259 is reached. This depth of 300 fathoms indicates the approximate depth to which salt and heat are carried through the process of evaporation at the surface. But there is another potent cause which puts the waters of the ocean into motion and which tends to diffuse salt and heat into spaces which are not reached

by the direct effects of evaporation. Two bodies of water containing different proportions of salt in solution can maintain equilibrium only if the denser water has a higher temperature. If two such differently constituted currents of water meet, an effort toward equalization of the proportions of salt and heat at the plane of contact will develop a tendency in the denser water to sink and in the lighter water to rise to a higher level. The waters of the South Pacific, being both denser and warmer in the upper strata than those of the North Pacific, we have reason to expect to find a place near the equator where the waters of the South Pacific will manifest a disposition to sink into great depths and those of the North Pacific to rise from great depths toward the surface. As a matter of fact we find that the water of a density of 1·0259 to 1·0260, which to the southward of the equator does not penetrate to a greater depth than 200 fathoms, descends under the equator to the depth of more than 1 000 fathoms. At the same time we see a body of light water of the density of 1·0254 at the depth of 800 fathoms in latitude 20° north commence to rise in an oblique direction toward the equator. In latitude 3° north, with a density of 1·0258, it is within 50 fathoms of the surface and by its presence reduces the surface density in that latitude to 1·0263. The effects of the sinking of the dense water and the rising of the light water are also made apparent in the diagram of temperatures.

We notice that between the equator and 10° north latitude, at all depths exceeding 150 fathoms, higher temperatures are found than either farther north or south, and conclude that the heat has been brought along from the surface by the waters of the South Pacific, which we assume to descend here into the great depths of the ocean. Similarly, we account for the appearance of a minimum temperature at the surface of 78°·7 at the equator itself by supposing that the cold water which rises to the northward here reaches the surface.

We notice a second example of bodies of water being in contact and changing their levels on account of differences in physical conditions on the upper left-hand part of the diagram, plate 3, where, in latitude 20° 18′ north, about the edge of the north equatorial current, water of the density of 1·0254, with a temperature of 40°·8, ascends in a southerly direction from the depth of 400 fathoms and reaches the surface in latitude 9° 28′, at the southern edge of the same current, with a density of 1·0250, and producing minima of temperatures between 50 fathoms depth and the surface ranging between 55° and 80°. This light and cold water comes in contact on its right hand at the surface with warmer and denser water having a specific gravity of 1·0260 and temperature of 81°·2 and occupying a position in the equatorial counter current, which flows westwardly. We find that this heavy water not merely sinks, but that it also advances in a northerly direction, undermining the light water to its right, and that it comes to rest in about 400 fathoms depth, with its density reduced to 1·0258 and its temperature to 42°.

Our diagram has the defect that it shows motion only in the plane of the meridian, representing but two components of free motion. The third one, that in an east-and-west direction, is not represented and has not hitherto received any recognition in our inquiry. It is important to note that in the region under consideration, that of the Tropics, with its equatorial currents, this east-and-west component predominates over the meridional the more we approach the surface and is not to be neglected if we wish to arrive at anything like correct views of oceanic circulation. Several peculiarities in the diagram which look like anomalies may be explained by considering this factor. The *Challenger's*

observation shows in latitude 13° 28′ south a surface density of 1·0264 and one of 1·0270 in 100 fathoms. Makaroff's observations between the Marquesas and Hawaiian Islands show several similar instances of denser water under the surface in the South Pacific, in latitude 9° 25′ for instance, he found a density of 1·0271 at the surface and 1·0273 at 55 fathoms, showing that this condition of higher densities below the surface is normal in this part of the Pacific Ocean. Ocean water sinking below the surface in consequence of evaporation is more liable to have the density decreased than increased by contact with lighter water, hence we have to assume that the low surface densities are caused either by local precipitation or, with greater probability, that this water has been carried to its present position by a cold and light surface current, the south equatorial from a region to the eastward (the direction of the American continent). Furthermore, we may assume that the denser water below the surface has not attained its position by merely sinking in a vertical direction, but that it has arrived from a region farther to the southward, where the surface densities are greater, and has drifted in a northerly, or, more properly speaking, in a northwesterly direction under the south equatorial current. Similarly, we find near the southern edge of the north equatorial current, where we assume the light water to rise toward the surface, a surface density of 1·0250, with 1·0256 in 50 fathoms as lowest density in the next station to the northward. We have to assume that light water rising toward the surface will gain in density by its contact with more saline water, and hence conclude that the surface water has not risen from any depth, but that its lightness is due either to precipitation or to a current of light water—the north equatorial. The water of the density of 1·0256 in 50 fathoms depth may not reach the surface, but should this happen it would probably be far to the westward of the position indicated on the diagram.

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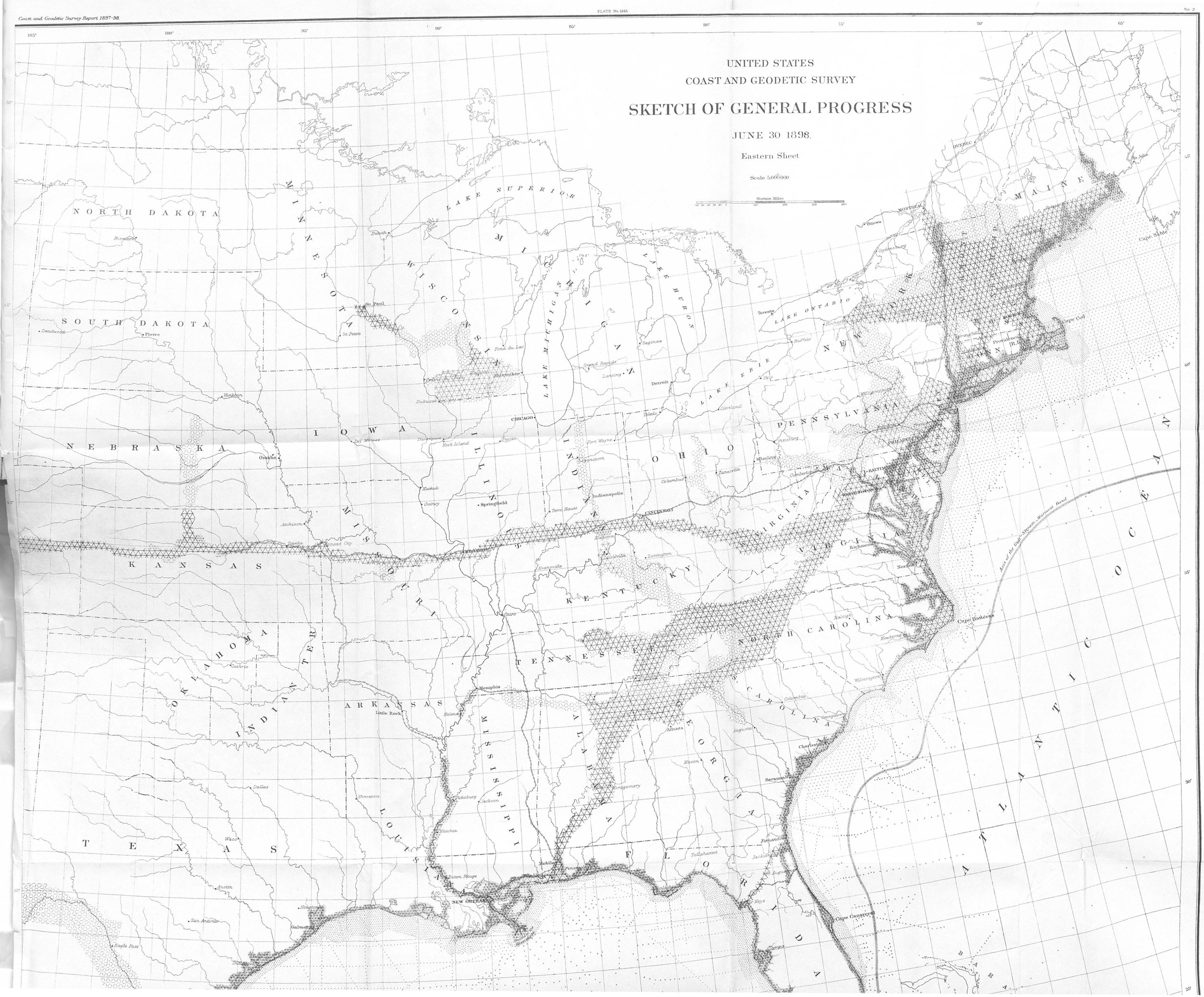

UNITED STATES
COAST AND GEODETIC SURVEY
SKETCH OF GENERAL PROGRESS
JUNE 30 1898.
Eastern Sheet
Scale 5,000,000
Statute Miles
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
INDIAN TER
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
S. CAROLINA
NORTH CAROLINA
VIRGINIA
W. VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE
MASS.
CONN.
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ATLANTIC OCEAN
BAHA
Cape Cod
Cape Hatteras
Cape Canaveral
Cape Sable
Axis of the Gulf-Stream-Warmest Band
St. Paul
Milwaukee
Chicago
Detroit
Toronto
Montreal
Ottawa
Quebec
Boston
Providence
Philadelphia
Baltimore
Washington
Richmond
Norfolk
Wilmington
Charleston
Savannah
Augusta
Atlanta
Montgomery
Mobile
New Orleans
Galveston
Houston
Austin
San Antonio
Dallas
Waco
Shreveport
Little Rock
Memphis
Cairo
Evansville
Indianapolis
Cincinnati
Columbus
Cleveland
Pittsburg
Buffalo
Rochester
Albany
Springfield
Omaha
Kansas City
Topeka
Atchison
Omaha
Des Moines
Davenport
Rock Island
Peoria
Springfield
Keokuk
Quincy
Fond du Lac
Grand Rapids
Lansing
Saginaw
Toledo
Port Wayne
Lexington
Huntsville
Helena
Vicksburg
Jackson
Natchez
Baton Rouge
Tallahassee
Jacksonville
Fernandina
Tampa
Key Keys
Eagle Pass
Yankton
Pierre
Deadwood
Bismarck
Duluth
Dubuque
Sheboygan
Wheeling
Zanesville
Columbus
Terre Haute
Cairo
Hunsville
Macon
Augusta
Columbia
Georgetown
Raleigh
Newbern
Wilmington
Richmond
Lynchburg
Cumberland
Williamsport
Poughkeepsie
Albany
Springfield
Providence
Ottawa
Ogdensburg
St. John
Cape Sable
Cape Hatteras
Cape Canaveral
Mouths of the Mississippi

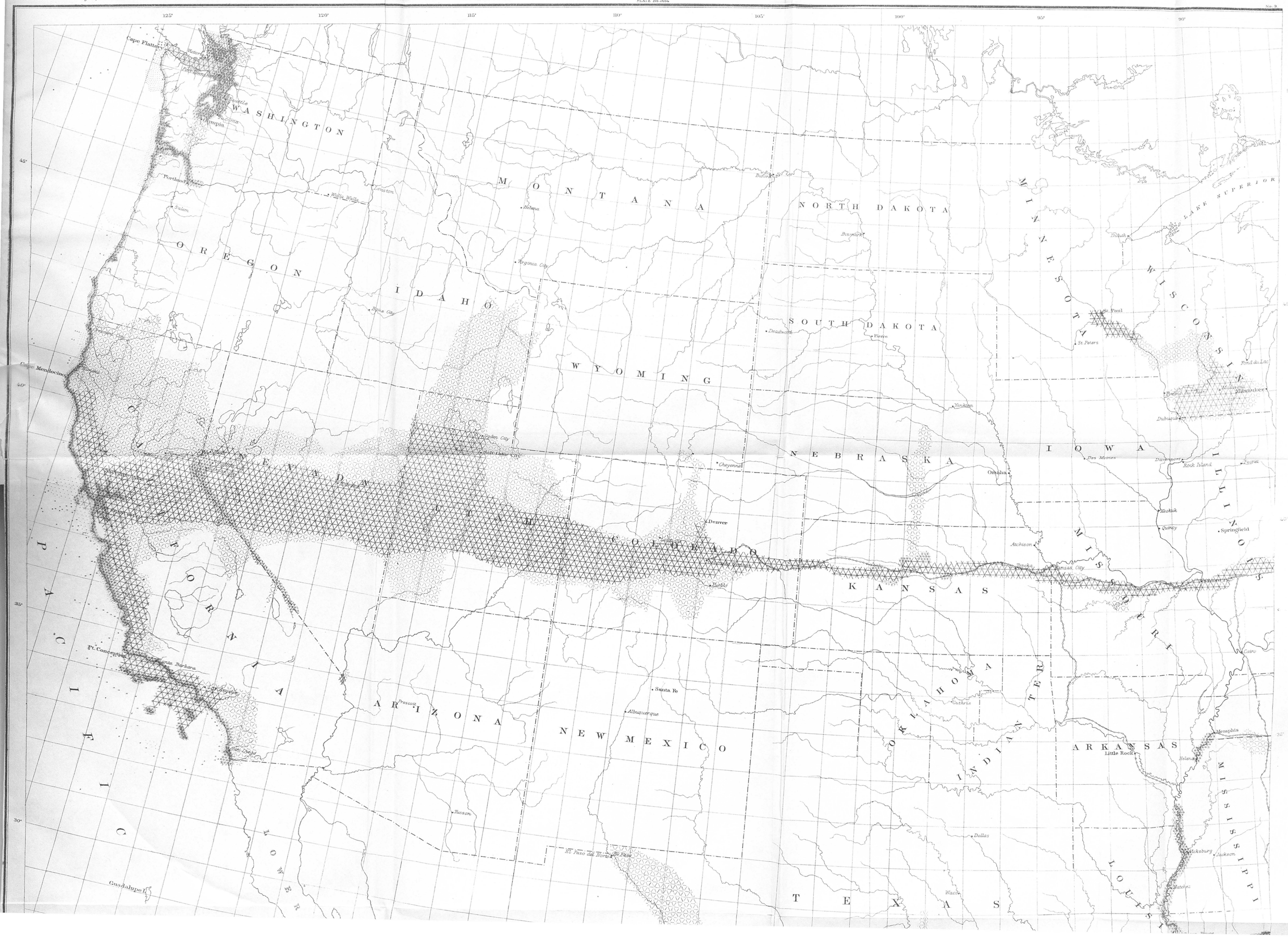
INDIAN TERRITORY
OKLAHOMA
ARKANSAS
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
MISSISSIPPI
LOUISIANA
TEXAS
FLORIDA
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
CUBA
BAHAMAS

Cultore
Memphis
Little Rock
Helena
Huntsville
Nashville
Columbia
Georgetown
Wilmington
Newberne
Augusta
Charleston
Atlanta
Macon
Savannah
Montgomery
Dallas
Shreveport
Vicksburg
Jackson
Natchez
Waco
Mobile
Pensacola
Tallahassee
Fernandina
Jacksonville
Baton Rouge
NEW ORLEANS
Austin
Houston
San Antonio
Galveston
Eagle Pass
Indianola
Corpus Christi
Laredo
Cape Canaveral
Keys
Tampa
Nassau
Monterey
Matamoras
Rio Grande
Tortugas
Key West
HAVANA
Cienfuegos
C. San Antonio
Santiago de Cuba
Tampico
Cape Catoche
Progreso
Campeche
Vera Cruz
Tlacotalpan
Belize

EXPLANATION OF SYMBOLS

Primary Triangulation
Secondary, Tertiary } Triangulation
Reconnaissance
Surveyed Topography
do. In-shore Hydrography
do. Off-shore do.
Lines of Deep Sea Soundings
do. Geodetic Levelling

35°
30°
25°
20°
100°
95°
90°
85°
80°
75°


125°
120°
115°
110°
105°
100°
95°
90°
50°
45°
40°
35°
30°
Cape Flattery
Victoria
Port Townshend
Seattle
Tacoma
Olympia
WASHINGTON
Portland
Salem
Walla Walla
Lewiston
OREGON
IDAHO
Boise City
MONTANA
Helena
Virginia City
NORTH DAKOTA
Bismarck
Buford
SOUTH DAKOTA
Deadwood
Pierre
WYOMING
Yankton
MINNESOTA
St. Paul
St. Peters
Duluth
LAKE SUPERIOR
WISCONSIN
Fond du Lac
Madison
Milwaukee
Dubuque
IOWA
Des Moines
Davenport
Rock Island
Peoria
ILLINOIS
Keokuk
Quincy
Springfield
NEBRASKA
Omaha
Cheyenne
Denver
Salt Lake City
Ogden City
NEVADA
UTAH
COLORADO
Colorado Springs
Pueblo
KANSAS
Atchison
Topeka
Kansas City
MISSOURI
Cairo
Cape Mendocino
CALIFORNIA
Pt. Conception
Santa Barbara
Los Angeles
San Diego
Guadalupe I.
PACIFIC
LOWER
ARIZONA
Prescott
Tucson
NEW MEXICO
Santa Fe
Albuquerque
El Paso del Norte
OKLAHOMA
Guthrie
INDIAN TER.
ARKANSAS
Little Rock
Helena
Memphis
MISSISSIPPI
Vicksburg
Jackson
Matchez
LOUISI
TEXAS
Dallas
Waco

UNITED STATES
COAST AND GEODETIC SURVEY

SKETCH OF GENERAL PROGRESS

JUNE 30 1898.

Western Sheet

Scale 5,000,000

Statute Miles

10 40 30 20 10 0 50 100 150 200

EXPLANATION OF SYMBOLS

- Primary Triangulation
- Secondary / Tertiary } Triangulation
- Reconnaissance
- Surveyed Topography
- do. In-shore Hydrography
- do. Off-shore do.
- Lines of Deep Sea Soundings
- do. Geodetic Levelling

CALIFORNIA
ARIZONA
NEW MEXICO
OKLAHOMA
INDIAN TER.
TEXAS
ARKANSAS
LOUISIANA
MISSISSIPPI
MEXICO
PACIFIC OCEAN
GULF OF MEXICO
LOWER CALIFORNIA

Ft. Concepcion
Santa Barbara
Los Angeles
San Diego
Prescott
Santa Fe
Albuquerque
Tucson
El Paso del Norte
El Paso
Guadalupe I.
Cerros I.
Guaymas
Chihuahua
Presidio del Norte
Eagle Pass
Laredo
Cape San Lazaro
La Paz
Cape San Lucas
Mazatlan
San Blas
Cape Corrientes
Manzanilla
Monterey
Matamoras
Rio Grande
Dallas
Austin
San Antonio
Waco
Houston
Galveston
Corpus Christi
Guthrie
Memphis
Little Rock
Helena
Vicksburg
Jackson
Natchez
Baton Rouge
NEW ORLEANS
Shreveport
Tampico
Vera Cruz
Campeche
Frontera

115° 110° 105° 100° 95° 90°
30° 25° 20°