REPORT OF THE SUPERINTENDENT

OF THE

COAST AND GEODETIC SURVEY

SHOWING

THE PROGRESS OF THE WORK

FROM

JULY 1, 1899, TO JUNE 30, 1900.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1901.

National Oceanic and Atmospheric Administration

Annual Report of the Superintendent of the Coast Survey

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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.

TREASURY DEPARTMENT, OFFICE OF THE SECRETARY,
Washington, D. C., December 20, 1900.

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 transmitted to this Department by Mr. O. H. Tittmann, Superintendent of the Coast and Geodetic Survey, showing the progress made in that work during the fiscal year ended June 30, 1900. This Report was prepared under the direction of Dr. Henry S. Pritchett, Superintendent during the period mentioned. It is 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 PRESIDENT OF THE SENATE.

LETTER

FROM THE

SUPERINTENDENT OF THE UNITED STATES COAST AND GEODETIC SURVEY

SUBMITTING THE

Annual Report for the fiscal year ended June 30, 1900.

UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C., December 20, 1900.

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, 1900, prepared under the direction of my predecessor, Dr. Henry S. Pritchett. It is accompanied by maps illustrating the general advance in the field work of the Survey up to that date.

Respectfully, yours,

O. H. TITTMANN,
Superintendent.

The Honorable the SECRETARY OF THE TREASURY.

SPECIAL FEATURES OF THE PRESENT VOLUME.

THE INTERNATIONAL LATITUDE OBSERVATIONS AT GAITHERSBURG, MD., AND UKIAH, CAL.

THE CRUISE OF THE STEAMER PATHFINDER FROM WASHINGTON, D. C., TO SAN FRANCISCO, CAL., AND TO HONOLULU, H. I.

THE ALASKAN SURVEYS AT THE MOUTHS OF THE YUKON AND COPPER RIVERS AND AT CAPE NOME.

THE BOUNDARY LINE BETWEEN CALIFORNIA AND NEVADA.

PREFACE.

The entire field of activity of the United States Coast and Geodetic Survey may be classified under the following synopsis. In the general statement of progress made during the past fiscal year the subject is treated in the order stated. This analysis of the Survey's operations will enable the reader to understand the actual life of the organization in a short time and in a space as restricted as the importance of the matter will permit. Further detail, both in field and office work, may be found in the appendices, where, for the sake of continuity of narration, all the operations of individual parties in the several localities are better disposed of in a continuous statement.

SYNOPSIS

ADMINISTRATION.

SUPERINTENDENT.

ASSISTANT SUPERINTENDENT.

I.

ASSISTANT IN CHARGE OF OFFICE.

II.

INSPECTOR OF HYDROGRAPHY AND TOPOGRAPHY.

III.

INSPECTOR OF GEODETIC WORK.

IV.

INSPECTOR OF MAGNETIC WORK.

V.

DISBURSING AGENT.

VI.

EDITOR.

VII.

INSPECTOR OF WEIGHTS AND MEASURES.

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INTRODUCTION.

I. GENERAL ADMINISTRATION.

A. Duties.

The administrative duties during the year were continued on the same general lines as those prevailing on June 30, 1899. The Assistant Superintendent was charged with all matters of routine pertaining to the Superintendent's Office, and the Assistant in Charge continued, as heretofore, to have immediate direction of the Divisions of the Office.

B. Personnel.

The personnel of the Coast and Geodetic Survey service was made up as follows

1. Office force:	
Disbursing agent	1
Chief of the library and archives	1
Clerical force	15
Chart correctors, writers, etc	14
Draftsmen	16
Computers	13
Engravers	17
Electrotypers, photographers, etc	21
Watchmen, messengers, etc	19
	117
2. Field force:	
Assistants	47
Aids	14
	61
3. Naval contingent:	
Petty officers, seamen, firemen, cooks, etc	342
4. Civilian watch officers	18
	360

From the above table it will be seen that a total number of 538 persons were regularly attached to the Coast and Geodetic Survey during the year.

II. EXPENDITURES.

Salaries of field force	$112, 333. 52
Salaries of office force	134, 084. 43
Party expenses	*215, 398. 50
Repairs of vessels	37, 179. 49
General expenses	31, 620. 38
Salaries, office of Weights and Measures	8, 237. 44
Miscellaneous expenses, office of Weights and Measures	983. 83
	539, 837. 59

In addition to the above, the salaries of 342 petty officers and enlisted men were paid out of the appropriation for pay of the Navy.

III. THE WORK OF THE YEAR.

A. Field Operations.

Magnetic work, which had considerable development during the past year, was executed in many parts of the United States, including a systematic survey of the State of North Carolina.

The investigation of the literature bearing on Mason and Dixon's Line was made, and the result will be published hereafter.

A standard of length was established in Boston for the street commissioners' office, and a set of length measures has been verified for the State of Maine by the Office of Weights and Measures.

In view of the necessity of making charts in the Philippine Islands, an Assistant was detailed in the latter part of the fiscal year to acquire, at Manila, such information as would bear on the subject. He arrived during the month of June, and continued his studies for several weeks, getting information of value for the intelligent prosecution of subsequent hydrographic and topographic work.

Under the supervision of the Superintendent, latitude observations were begun at Gaithersburg, Md., and at Ukiah, Cal., in October, 1899, and continued during the period covered by this Report The work at these stations was executed under the direction and at the expense of the International Geodetic Association.

The resurvey of Chesapeake Bay was continued by all the parties available for this important work. Topography was executed at a number of points on the northern shores of the bay.

An Assistant of the Coast and Geodetic Survey is a member of the Mississippi River Commission, and in this capacity was engaged during the greater portion of the year in performing the various duties resulting from his appointment to this position.

Lines of precise leveling were carried westward, with the ultimate object of crossing the continent and establishing the difference of level between the Atlantic and Pacific oceans, as well as to give heights along the line in the different States traversed. This line will also serve as a base from which innumerable points in the interior of the country may have their altitude above tide water established.

*The salaries of the civilian watch officers were paid under this heading.

Prominent among the schemes of work now in hand by the Coast and Geodetic Survey stands the triangulation along the ninety-eighth meridian. This was prosecuted during the past year in Texas, Kansas, and Nebraska.

The work in Alaska was carried on by a number of parties operating at Cape Nome, the mouth of the Yukon, Scammon Bay, and on the Copper River.

Several vessels were sent to Porto Rico, and were engaged in making surveys of this island and the adjacent ones.

The *Pathfinder* was for some months in the Hawaiian Islands. The party did triangulation on Maui, Molokai, and at Hilo, on Hawaii. A hydrographic survey of four harbors in these islands was also made.

An Assistant made an inspection of the chart agencies on the Atlantic coast, and valuable information was acquired, as to the needs of the maritime public concerning charts.

The Coast Pilot party was engaged in the compilation of data derived from its own field observations and from other sources.

In connection with the solar eclipse of May 28, 1900, an Assistant of the Coast and Geodetic Survey was detailed to make time observations and to establish meridian lines, as requested by the Smithsonian Institution, and others of the Coast Survey personnel were employed in making magnetic observations during totality at points on the line of the eclipse.

Availing himself of a brief sojourn in Porto Rico, one of the surgeons attached to the service made a special study of the sanitary conditions of Porto Rico and Culebra, and abstracts of his reports are published in Appendix No. 2.

Gravity connections were made toward the close of the fiscal year by an Assistant on the Survey, between the station at Washington, D. C., and some of the principal stations of Europe. This work was in progress at the close of the fiscal year.

A survey of the Brunswick outer bar, called for by a special act of Congress, and made by an Assistant of the Coast and Geodetic Survey, under the direction of the Secretary of War, was completed during the year.

The *Pathfinder* sailed from Washington in June, 1899, and arrived at San Francisco three months later. A detailed account of this successful voyage is given in one of the appendices to the present Report.

With the view of utilizing the Marconi system of wireless telegraphy, the Inspector of Standards was detailed to witness the experiments made by the Navy Department, off Navesink, late in the month of October.

The work on Chesapeake Bay has already been mentioned as far as the land operations are concerned, and it only remains in this place to say that the hydrographic survey was continued, and at many points formed the principal occupation of the parties.

This same remark applies to the work in Alaska, where hydrography was done at many points, including some offshore work by the steamer *Patterson* in the development of the great bar off the mouth of the Yukon.

Hydrographic surveys were made in many places in the waters of Porto Rico, notably in the harbor of San Juan and in the sound lying between Culebra and the east coast of Porto Rico.

A speed-trial course for the ships of the Navy was laid out at Cape Charles City, Chesapeake Bay, at the request of the Navy Department.

The work of marking the temporary boundary line between Alaska and British Columbia, in accordance with the terms of a modus vivendi dated October 20, 1899, was undertaken at the request of the Department of State, by an officer of the Survey, as Commissioner of the United States, and was in progress at the close of the fiscal year.

B. Office Computations.

1. General.

The regular computations of the Survey were carried on in the lines of geodesy, leveling, magnetism, etc.

2. Special.

Besides the regular work of the Survey in the matter of computations, special investigations have been made with a view of determining the size and shape of the earth. One very important contribution to the solution of this problem has been made in the transcontinental triangulation, the results of which appear in Special Publication No. 4, of this Bureau. The Arc Section during the past year was engaged in the recomputation of the triangulation along the eastern coast of the United States, following the Appalachian chain and extending from Calais, Me., to New Orleans, La. This work is almost ready for publication, and will form an important contribution to the subject. Some work has also been done on an oblique arc from San Francisco to the Mexican Boundary.

C. Publication of Results.

During the year the Report for the year 1898 was sent to the printer; that for 1899 was finished, and considerable work had been done on that for 1900. This brought the publication of the Annual Reports practically up to date.

Second editions of several bulletins were issued, and supplements to the Coast Pilots published as occasion demanded. The usual Tide Tables were prepared for the year 1901. Notices to Mariners were sent out monthly and three special publications, Nos. 3, 4, and 5, were prepared and sent to the printer. Of especial interest is the first named, which is an Atlas of the Philippine Islands, containing about 30 charts, with text in Spanish and English. The second one, Special Publication No. 4, is The Transcontinental Triangulation and the American Arc of the Parallel, a volume of 871 pages, the material for which had been accumulating for twenty-five years. Other reference to these publications is made in the body of the report, both in the details of office work and in the account of general progress.

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REPORT—1900.

ADMINISTRATIVE STATEMENT.

OFFICE AND FIELD OPERATIONS.

ADMINISTRATIVE STATEMENT.

HENRY S. PRITCHETT, *Superintendent.*
O. H. TITTMANN, *Assistant Superintendent.*

OFFICE OF SUPERINTENDENT.

Personnel.

Name.	Occupation.
D. B. WAINWRIGHT	Assistant.
W. B. CHILTON	Clerk.
H. M. FITCH	Confidential clerk.

1. PLAN OF OPERATIONS.

a. General statement.

The work during the year has been a continuation on the general lines previously followed. The localities in which work was done were determined by the necessities of the case. Changes are continually going on in many localities, and this has necessitated many resurveys.

The general expansion of the material interests of the United States within the last few years has resulted in calling upon the surveying departments of the Government for renewed efforts and the development of new plans of work in the outlying Territories.

The gold fields of Alaska having brought this Territory into extreme prominence, the Survey has been called upon to furnish preliminary charts of the entrances to the Klondike and other gold-bearing regions. With this end in view parties have been dispatched to Cape Nome, the mouth of the Yukon, Scammon Bay, and the Copper River Delta.

b. Resurveys.

The principal resurveys of the year have been that of Chesapeake Bay and of the bar outside the Golden Gate, at San Francisco. In the former case a comparison of the old work with the new shows the necessity for much resurveying, and this work is being carried on by numerous parties as rapidly as the appropriations permit. The survey of the bar off the entrance to San Francisco Harbor was completed just before the termination of the year.

c. New work.

By far the larger part of the resources of the Survey was devoted to the development of regions where work had not been done before. An unusual amount of work was done in Alaska, but in view of the great demands for information from this quarter, it seemed necessary to send all the parties there which could be economically employed. Much work was done in Porto Rico in triangulation, reconnaissance, and hydrography, the result of which has been the development of several harbors and their approaches. The *Pathfinder* spent several months in the Hawaiian Islands making supplementary surveys of four harbors and their approaches.

2. ORGANIZATION OF PARTIES.

The organization of parties has been in conformity with the needs of the situation. There were during the year 6 engaged on reconnaissance, 20 on topography, and 26 on triangulation. Eighteen hydrographic parties were in operation during the year in the localities previously mentioned, and current and tide observations were made by these parties in numerous places.

The geographic distribution of these parties was as follows: twenty-four parties were in the Eastern Division, 6 in the Middle, 8 in the Western, 6 in Alaska, 1 in Hawaii, and 5 in Porto Rico.

3. GEOGRAPHIC DISTRIBUTION OF THE WORK.

a. Eastern Division.

Triangulation was done in New Jersey, Maryland, and South Carolina; topography in Massachusetts, New Jersey, Maryland, and South Carolina; hydrography in Massachusetts, New York, Pennsylvania, and South Carolina; leveling in Kentucky and Tennessee; magnetic work in Rhode Island, West Virginia, Maryland, District of Columbia, Virginia, North Carolina, South Carolina, Georgia, Florida, Ohio, Kentucky, Tennessee, and Alabama; tidal work in Maryland and South Carolina.

b. Middle Division.

Reconnaissance work was done in Nebraska, Kansas, and Texas; triangulation in Nebraska and Kansas; leveling in Nebraska; and magnetic work in Kansas and Texas.

c. Western Division.

Triangulation was done in California and Washington; astronomic work in Arizona; topography in California and Washington; hydrography in California; leveling in Colorado and Wyoming; magnetic work in New Mexico and Colorado; and tidal work in California and Washington.

d. Division of Alaska.

The operations in Alaska included reconnaissance, base measurement, astronomic, triangulation, topographic, hydrographic, magnetic, tidal, and current work.

e. Outlying Territory.

Work in nearly all of the above classes was done in Porto Rico and Hawaii.

f. Special duty.

Numerous assignments for special duty were made during the year, the details of which are given under the above heading in the proper place in this Report.

I. OFFICE OF THE ASSISTANT IN CHARGE.

ANDREW BRAID, *Assistant in Charge.*

The Assistant in Charge has direction of the divisions of the Office, and furnishes information to the field officers and to outside parties. Details under this heading are given in Appendix No. 1.

A. COMPUTING DIVISION.

1. GEODETIC.

a. Triangulation.

The Computing Division was largely occupied during the year on the triangulation extending across the continent and that along the Eastern and Western coasts. A report on the transcontinental work was submitted in September, 1899.

b. Leveling.

The precise leveling carried on by the Coast and Geodetic Survey was subjected to a careful adjustment, and the results of this work, together with some collected data from other Government organizations, were published as an appendix to the last Annual Report.

2. ASTRONOMIC.

The astronomic computations consisted in the calculation of the apparent places of stars and of the determinations of latitude, longitude, and azimuth.

B. DIVISION OF TERRESTRIAL MAGNETISM.

The work in the Division of Terrestrial Magnetism consisted in editing a final report on the magnetic survey of Maryland and one on the survey of North Carolina. Magnetic declinations at about 3 000 places were prepared for publication in the Tide Tables for 1901.

C. TIDAL DIVISION.

1. TIDES.

Harmonic analyses were completed for several short series of hourly heights, and several series of a year each have been partially analyzed. The harmonic tidal constants for the world are being collected, and at present the list contains 248 stations for which five hundred and three years of analysis have been made. A plane of reference was determined for 37 stations in San Francisco and San Pablo bays by comparison of their observations with simultaneous tides at Sausalito or Presidio.

2. CURRENTS.

Current tables for 50 stations were prepared, in response to calls for information by outside parties.

D. DRAWING AND ENGRAVING DIVISION.

1. DRAWING SECTION.

There have been an unusually large number of charts drawn during the year, much work being demanded by the necessity of preparing charts in the territory recently brought under the jurisdiction of the United States.

2. ENGRAVING SECTION.

Five original plates were completed during the year and extensive corrections were made for 56 new editions. Many plates for new charts were commenced and many plates for new editions were under correction at the close of the fiscal year.

3. PRINTING SECTION.

About 64 000 impressions were made in this section and sent to the Chart Division for distribution and sale.

4. PHOTOGRAPHIC AND ELECTROTYPING SECTION.

The work of this section consisted in the preparation of negatives and prints, as required by the business of the Office. Forty basso plates and 30 altos were made during the year.

E. CHART DIVISION.

Under the Inspector of Charts, the work of the Chart Division was divided into the chart section and the hydrographic section. In the former all correspondence was carried on, as well as the bookkeeping relative to the business of the sales agents. In the latter the results of hydrographic work as they came from the field were platted and verified, and the proofs revised. A bulletin, No. 36, giving a table of depths for channels and harbors in the United States was prepared. A new edition of the Title and Notes for Charts was also prepared. The statistics of the Division show that during the year 1900 the total issue of charts was 19 per cent larger than the average; the free distribution was 16 per cent larger than the average; and the net sales were greater by 23 per cent, both in number of copies and in value.

F. INSTRUMENT DIVISION.

1. DESIGN AND REPAIR OF INSTRUMENTS.

In the Instrument Division such instruments as were necessary for the use of the field parties were repaired. When occasion required it, designs for new instruments were made, and experiments were carried on to evolve the best disposition of material and means of construction. Two new theodolites, eight new geodetic level rods, and two new geodetic levels were completed during the year.

2. GENERAL PROPERTY.

The Instrument Division, besides its regular work in the design and construction and repair of instruments, was charged with the care of the general property of the Survey.

G. DIVISION OF LIBRARY AND ARCHIVES.

The work of this Division may be classed into general matters of routine, accessions, indexing, shelf arrangement, binding, and special work. The records of the work in the field were registered, labeled, and filed as soon as received. During the year the books were examined and rearranged with special reference to their utility.

H. MISCELLANEOUS DIVISION.

The Miscellaneous Division transmits the original manuscript to the Public Printer through the Treasury Department, and receives the printed copies as they appear. A statement in detail of all matter passing through the Division, whether in the shape of manuscript or the printed volume, is given in Appendix No. 1.

By far the larger part of the work of this Division consists in the purchase of supplies necessary for the use of the office and in the field, and the distribution of these upon requisition from the officers requiring them.

I. SPECIAL DUTY.

The discussion of the oblique arc was continued, and progress was made on the computation of the triangulation from San Francisco southward to the Mexican boundary.

II. OFFICE OF INSPECTOR OF HYDROGRAPHY AND TOPOGRAPHY.

H. G. OGDEN, *Inspector of Hydrography and Topography.*

A. INSPECTION.

Personnel.

Name.	Occupation.
J. H. Roeth	Clerk.
R. D. Chase	Writer.
E. W. Ford	Writer (Sept. 1 to Nov. 9).

The Inspector has immediate supervision over all the topographic and hydrographic field work of the Survey, the most important data required in the construction of charts. On July 1, Assistant Ogden was at San Francisco, Cal., on inspection duty.

Late in July he returned to Washington, D. C., via Seattle, Wash., where he spent a day in consultation with Assistant Gilbert. He made frequent visits to the *Eagre* while at work in New York Harbor, and directed operations which resulted in the location of a range for carrying deep-draft vessels between Coenties and Diamond reefs. After completing this field work the *Eagre* was docked and Assistant Ogden personally inspected the vessel in connection with the local inspector of hulls.

He performed similar duty in inspecting the *Blake*, at Boston. Numerous other trips of inspection were made during the year.

The office work attending the care of the vessels required much labor, in consequence of the legislation by Congress for transferring the enlisted force from a naval to a civil basis. Plans and specifications for rebuilding the steamer *Bache* and the construction of a new steamer for the Coast Pilot work were prepared.

B. COAST PILOT PARTY.

Personnel.

Name.	Occupation.
John Ross	Nautical expert, chief of party.
H. C. Graves	Nautical expert.
H. L. Ford	Do.
J. M. Griffin	Clerk (July 1 to Nov. 7).
Talbot O. Pulizzi	Writer.

The duties of the Coast Pilot party are both in the field and in the office. It is necessary to check information and verify facts on the ground before they can be utilized in the compilation of the Coast Pilots. The party was engaged in the office from the beginning of the fiscal year until the 22d of July. The work consisted in the compilation of the Alaska Coast Pilot and the revision of the United States Coast Pilot, Part IV. Some work was also done relating to Peril Strait, Alaska. The work of the party, after taking the field in July, will be given in the description of the general field work, and it only remains in this place to state some of the duties performed in the office.

The party returned to Washington on September 1, and during this month and the following one were engaged in the preparation of the third edition of the Coast Pilot of the Atlantic Coast, Part IV, a copy being sent to the printer on October 25. One supplement to the Coast Pilot, Part III, and one to Coast Pilot, Part VIII, were prepared and the proof read. A notice of the range in the deep-water channel of East River, New York, was prepared.

During November and December the party was engaged in reading proof of Part IV, the collection of data and preparation of manuscript for the Alaska Coast Pilot, and the preparation of a supplement to Parts I–II, III, VI, and VIII. Some work was also done on the collection of data for the Pacific Coast Pilot.

During January and February the party was engaged in reading proof for the third edition of the Coast Pilot, Part IV; in preparing a second edition of Bulletin No. 40, Alaska, and data for the Pacific Coast Pilot; supplements for Parts I–II and IV were prepared and proof read, and discrepancies on charts covering the locality included in the third edition of the Coast Pilot, Part IV, were submitted. Lieut. D. H. Jarvis, United States Revenue-Cutter Service, gave valuable assistance in the preparation of the second edition of Bulletin No. 40, having been assigned to this duty at the request of the Superintendent.

During March and April the party was engaged in reading proof and in collecting data in the field for the second edition of the Coast Pilot, Atlantic Coast, Part VII, and during May and June in the preparation of the second edition of the Coast Pilot, Atlantic Coast, Part VII. This work was well advanced at the close of the year.

One member of the party was employed almost continuously during the year on routine work, consisting of the collection of the latest information for insertion in the Coast Pilot volumes and the correction of the volumes to date of issue.

The following is an abstract of the publications prepared by the party during the fiscal year, with the date of each:

Supplement to the United States Coast Pilot, Atlantic Coast, Part IV, September 30, 1899.
Supplement to the United States Coast Pilot, Atlantic Coast, Part VIII, November 23, 1899
Supplement to the United States Coast Pilot, Atlantic Coast, Part VI, February 24, 1900.
Supplement to the United States Coast Pilot, "Rules of the road, etc."
Supplement to the United States Coast Pilot, Atlantic Coast, Parts I–II, February 27, 1900.
United States Coast Pilot, Atlantic Coast, Part IV, third edition, March 28, 1900.
Bulletin No. 40, second edition, Coast Pilot Notes, Alaska, April 20, 1900.

III. OFFICE OF INSPECTOR OF GEODETIC WORK.

J. F. HAYFORD, *Inspector of Geodetic Work.*

The work of inspecting the geodetic operations of the Survey was carried on during the year almost exclusively by careful examinations of the records and computations sent to the Office by the field parties. The monthly reports and letters from the field parties were also examined systematically. On January 1, 1900, the Inspector of Geodetic Work was also made Chief of the Computing Division, and after that time the records and computations were necessarily subjected to a still more careful scrutiny during the progress of the computations. The only inspection in the field during the year was made on a single day spent with a leveling party running a line between the western end of Lake Erie and Cincinnati.

IV. OFFICE OF THE INSPECTOR OF MAGNETIC WORK.

L. A. BAUER, *Inspector of Magnetic Work.*

The duties of the Inspector involved the immediate direction of the field operations in terrestrial magnetism and the preparation of special reports on the progress of the work, as called for by the Superintendent.

In all, 226 different stations were occupied in various parts of the United States. A site for a magnetic base station was selected near Washington, D. C., and the correlation of the different magnetic instruments belonging to the Survey undertaken.

The special field work carried on by the Inspector as chief of party is given in detail elsewhere, and also his duties as Chief of the Division of Terrestrial Magnetism.

V. OFFICE OF THE DISBURSING AGENT.

SCOTT NESBIT, *Disbursing Agent.*

Personnel.

Name.	Occupation.
N. G. Henry	Confidential clerk and cashier.
Ida M. Peck	Typewriter and clerk.
Jennie H. Fitch	Clerk.

The disbursement of the funds of the Coast and Geodetic Survey is made not only by payments directly from the Disbursing Agent, but also largely through the medium of its Assistants and other officers, when acting as chiefs of parties. These officers, on approval of the Superintendent, receive advances of public funds from the Disbursing Agent in lump sums, under authority of an Executive order dated March 26, 1886, as follows:

EXECUTIVE MANSION, *Washington, D. C., March 26, 1886.*

Under authority of section 3648 of the Revised Statutes of the United States, permission is hereby given that needful advances of money be made to officers of the Navy detailed to duty as chiefs of parties in the service of the United States Coast and Geodetic Survey, and to all Assistants, Sub-Assistants, and Acting Assistants, or officers of the Coast and Geodetic Survey acting as chiefs of parties and engaged under instructions from the Superintendent of such Survey upon any work or operations of said Survey.

No compensation shall be allowed for the disbursement of any moneys hereby authorized to be advanced, and the officers or persons authorized to receive and disburse moneys so advanced, shall be subject to all the terms, provisions, and conditions of law as to the custody, disbursement, and rendering of accounts of public money of the United States.

But no advances of money shall be made to a civilian chief of any party in the service of said United States Coast and Geodetic Survey, unless a bond of such civilian officer shall be given in the penal sum of $2 000 with two sureties who shall have qualified in that sum, and which bond shall contain the usual condition of the bond required by law from disbursing agents or clerks, and shall be approved by the Solicitor of the Treasury, and be filed in his office, and shall from time to time be renewed, strengthened, or increased, as the Secretary of the Treasury may direct.

GROVER CLEVELAND.

In conformity to this order there are now 57 officers of this Survey bonded in the sum of $2 000, or more, each. When acting as chiefs of parties these officers receive, from time to time, such advances of public funds from the Disbursing Agent as are required to meet the necessary current expenses of the work in hand.

A ledger account is kept in the office of the Disbursing Agent with each chief of party receiving an advance, each one being charged with all advances made to him, and on the other hand receiving credit for all proper expenditures made by him when presented on regularly supported vouchers, and after such accounts have been audited in the office of the Disbursing Agent and found to be correct. All of these accounts, with their supporting vouchers, are then sent to the First Auditor of the Treasury for examination and audit by him.

This system has met the needs of this service and results, in the main, in economy and good order in its expenditures.

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900.

[Prepared pursuant to sec. 264, R. S.]

SALARIES—PAY OF FIELD OFFICERS.

To whom paid.	Time employed.	Amount.
SUPERINTENDENT.		
Henry S. Pritchett	One year	$5 000·00
ASSISTANTS.		
Chas. 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
John F. Hayford	Eleven months and twenty-nine days	2 983·71
Erasmus D. Preston	One year	2 500·00
Cephas H. Sinclair	do	2 500·00
William Eimbeck	do	2 500·00
Frank D. Granger	do	2 500·00
L. A. Bauer	do	2 500·00
Frank Walley Perkins	do	2 091·23
J. J. Gilbert	do	2 200·00
Henry L. Marindin	do	2 200·00

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—PAY OF FIELD OFFICERS—Continued.

To whom paid.	Time employed.	Amount.
ASSISTANTS—continued.		
John F. Pratt	One year	$2 200.00
Edmund F. Dickins	....do	2 200.00
Dallas B. Wainwright	....do	2 200.00
Isaac Winston	....do	2 200.00
Wm. C. Hodgkins	....do	2 200.00
Philip A. Welker	....do	2 000.00
James B. Baylor	....do	1 989.13
John Nelson	....do	2 000.00
John A. Flemer	....do	1 383.33
Fremont Morse	....do	2 000.00
Stehman Forney	....do	2 000.00
Gershom Bradford	....do	2 000.00
Oscar W. Ferguson	....do	2 000.00
Walter B. Fairfield	....do	1 800.00
W. Irving Vinal	....do	1 800.00
George R. Putnam	....do	1 800.00
Fred. A. Young	....do	1 600.00
Ferdinand Westdahl	....do	1 600.00
Homer P. Ritter	....do	1 600.00
John B. Boutelle	....do	1 600.00
E. B. Latham	....do	1 400.00
Robert L. Faris	....do	1 400.00
Chas. C. Yates	....do	1 400.00
Geo. L. Flower	....do	1 200.00
Owen B. French	....do	1 102.18
John E. McGrath	....do	1 200.00
Edwin Smith	....do	1 200.00
William Bowie	....do	1 200.00
Harry F. Flynn	....do	1 200.00
Frank W. Edmonds	....do	1 200.00
Frank M. Little	Eleven months and nineteen days	1 160.76
AIDS.		
Hugh C. Denson	One year	900.00
R. B. Derickson	....do	900.00
Benj. E. Tilton	....do	900.00
Edgar R. Frisby	One year	900.00
H. W. Rhodes	....do	900.00
F. F. Weld	Eleven months and six days	838.87
Gurley S. Phelps	One year	364.89
Hugh C. Mitchell	....do	720.00
H. W. Vehrenkamp	One month twenty-three and one-half days	106.58
Clarence W. Noble	Eleven months and twenty days	698.53
Frank H. Brundage	Eleven months and fifteen days	688.75
Jno. A. Fleming	Eleven months and thirteen days	661.30
William H. Burger	Eleven months and eleven days	680.82
Royal J. Mansfield	Four months and fifteen days	269.90
Vladimir Sournin	Six months and fourteen days	388.71
Raymond C. Dennison	Fourteen days	27.39
Roscoe Severs	Four months	239.06
B. A. Baird	One month and eleven days	81.06
Walter C. Dibrell	Twenty-nine days	57.32
Expenditures		112 333.52
Appropriation		114 060.00
Expenditures		112 333.52
Unexpended balance		1 726.48

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—PAY OF OFFICE FORCE, 1900.

To whom paid.	Time employed.	Amount.
DISBURSING AGENT.		
Scott Nesbit	One year	$2 200·00
CHIEF OF DIVISION OF LIBRARY AND ARCHIVES.		
Edw. L. Burchard	One year	1 800·00
CLERKS.		
Wm. B. Chilton	One year	1 650·00
Nicholas G. Henry	do	1 650·00
John H. Smoot	do	1 000·55
W. C. Maupin	do	1 400·00
F. R. Green	Eight months and twenty-nine days	1 042·18
A. B. Simons	One year	1 400·00
J. Henry Roeth	do	1 247·23
Eugene B. Wills	One year	1 196·74
Sophie S. Hein	Four months and two days	407·62
Ida M. Peck	One year	1 200·00
Herbert M. Fitch	do	1 200·00
Geo. A. Fairfield	do	1 200 00
James M. Griffin	Seven months and twenty-nine days	776·10
John G. Townsend	One month and twenty-six days	187·92
Jennie H. Fitch	One year	1 000·00
Alice G. Reville	do	1 000·00
Patrick V. Dolan	Three months	228·18
Lily A. Mapes	One month and twenty-four days	149·50
CHART CORRECTORS.		
E. H. Wyvill	Four months and sixteen days	453·27
Henry R. Garland	One year	1 200·00
Lily A. Mapes	Seven months and fifteen days	746·73
Archie Upperman	Eight months	478·00
Mary L. Handlan	One year	720·00
Anna H. Welcke	Two days	4·00
Virginia E. Campbell	Three months and twenty-four days	228·00
WRITERS.		
Lily A. Mapes	Two months and twenty-two days	205·40
Kate Lawn	One year	900·00
Mary E. Campbell	Eight months	597·50
A. F. Zust	One year	877·23
Joseph B. Quinlan	do	906·03
Harlan C. Allen	do	827·19
Archie Upperman	Four months	268·90
R. D. Chase	Four months and seven days	254·30
Edgar W. Ford	Seven months and six days	428·13
George Baber	One month and twenty-nine days	117·70
W. H. Ward	One month and sixteen days	94·03
Peyton B. Fletcher	Two months and seven days	133·95
Joseph A. West	Twenty-three days	45·00
Elizabeth Wilson	Five days	9·78
Chas. C. Cooper	Six days	11·74
Calvin W. Jones	Five months and eight days	316·00
Wm. H. Davis	Five months and twenty-four days	346·00

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—PAY OF OFFICE FORCE, 1900—Continued.

To whom paid.	Time employed.	Amount.
WRITERS—continued.		
Jefferson H. Millsaps	Five months and twenty-seven days	$366.38
El. Bie K. Foltz	Four months and sixteen days	274.00
Eugene Meads	Sixteen days	31.65
Marie L. Baldwin	Four days	7.91
Mary A. Grant	One year	596.74
BUOY COLORISTS.		
Edward Belford	Six months and four days	368.00
A. B. Simons, jr	Five months and twenty-four days	346.00
DRAFTSMEN.		
Edwin H. Fowler	One year	2 400.00
Henry Lindenkohl	....do	2 200.00
Adolph Lindenkohl	....do	2 000.00
Wm. C. Willenbucher	....do	2 000.00
Ernest J. Sommer	....do	1 790.22
F. C. Donn	....do	1 800.00
David M. Hildreth	....do	1 800.00
Chas. C. Deetz	....do	1 400.00
Edmund P. Ellis	....do	1 400.00
John T. Watkins	....do	1 200.00
P. Erichsen	....do	1 000.00
Harlow Bacon	....do	1 000.00
Williams Welch	....do	1 000.00
James P. Keleher	....do	900.00
E. M. Sunderland	Fifteen days	36.68
Sully B. Maize	Eleven months and fifteen days	860.88
Charles Mahon	One year	700.00
COMPUTERS.		
John F. Hayford	Two days	13.04
Herman S. Davis	Four months and sixteen days	827.66
E. H. Courtenay	One year	2 000.00
Myrick H. Doolittle	....do	2 000.00
Leland P. Shidy	....do	1 800.00
Daniel L. Hazard	....do	1 600.00
Rollin A. Harris	....do	1 600.00
Frank M. Little	Twelve days	52.17
Albert L. Baldwin	One year	1 600.00
John C. Hoyt	Nine months and eight days	1 234.78
Artemas Martin	One year	1 400.00
Lilian Pike	....do	1 200.00
Wm. H. Dennis	....do	1 000.00
Deane S. Bliss	....do	1 000.00
Margaret Fawcett	Three months	250.00
Chas. R. Duvall	Eight months	665.80
COPPERPLATE ENGRAVERS.		
Wm. A. Thompson	One year	2 000.00
H. M. Knight	....do	2 000.00
Theodore Wasserbach	....do	1 994.57
Wm. H. Davis	....do	1 800.00
E. H. Sipe	....do	1 800.00
W. F. Peabody	....do	1 600.00
H. L. Thompson	....do	1 600.00
Wm. A. Van Doren	....do	1 400.00
Alfred H. Sefton	....do	1 198.37

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—PAY OF OFFICE FORCE, 1900—Continued.

To whom paid.	Time employed.	Amount.
COPPERPLATE ENGRAVERS—cont'd.		
Peter H. Geddes	One year	$1 200·00
Harry R. McCabe	Four months and eleven days	358·66
Wm. Mackenzie	One year	1 000·00
Geo. Hergesheimer	do	956·54
Frank G. Wurdemann	do	900·00
Wm. H. Holmes	do	900·00
Hugo Franke	do	900·00
Rowland H. Ford	do	813·00
Franklin Geoghegan	Six months and twenty-four days	395·65
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
Eberhard Fordan	do	1 000·00
Neil Bryant	do	1 000·00
Chas. J. Harlow	do	1 000·00
James L. Smith	Five months and eleven days	445·69
Chas. F. Locraft	One year	1 000·00
Wm. M. Conn	Six months and nineteen days	551·63
PLATE PRINTERS' HELPERS.		
Wm. M. Conn	Five months and twelve days	275·80
Chas. Buckingham	One year	697·15
R. J. Fondren	do	700·00
E. F. Campbell	do	700·00
Raoul F. Le Mat	Four months and nineteen days	272·24
INSTRUMENT MAKERS.		
Ernest G. Fischer	One year	1 800·00
Clement Jacomini	do	1 200·00
W. R. Whitman	do	1 000·00
M. Lauxmann	do	959·24
Thos. A. Gibson	do	900·00
J. A. Clark	do	900·00
CARPENTERS.		
Horace O. French	One year	1 200·00
Geo. W. Clarvoe	do	1 000·00
Chas. N. Darnall	do	1 000·00
WATCHMEN.		
David Parker	One year	880·00
J. W. Drum	do	880·00

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—PAY OF OFFICE FORCE, 1900—Continued.

To whom paid.	Time employed.	Amount.
FIREMAN.		
Horace Dyer	One year	$630·00
MESSENGERS.		
Thomas McGoines	One year	880·00
Charles Over	....do	820·00
Chas. H. Jones	....do	820·00
Wm. R. McLane	....do	820·00
Wm. H. Butler	....do	820·00
Wm. J. Diercks	....do	700·00
Attrell Richardson	....do	700·00
J. W. Hunter	....do	640·00
Owen E. McNeille	Eleven months and twelve days	602·50
Thomas E. Vaughn	Thirty days	52·17
Meredith Gilmore	Five days	8·70
Joseph E. Lee, jr	Two days	3·48
Ulysses Houston	Twenty-eight days	52·18
Peter H. Allen	Three days	5·33
Harrison Murray	Five months and twenty-four days	303·47
Lena Thatcher	Six days	10·55
J. H. Brown	One year	630·00
Belton D. Stewart	Thirty days	52·17
LABORERS.		
Frank Thomas	One year	628·29
Hans Bowdwin	....do	550·00
John H. Mason	....do	550·00
Virginia McGliney	....do	365·00
Samuel B. Wallace	Seven months	213·25
Floyd A. Stewart	One month and twenty-nine days	60·50
Leo. P. Wheat	One month and eight days	61.49
Expenditures		133 084·43
Appropriation		136 090·00
Expenditures		133 084·43
Unexpended balance		3 005·57

RECAPITULATION.

Pay of field officers	$112 333·52
Pay of office force	133 084·43
Expenditures	245 417·95
Total sum appropriated for salaries	250 150·00
Total sum expended for salaries	245 417·95
Unexpended balance	4 732·05

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1900.

TIDES, ETC.

To whom paid.	On what account.	Amount.
Chas. L. Beard	Services	$10·00
E. F. Dickins	Seattle tidal	57·00
W. R. Gherardi	San Juan tidal	39·00
S. L. Ginsburg	Services	1·50
F. A. Kummell	....do	391·67
F. M. Little	Erecting tide gauge at Philadelphia, Pa.	120·95
Aug. F. Rodgers	San Francisco tidal	1 012·49
J. J. Rooney	Services	5·00
L. P. Shidy	Washington tidal	32·72
J. G. Spaulding	Fort Hamilton tidal	1 056.42
United States Express Co	Transportation	11·30
B. W. Weeks	Fernandina tidal	601·88
Amount disbursed		3 339·93
Railroad accounts referred for settlement		·36
Expenditures		3 340·29
Appropriation		5 000·00
Expenditures		3 340·29
Unexpended balance		1 659·71

OFFSHORE WORK, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$1·10
D. Ballauf	Sounding machine and attachments	624·00
R. D. Chase	Services	582·05
E. F. Dickins	Coast pilot	166·74
H. L. Ford	Services	1 500·00
H. C. Graves	....do	1 648·40
James M. Griffin	....do	242·12
J. F. Pratt	Coast pilot	325·45
Talbot Pulizzi	Services	978·87
John Ross	Services and Coast Pilot	3 249·64
E. H. Wyvill	Services	933·47
Amount disbursed		10 251·84
Railroad accounts referred for settlement		78·25
Expenditures		10 330·09
Appropriation		10 100·00
Add 10 per cent transferred from Navy travel, etc		340·00
		10 440·00
Expenditures		10 330·09
Unexpended balance		109·91

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1900—Continued.

STATE SURVEYS, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$5·95
A. L. Baldwin	Base measurements	172·08
L. A. Bauer	Magnetics	3 000·96
J. B. Baylor	....do	611·72
Blue Line Transfer Co	Transportation	·75
W. H. Burger	Traveling expenses	48·21
M. G. Copeland & Co	Tents	70·00
Frank W. Edmonds	California boundary	73·50
Wm. Eimbeck	Triangulation	3 996·42
O. W. Ferguson	Precise leveling	2 483·39
J. A. Fleming	Magnetics	828·06
Stehman Forney	Reconnaissance	3 397·03
Geo. W. Knox Express Co	Transportation	·50
F. D. Granger	Triangulation	5 026·31
John F. Hayford	Traveling expenses	21·40
Danl. L. Hazard	Magnetics	556·85
John E. McGrath	Longitudes	477·77
A. T. Mosman	Storage and pasturage	33·00
Jas. A. Nicholson & Son	Tents	152·50
C. H. Sinclair	Longitudes	398·12
Edwin Smith	Longitude and magnetics	1 115·31
Benj. E. Tilton	Precise leveling	2 690·78
United States Express Co	Transportation	3·20
H. W. Vehrenkamp	Magnetics	16·15
Isaac Winston	Precise leveling	1 520·01
Amount disbursed		26 699·97
Railroad accounts referred for settlement		60·66
Expenditures		26 760·63
Appropriation		27 000·00
Expenditures		26 760·63
Unexpended balance		239·37

SAN FRANCISCO TIDE INDICATOR.

To whom paid.	On what account.	Amount.
Aug. F. Rodgers	Construction of tide indicator in San Francisco Harbor.	$4 593·00
Appropriation		4 593·00
Expenditure		4 593·00

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1900—Continued.

NAVY TRAVEL, ETC.

To whom paid.	On what account.		Amount.
J. B. Boutelle	Special survey and traveling expenses		$1 562·86
Owen B. French	Traveling expenses		26·40
J. J. Gilbert	do		52·85
W. C. Hodgkins	do		36·37
Thos. S. Hundley	do		10·40
Geo. Olsen	do		6·25
J. F. Pratt	do		98·80
Riley & Cowley	Repairing dragging machine		173·67
J. E. Shepherd	Traveling expenses		71·15
O. H. Tittmann	do		35·43
United States Express Co	Transportation		2·85
Eugene Veith	Traveling expenses		112·30
P. A. Welker	do		33·05
Ferdinand Westdahl	do		76·85
C. C. Yates	do		39·28
Fred. A. Young	do		8·00
Amount disbursed			2 346·51
Railroad accounts referred for settlement			462·50
Expenditures			2 809·01
Appropriation			3 400·00
Less 10 per cent transferred to offshore work, etc		$340·00	
Expenditures		2 809·01	
			3 149·01
Unexpended balance			250·99

OBJECTS NOT NAMED.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$2·50
Pedro Alvarez	Services as ship keeper	318·39
L. A. Bauer	Traveling expenses	676·15
E. L. Burchard	do	173·91
C. Caspersen	Services as ship keeper	41·61
Will Ward Duffield	Traveling expenses	24·30
C. Durm & Son	Storage	154·50
L. B. Friendt	Plans for constructing vessels	650·00
Chas. E. Hansen	Services as ship keeper	109·50
J. F. Heiberger, jr	Designs	35·00
Thos. Manning	Services	23·50
Eugene Mugnier	Oil for Schooner Quick	1·50
H. G. Ogden	Traveling expenses	26·30
Henry S. Pritchett	do	478.64
Aug. F. Rodgers	do	11·10
The Norris Peters Co	Reproducing designs	15·00
Chas. C. Yates	Traveling expenses	375·00
Amount disbursed		3 116·90
Railroad accounts referred for settlement		207·58
Expenditures		3 324·48
Appropriation		4 000·00
Expenditures		3 324·48
Unexpended balance		675·52

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1900—Continued.

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Tides	$3 339·93
Offshore work, etc	10 251·84
State surveys, etc	26 699·97
San Francisco tide indicator	4 593·00
Navy travel, etc	2 346·51
Objects not named	3 116·90
Amount disbursed	50 348·15
Railroad accounts referred for settlement	809·35
Expenditures	51 157·50
Total amount appropriated for party expenses, 1900	54 093·00
Total amount expended for party expenses, 1900	51 157·50
Unexpended balance	2 935·50

CLASSIFICATION OF EXPENDITURES FOR PARTY EXPENSES, 1900.

On what account.	Amount.
Triangulation	$12 775·52
Hydrography	3 009·53
Coast Pilot	9 704·99
Leveling	6 728·08
Magnetics	5 571·39
Geographic positions	1 433·55
Tidal operations	3 340·29
Base measurements	172·08
Construction of tide indicator	4 593·00
Plans for constructing vessels	650·00
Traveling expenses, transportation, etc	3 179·07
Total	51 157·50

REPAIRS OF VESSELS, 1900.

To whom paid.	On what account.	Amount.
J. B. Boutelle	Schooner Eagre	$123·66
E. F. Dickins	Steamer Gedney	133·77
Geo. Eiseman	Schooner Eagre	1 500·00
L. B. Friendt	Steamer Bache	500·00
Gas Engine and Power Co. and Chas. L. Seabury & Co., Consolidated.	Steamers Yukon and Delta	24·50
J. J. Gilbert	Steamers Fuca and Pathfinder	793·22
Wm. Gokey & Son	Schooner Eagre and launch Inspector	2 712·77
W. C. Hodgkins	Steamer Blake	5 094·57

Statement of expenditures of the United States Coast and Geodetic Survey for the fisca year ended June 30, 1900—Continued.

REPAIRS OF VESSELS, 1900—Continued.

To whom paid.	On what account.	Amount.
James Reilly Repair and Supply Co.	Steamer Pathfinder	$144·00
Marine Vapor Engine Co	Steam launch Inspector	172·50
Moran Bros. Co	Steamer Patterson	2 250·00
H.G. Ogden	Traveling expenses and schooner Transit.	885·91
E. L. Peacock	Steamer Patterson	50·00
F. W. Perkins	Steamer Pathfinder	3 967·90
J. F. Pratt	Steamers Gedney and Patterson	3 840·52
C. S. Rossiter & Co	Schooner Eagre and steamer Blake	180·00
Spedden Shipbuilding Co	Steamer Blake	5 603·97
Walter M. St. Elmo	Schooner Matchless	55·00
The Roberts Safety Tube Boiler Co.	Steam launch No. 28	400·37
W. Irving Vinal	Schooner Matchless and steamer Bache	724·19
D. B. Wainwright	Traveling expenses	45·00
P. A. Welker	Steamer Bache and launch 25	1 575·35
Ferd. Westdahl	Steamer McArthur	583·64
Wm. E. Woodall & Co	Steamer Gedney, schooners Eagre and Matchless.	5 270·68
Chas. C. Yates	Steamer Endeavor	55·75
Fred. A. Young	do	492·22
Expenditures		37 179·49
Appropriations		44 600·00
Expenditures		37 179·49
Unexpended balance		7 420·51

CLASSIFICATION OF EXPENDITURES FOR REPAIRS OF VESSELS.

Name of vessel.	Amount.
Steamer Bache	$2 230·75
Steamer Blake	10 788·54
Schooner Eagre	8 898·93
Steamer Endeavor	547·97
Steamer Fuca	4·50
Steamer Gedney	419·76
Steam launches Nos. 25 and 28	494·97
Steam launch Inspector	342·50
Schooner Matchless	993·47
Steamer McArthur	583·64
Steamer Pathfinder	4 900·62
Steamer Patterson	6 018·43
Schooner Transit	699·13
Steamers Yukon and Delta	24·50
Traveling expenses of inspection officers	231·78
Total	37 179·49

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PUBLISHING OBSERVATIONS, 1900.

To whom paid.	On what account.	Amount.
Arthur F. Belitz	Services	$1 000·00
Expenditures		1 000·00
Appropriation		1 000·00
Expenditures		1 000·00

GENERAL EXPENSES, 1900.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$167·24
A. Leitz Co	Repairs	2·60
American Arithmometer Co	Adding machine	350·00
American Engineer and Railroad Journal.	Subscription	·50
American Journal of Science	Book	6·00
American Radiator Co	Repairs	46·45
American Wood Working Machine Co., Williamsport Machine Co. Branch.	Carpenter shop	4·38
R. P. Andrews & Co	Stationery and contingencies	18·60
E. & H. T. Anthony & Co	Photograph supplies	6·60
D. Appleton & Co	Subscription	2·00
The Automatic Telephone Exchange Co., Limited.	Rent of telephone	140·50
Wm. Ballantyne & Sons	Stationery	16·18
R. Carter Ballantyne	....do	217·22
D. Ballauf	Contingencies	6·50
L. A. Bauer	Books	74·79
H. Baumgarten	Stationery, etc	17·54
J. Baumgarten & Son	....do	1·10
Bausch & Lomb Optical Co	Instruments and photograph supplies	53·59
Bell Manufacturing Co	Contingencies	7·00
John Bliss & Co	Books and charts	59·42
Blue Line Transfer Co	Transportation	1·95
Wm. Bond & Son	Instruments	307·00
Blum Bros	Contingencies	95·45
R. R. Bowker	Subscription	5·00
Andrew Bond	Books	25·00
Gershom Bradford	Traveling expenses	246·21
Andrew Braid	Office travel and stationery	14·20
Browne & Sharp Manufacturing Co.	Instrument shop	20·00
The E. F. Brooks Co	Contingencies	6·57
J. H. Bunnell & Co	Instrument shop	41·20
Bureau of Engraving and Printing	Printing supplies	1 179·61
Darius E. Burton	Carpenter shop, etc	13·62
Butters & Anderson	Instruments	170·97
Lew Callisher	Repairing clock	3·50
Capital Traction Co	Office travel	51·00
Louis P. Casella	Instruments	45·24
John Chatillon & Sons	....do	30·40
Chesapeake and Potomac Telephone Co.	Exchange rental and calls	91·30
R. P. Clarke & Co	Chart paper, carpenter shop, and contingencies.	1 968·96

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

GENERAL EXPENSES, 1900—Continued.

To whom paid.	On what account.	Amount.
Clendenin Bros	Copper and copperplates	$415·90
James Connor	Office horse	25·75
M. G. Copeland & Co	Repairs and contingencies	17·04
H. S. Crocker Co	Books	10·00
Joseph L. Crupper	Repairs and carpenter shop	31·80
John B. Daish	Fuel	722·60
John Daly	Repairs	4·00
F. W. Devoe & C. T. Raynolds Co	Stationery and drawing supplies	41·95
Doremus & Just Co	Instrument shop	2·00
Will Ward Duffield	Office travel	2·75
R. G. Dunham	Repairs, telephone	11·07
M. Du Perow	Electric supplies	7·04
W. J. Eck	Repairs	4·73
Economy Gas Lamp Co	Miscellaneous	52·85
Edmund P. Ellis	Office travel	1·60
Eimer & Amend	Photograph supplies and contingencies	35·29
Electric Storage Battery Co	Repairs and contingencies	84·07
Elliott Electric Blue Print Co	Drawing supplies	7·65
E. Morrison Paper Co	Stationery and printing supplies	3 269·76
The Engineering Magazine	Subscriptions	·75
Geo. T. Ennis & Co	Instrument shop	108·35
The J. C. Ergood Co	Instrument shop and contingencies	48·23
John B. Espey	Carpenter shop and instrument shop	296·26
The Evening Star Newspaper Co	Advertising and contingencies	13·87
Felt & Tarrant Manufacturing Co	Instruments	18·95
Forsberg & Murray	Repairs	17·50
General Electric Co	Electric supplies	10·20
Geological Publishing Co	Subscription	·87
Z. D. Gilman	Photograph and engraving supplies, etc	115·66
J. K. Glennon & Co	Transportation	·75
Goodell Co	Stationery	·10
F. D. Granger	....do	2·75
Henry J. Green	Instruments	204·50
Grimme, Natilie & Co	....do	123·80
The Grove Lime and Coal Co	Contingencies	7·10
Andrew B. Graham	Photolithographing	1 981·93
Wm. Hahan & Co	Contingencies	1·25
The Hanson & Van Winkle Co	Instrument shop	11·75
The Hartman Printing Co	Books	2·25
Jeremiah Hawkins	Extra labor	600·00
Hellman Oil Co	Instrument shop and contingencies	3·00
Mrs. A. Hellmuth	Washing	153·02
The Helman-Taylor Co	Subscription	5·00
G. H. Henderson	Extra labor	274·19
Norman W. Henley & Co	Books	3·00
J. Hillengass	Repairs	142·50
E. M. Hobson	....do	115·45
Wm. Hollingsworth	Instrument shop	25·00
Wm. H. Hoopes	Extra labor	138·08
The International Arithmometer Co	Book	1·00
James H. Johnson	Repairs	461·00
Jones & Laughlin, Limited	Carpenter shop and repairs	21·24
Jordan & Christie	Contingencies	23·00
M. E. Kahler	Instruments	69·90
G. Ashton Kay	....do	14·50
Thos. Keely	Contingencies	28·35
Kennedy & Schaefer	Repairs and contingencies	79·62
Keuffel & Esser Co	Instruments	34·45
Knickerbocker Ice Co	Ice	203·85

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

GENERAL EXPENSES, 1900—Continued.

To whom paid.	On what account.	Amount.
The Geo. W. Knox Express Co	Transportation	$84·55
Krag Manufacturing Co	Stationery and contingencies	6·41
J. H. Kuehling	Repairs	16·35
James B. Lambie	Carpenter and instrument shop and contingencies.	159·73
Lansburgh & Bro	Contingencies	94·55
Julius Lansburgh Furniture and Carpet Co.	....do	·55
W. H. Larmen	....do	7·00
Nannie D. Lee	Miscellaneous	2·25
Leland Faulconer Manufacturing Co.	Contingencies	·85
R. F. Le Mat	Extra labor	355·59
Lemcke & Buechner	Books and subscription	184·89
John Lengs Sons & Co	Instrument shop	·75
Library Bureau	Books and stationery	86·35
A. Lietz Co	Instruments	8·00
Melville Lindsay	Engraving supplies	18·56
J. B. Lippincott & Co	Books	4·50
W. H. Lowdermilk & Co	....do	100·25
Lowman & Hanford Stationery and Printing Co	Maps	1·80
Lutz & Co	Office horse	18·00
Mackall Bros	Electric and photographic supplies and contingencies.	186·87
The Macmillan Co	Books	2·88
M. E. Mann	Book	6·00
P. Mann & Co	Contingencies	2·40
Marine-Hospital Service	Engraving aud Printing supplies	6·15
The Marine Review Publishing Co.	Books	5·00
Matthiessen & Hegler Zinc Co	Zinc	223·72
F. P. May & Co	Contingencies	8·00
Clarence E. McCoy	....do	4·31
The McDermott Carriage Co	Office wagon	62·50
Geo. McLaine	Repairs	46·50
Meads & Reynolds	....do	1 100·00
W. H. Mehler	Repairs and contingencies	130·95
Chas. E. Miller & Bros	Contingencies	1·20
Francis Miller	Carpenter shop	53·91
F. J. Monrote	Instrument shop and repairs	17·50
Moore Bros	Typewriter supplies	·50
W. B. Moses & Sons	Office furniture and contingencies	358·83
J. L. Moss, financial agent, Newbury Library	Stationery	37·50
A. Muddiman & Co	Contingencies	13·74
Munn & Co	Books	7·00
N. Murray	Contingencies	15·50
Geo. F. Muth & Co	Drawing and engraving supplies and contingencies.	380·60
J. M. Myers	Stationery	60·00
National Disinfecting Manufacturing Co.	Contingencies	1·20
The National Electric Supply Co	Instrument shop and contingencies	2·55
J. P. Nawrath	Contingencies	3·20
New York Steel and Copper Plate Co	Copperplates	240·00
Thos. O'Brien	Contingencies	7·50
Otis Elevator Co	Repairs	6·05
John C. Parker	Stationery and contingencies	286·98
A. Persler & Sohn	Instruments	52·47

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

GENERAL EXPENSES, 1900—Continued.

To whom paid.	On what account.	Amount.
J. A. Pierpoint	Contingencies	$98·50
Chas. S. Platt	Instrument shop	20·18
Samuel I. Pope	Repairs	3 580·00
Postal Telegraph-Cable Co	Telegrams	5·24
Postmaster, Washington, D. C	Box rent	16·00
Professional Photograph Publishing Co.	Subscription	1·00
Publisher of Science	....do	5·00
E. J. Pullman	Photographic supplies	265·34
P. R. Pullman	Contingencies	48·00
Queen & Co	Drawing and photographic supplies	37·04
Rand, McNally & Co	Maps	10·47
John C. Rau	Repairs	125·80
Josephine Reed	Extra labor	180·00
Hugh Reilly	Printing supplies	30·98
Revenue-Cutter Service	Flags	19·25
E. S. Ritchie & Sons	Contingencies	20·00
Rochester Optical and Camera Co	Photographic supplies	40·31
Aug. F. Rodgers	Suboffice expenses	203·58
John Rome	Office horse	10·00
A. C. Rowe	Contingencies	276·00
Rudolph, West & Co	Carpenter shop and contingencies	103·88
Saks & Co	Contingencies	6·08
E. G. Schaefer & Co	Repairs and contingencies	28·28
Schmedtie Bros	Repairs to clock and instruments	24·25
Fred. A. Schmidt	Drawing and printing supplies	443·55
John Schonenburger	Stationery	2·15
Schumann & Co	Instrument shop	·58
M. Schuster	....do	1·25
Frank P. Serrin	Contingencies	10·00
Seth Thomas Clock Co	Instruments	124·80
Chas. W. Sever & Co	Stationery	10·79
B. F. Shaw	Office horse	290·68
Geo. A. Shehan	Carpenter shop	597·55
T. W. & C. B. Sheridan	Contingencies	22·50
Shoemaker & Busch	....do	5·98
M. Silverberg & Co	Carpenter shop and contingencies	35·09
Smith Premier Typewriter Co	Typewriter stand	4·50
Thos. W. Smith	Carpenter shop	106·20
Smithsonian Institution	Transportation exchange	107·25
Thos. Somerville & Sons	Repairs	4·42
C. F. Starke	Instrument shop	10·60
Standard Oil Co	Engraving supplies and contingencies	48·30
Gustav E. Stechert	Books and subscription	207·22
Hazard Stevens	Book	5·00
Sussfeld, Lorsch & Co	Instruments	336·00
Sutherland & Carr	Instrument shop and contingencies	4·50
Tilden Manufacturing Co	Stationery	13·25
Otto Toepfer	Instruments	518·03
James S. Topham	Contingencies	35·25
Richard Trostler	Extra labor	10·00
Max F. Trostler	....do	20·97
John H. Tyler	Contingencies	3·50
The University of Chicago Press	Book	4·00
United Typewriter Supply Co	Contingencies	64·85
United States Battery Co	Instrument shop	7·25
United States Electric Lighting Co	Electricity	48·89
United States Express Co	Transportation	33·61
United States Naval Institute	Book	3·50

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

GENERAL EXPENSES, 1900—Continued.

To whom paid.	On what account.	Amount.
Chas. C. Van Horn	Contingencies	$22·20
Wagner Typewriter Co	....do	73·50
Wallace & Menchino	Repairs	7·50
Washington Gaslight Co	Gas	1 297·80
Washington Post Co	Advertising	6·15
John Welsh	Repairs	65·00
Western Union Telegraph Co	Telegrams	399·86
Western Electric Instrument Co	Repairs, instruments	27·50
Louis Weule	Instruments and repairs	17·50
Williams, Brown & Earle	Contingencies	18·00
B. M. Winters	Extra labor	324·19
Woodruff Manufacturing Co	Stationery	51·20
Woodward & Lothrop	Contingencies	2·30
Wyckoff, Seamans & Benedict	Typewriter and contingencies	413·63
Amount disbursed		31 152·17
Accounts for stationery, etc., settled by Auditor		445·23
Expenditures		31 597·40
Appropriation		32 000·00
Expenditures		31 597·40
Unexpended balance		402·60

CLASSIFICATION OF EXPENDITURES FOR GENERAL EXPENSES, 1900.

On what account.	Amount.
Instruments, and repairs of same	$2 751·29
Instrument shop and carpenter shop	1 739·05
Drawing division	28·30
Books, maps, charts, and subscriptions	780·79
Copperplates and zinc	639·62
Chart paper	4 751·75
Engraving, printing, photolithographing, and electrotyping supplies	2 771·74
Photolithographing and printing from stone and copper	1 951·18
Stationery	1 457·43
Office horse and wagon	405·07
Transportation of instruments and supplies	395·35
Fuel	722·60
Gas	1 297·80
Electricity	45·29
Telegrams	405·10
Ice	203·85
Washing	153·02
Telephones	235·50
Miscellaneous expenses and contingencies of all kinds	1 973·06
Office furniture	474·19
Repairs	6 201·64
Extra labor	1 903·02
Traveling expenses (Office)	310·76
Total	31 597·40

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

SALARIES—OFFICE OF STANDARD WEIGHTS AND MEASURES, 1900.

To whom paid.	Time employed.	Amount.
INSPECTOR OF STANDARDS.		
Samuel W. Stratton	Eight months and four days	$2 029·91
ADJUSTER.		
Louis A. Fischer	One year	1 426·66
VERIFIER.		
Frank A. Wolff, jr	One year	1 500·00
MECHANICIAN.		
Otto Storm	One year	1 250·00
WATCHMAN.		
J. A. McDowell	One year	720·00
ASSISTANT MESSENGER.		
George Newman	One year	720·00
ADJUSTER'S HELPERS.		
Wiley Crist	One month and nineteen days	99·73
Norman P. Lake	Five months and sixteen days	342·79
Walter S. Rich	Two montns and fourteen days	148·35
Expenditures		8 237·44
Appropriation		9 410·00
Expenditures		8 237.44
Unexpended balance		1 172·56

CONTINGENT EXPENSES, OFFICE OF STANDARD WEIGHTS AND MEASURES.

MATERIALS AND APPARATUS AND INCIDENTAL EXPENSES.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$5·40
Herman Baumgarten	Contingencies	1·50
Blue Line Transfer Co	Freight	·35
J. Chatillon & Sons	Apparatus	3·88
R. P. Clarke Co	Contingencies	3·61
Joseph F. Collins	....do	35·00
M. Du Perow	Apparatus	8·92
Eimer & Amend	Apparatus and contingencies	20·86
Z. D. Gilman	Contingencies	3·20
Library Bureau	....do	20·75
Melville Lindsay	....do	9·57

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

CONTINGENT EXPENSES, OFFICE OF STANDARD WEIGHTS AND MEASURES—Cont'd.

MATERIALS AND APPARATUS AND INCIDENTAL EXPENSES—continued.

To whom paid.	On what account.	Amount.
Mackall Brothers	Contingencies	$28·00
W. H. Mehler	do	7·45
W. B. Moses & Sons	do	87·50
Geo. F. Muth & Co	do	4·65
Standard Oil Co	do	4·80
C. E. Stanton	Typewriter and contingencies	77·00
S. W. Stratton	Traveling expenses	126·90
The Carnegie Steel Co	Contingencies	15·00
The Geo. W. Knox Express Co	Transportation, freight, and drayage	22·18
Henry Troemner	Apparatus	10.80
United States Express Co	Transportation	6·43
Leonard Ward Electric Co	Apparatus	15·33
Frank A. Wolff, jr	Traveling expenses	18·35
Otto Wolff	Apparatus	221·92
Carl Zeiss	do	184·83
Expenditures		944·18
Appropriations		1 475·00
Expenditures		944·18
Unexpended balance		530·82

PARTY EXPENSES, 1898.

GULF COAST, ETC.

On what account.	Amount.
Railroad accounts referred for settlement	$4·51
Balance on hand, Report for 1898	455·95
Expended since, as above	4·51
Present unexpended balance	451·44

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitem.	Amount.
Gulf coast, etc	$4·51
Balance on hand, Report for 1899	9 478·92
Expended since, as above	4·51
Present unexpended balance	9 474·41

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1899.

ATLANTIC COAST, ETC.

To whom paid.	On what account.	Amount.
United States Express Co	Transportation	$0·50
Balance on hand, Report for 1899		188·01
Expended since, as above		·50
Present unexpended balance		187·51

TIDES, ETC.

To whom paid.	On what account.	Amount.
B. W. Weeks	Fernandina tidal	$0·64
Balance on hand, Report for 1899		1 590·94
Expended since, as above		·64
Present unexpended balance		1 590·30

OFFSHORE WORK, ETC.

To whom paid.	On what account.	Amount.
Quartermaster's Department, U. S. A.	Coal for steamer Blake	$135·80
Railroad accounts referred for settlement		8·35
Expenditures		144·15
Balance on hand, Report for 1899		241·86
Expended since, as above		144·15
Present unexpended balance		97·71

CALIFORNIA BOUNDARY.

To whom paid.	On what account.	Amount.
Aug. F. Rodgers	Boundary survey	$15·00
Railroad accounts referred for settlement		86·71
Expenditures		101·71
Balance on hand, Report for 1899		138·36
Expended since, as above		101·71
Present unexpended balance		36·65

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1899—Continued.

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitem.	Amount.
Atlantic coast, etc	$0·50
Tides, etc,	·64
Offshore work, etc	144·15
California boundary	101·71
Expenditures	247.00
Balance on hand, Report for 1899	2 997·32
Expended since, as above	247·00
Present unexpended balance	2 750·32

GENERAL EXPENSES, 1899.

To whom paid.	On what account.	Amount.
Harvard University	Books	$2·00
Lemcke & Buechner	do	·90
W. H. Mehler	Miscellaneous	10·00
Professional Photograph and Publishing Co.	Subscriptions	1·00
The Chesapeake and Potomac Telephone Co.	Telephone calls	·65
The Helman Taylor Co	Books	2·50
The Sugar Beet	Subscription	·50
United States Express Co	Transportation	2·15
Western Union Telegraph Co	Telegrams	3·28
Expenditures		22·98
Balance on hand, Report for 1899		83·18
Expenditures since, as above		22·98
Present unexpended balance		60·20

CONTINGENT EXPENSES, OFFICE OF STANDARD WEIGHTS AND MEASURES, 1899.

MATERIALS AND APPARATUS AND INCIDENTAL EXPENSES.

To whom paid.	On what account.	Amount.
Eimer & Amend	Contingencies	$5·00
Otto Wolff	Apparatus	34·65
Expenditures		39·65
Balance on hand, Report for 1899		534·07
Expended since, as above		39·65
Present unexpended balance		494·42

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1899 AND 1900.

PAY OF PROFESSIONAL SEAMEN.

To whom paid.	On what account.	Amount.
J. B. Boutelle	Pay of professional seamen	$780·00
E. F. Dickins	do	1 634·65
H. F. Flynn	do	526·00
J. J. Gilbert	do	1 030·00
W. C. Hodgkins	do	3 343·38
W. A. O'Malley	Services	1 260·00
F. Walley Perkins	Pay of professional seamen	2 578·00
J. F. Pratt	do	1 330·50
Wm. B. Proctor	Services	196·61
Aug. F. Rodgers	Pay of professional seamen	260·67
G. F. Thomae	Services	705·00
W. I. Vinal	Pay of professional seamen	625·00
P. A. Welker	do	825·50
Expenditures		15 095·31
Balance on hand, Report for 1899		15 158·16
Expended since, as above		15 095·31
Present unexpended balance		62·85

ATLANTIC COAST, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$24·55
Pedro Alvarez	Services	180·00
Baltimore and Ohio R. R. Co	Transportation	123·98
J. B. Boutelle	Combined operations, schooners Eagre and Matchless.	6 336·17
Wm. Bowie	Topography	484·49
F. J. Cardone	Oil for schooner Quick	2·00
M. P. Dimpfel	Storage	1·29
John W. Donn	Topography	4 761·20
M. Du Perow	Outfit, launch Rudy	32·00
Flint, Eddy & Co	Outfit, steamer Blake	62·90
W. B. Fairfield	Triangulation	1 002·00
J. A. Flemer	Topography	526·73
Geo. L. Flower	Combined operations, schooner Matchless	69·04
Harry L. Ford	Traveling expenses	46·90
Stehman Forney	Triangulation and topography	3 580·63
Geo. W. Knox Express Co	Transportation	23·57
Forsberg & Murray	Outfit for launch Rudy	42·64
O. B. French	Topography	360·90
Chas. E. Hansen	Services	283·60
S. J. Haislett	Tent	6·50
W. C. Hodgkins	Topography and hydrography, steamer Blake.	13 533·84
E. B. Latham	Triangulation	44·06
F. M. Little	Traveling expenses	93·15
H. L. Marindin	Hydrography and topography	934·63
J. E. McGrath	Topography	333·33
Moore Bros	Outfit, schooner Matchless	36·00

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued

PARTY EXPENSES, 1899 AND 1900—Continued.

ATLANTIC COAST, ETC.—continued.

To whom paid.	On what account.	Amount.
W. B. Moses & Sons	Outfit, launch Rudy	$7·00
Geo. F. Muth & Co	....do	2·25
Mutual District Messenger Co	Outfit, schooner Eagre	5·00
John Nelson	Triangulation and topography	6 309·83
W. C. F. Nespital	Services	90·00
C. W. Noble	Traveling expenses	1·30
H. G. Ogden	....do	179·38
Pennsylvania R. R. Co	Transportation	84·00
James F. Pfau	Services	180·00
E. D. Preston	Topography	148·81
Henry S. Pritchett	Traveling expenses	7·50
Wm. B. Proctor	....do	33·72
Miguel Portell	Storage	40·00
M. M. Ramsay, U. S. N	Contingent stores for vessels	302·13
Revenue-Cutter Service	Flags and bunting	257·44
Louis C. Ritchie	Traveling expenses	9·00
Gulian Ross	Signal lumber	162·50
Wm. Sanger	Traveling expenses	2·35
Sparrows Point Store Co	Purchase of launch	500·00
Fred'k Springman	Transportation	·63
Standard Oil Co	Oil for launch Rudy	4·75
Vladimir Sournin	Services	498·58
O. H. Tittmann	Traveling expenses	2·60
United States Express Co	Transportation	1·45
C. C. Van Horn	Outfit, launch Rudy	4·20
W. I. Vinal	Combined operations, schooner Matchless.	4 613·78
F. F. Weld	Topography	1 174·34
P. A. Welker	Combined operations, steamers Blake and Bache.	7 814·02
Williams, Brown & Earle	Outfit, launch Rudy	1·50
Wm. E. Woodall & Co	Storage and freight on launch	186·00
C. C. Yates	Hydrography, steamer Endeavor	2 466·66
Wm. H. Yerkes, jr	Purchase of launch	700·00
Fred. A. Young	Hydrography, steamer Endeavor	3 130·17
Amount disbursed		61 846·99
Railroad accounts referred for settlement		18·78
Expenditures		61 865·77
Balance on hand, report for 1899		56 651·64
Appropriation, sundry civil act, June 6, 1900		70 000·00
Total amount available		126 651·64
Expenditures as above		61 865·77
Present unexpended balance		64 785·87

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1899 AND 1900—Continued.

PACIFIC COAST, ETC.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$74.90
A. Lietz Co	Outfit, steamer Pathfinder	154.50
S. Applegate	Services	616.13
D. Ballauf	Deep-sea sounding machine	550.00
Bureau of Equipment, Navy	Coal for steamer McArthur	367.85
P. B. Castles	Services	319.35
R. J. Christman	....do	174.11
E. F. Dickins	Triangulation and hydrography, steamer Gedney.	3 524.72
Harry F. Flynn	Combined operations, steamer Pathfinder	1 576.10
E. H. Francis	Services	217.10
Gas Engine and Power Co., and Chas. L. Seabury & Co., consolidated.	Outfit, steamer Yukon	27.00
J. J. Gilbert	Combined operations, steamer Pathfinder	8 516.19
J. Kilpatrick	Storage	15.00
Chas. Lyman	Traveling expenses	14.95
Marine Vapor Engine Co	Outfit, steamer Pathfinder	173.20
Fremont Morse	Topography and hydrography	3 592.67
T. S. & J. D. Negus	Outfit, steamer Gedney	60.00
H. G. Ogden	Traveling expenses	106.20
W. A. O'Malley	Hydrography, steamer Patterson	1 283.99
Pacific Coast Co	Coal for Pathfinder	345.00
F. Walley Perkins	Combined operations, steamer Pathfinder	10 930.12
J. F. Pratt	Combined operations, steamers Gedney and Patterson.	10 873.41
M. M. Ramsay, U.S.N	Contingent stores for vessels	337.01
James Reilly Repair and Supply Co	Outfit, steamer McArthur	9.75
Revenue-Cutter Service	Flags and bunting	200.30
Homer P. Ritter	Combined operations	9 968.73
Aug. F. Rodgers	Hydrography and topography	655.36
J. F. Rutledge	Commutation	63.35
Fred'k Springman	Transportation	.21
W. E. Taliaferro	Services	76.25
G. F. Thomae	Triangulation and hydrography, steamer Gedney.	625.93
United States Express Co	Transportation	41.55
J. T. Watkins	Traveling expenses	41.30
Wells, Fargo & Co.'s Express	Transportation	23.15
Ferdinand Westdahl	Hydrography, steamer McArthur	7 032.06
Amount disbursed		62 587.44
Railroad accounts referred for settlement		596.00
Expenditures		63 183.44
Balance on hand, report for 1899		47 368.72
Appropriation, sundry civil act, June 6, 1900		107 500.00
Total amount available		154 868.72
Expenditures as above		63 183.44
Present unexpended balance		91 685.28

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

PARTY EXPENSES, 1899 AND 1900—Continued.

RECAPITULATION.

[Showing expenditures in gross by subitems.]

Subitems.	Amount.
Atlantic coast, etc	$61 846·99
Pacific coast, etc	62 587·44
Amount disbursed	124 434·43
Railroad accounts referred for settlement	614·78
Expenditures	125 049·21
Balance on hand report for 1899	104 020·36
Appropriation sundry civil act approved June 6, 1900	177 500·00
	281 520·36
Expenditures	125 049·21
Present unexpended balance	156 471·15

CLASSIFICATION OF EXPENDITURES FOR PARTY EXPENSES.

Subitems.	Amount.
Triangulation	$28 242·07
Topography	45 529·56
Hydrography	51 277·58
Total	125 049·21

SURVEY OF YUKON RIVER, ALASKA.

To whom paid.	On what account.	Amount.
E. F. Dickins	Office rent	$49·80
R. L. Faris	Combined operations	9 180·87
J. J. Gilbert	Office rent	48·85
J. F. Pratt	Combined operations and office rent	3 204·74
Geo. R. Putnam	Combined operations	8 959·65
Homer P. Ritter	Transferring steamer Taku	2 283·41
Expenditures		23 727·32
Balance on hand, report for 1899		25 089·07
Expended since, as above		23 727·32
Unexpended balance		1 361·75

Statement of expenditures of the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1900—Continued.

ALASKA BOUNDARY SURVEY.

To whom paid.	On what account.	Amount.
Adams Express Co	Transportation	$1·00
O. H. Tittmann	Boundary survey	115·65
United States Express Co	Transportation	1·00
Expenditures		117·65
Balance on hand, report for 1896		583·12
Expended since, as above		117·65
Present unexpended balance		465·47

GENERAL RECAPITULATION.

[Showing appropriations, expenditures, and balances for the fiscal year ended June 30, 1900, and for all other accounts included in this report.]

Name of appropriation.	Appropriated.	Expended.	Balances.
Salaries, 1900, sundry civil act, March 3, 1899:			
Pay of field officers	$114 060·00	$112 333·52	$1 726·48
Pay of office force	136 090·00	133 084·43	3 005·57
Party expenses, 1900, sundry civil act, March 3, 1899	54 093·00	51 157·50	2 935·50
Repairs of vessels, 1900:			
Sundry civil act, March 3, 1899 $29 600·00			
Urgent deficiency act, February 9, 1900 15 000·00			
	44 600·00	37 179·49	7 420·51
Publishing observations, 1900, sundry civil act, March 3, 1899	1 000·00	1 000·00	....
General expenses, 1900, sundry civil act, March 3, 1899	32 000·00	31 597·40	402·60
Salaries, Office of Standard Weights and Measures, 1900, legislative act, February 24, 1899	9 410·00	8 237·44	1 172·56
Contingent expenses, Office of Standard Weights and Measures, 1900, legislative act, February 24, 1899	1 475·00	944·18	530·82
Party expenses, 1898, balance on hand last report	9 478·92	4·51	9 474·41
Party expenses, 1899, balance on hand last report	2 997·32	247·00	2 750·32
General expenses, 1899, balance on hand last report	83·18	22·98	60·20
Contingent expenses, Office of Standard Weights and Measures, 1899, balance on hand last report	534·07	39·65	494·42
Party expenses, 1899 and 1900, balance on hand last report	15 158·16	15 095·31	62·85
Party expenses:			
Balance on hand last report $104 020·36			
Sundry civil act, June 6, 1900 177 500·00			
	281 520·36	125 049·21	156 471·15
Survey of Yukon River, Alaska, balance on hand last report	25 089·07	23 727·32	1 361·75
Alaska boundary survey, balance on hand report for 1896	583·12	117·65	465·47
Total	728 172·20	539 837·59	188 334·61

VI. OFFICE OF EDITOR OF PUBLICATIONS.

E. D. PRESTON, *Editor*.

Personnel.

Name.	Occupation.
Arthur F. Belitz................................	Stenographer.

A. ANNUAL REPORTS.

During the past year, besides editing the Transcontinental Triangulation, a volume of 871 pages, work has been done on three separate annual reports, with the object of bringing the publication of results of the Survey as near as possible up to date. The Report for the year 1897–98 was sent to the Public Printer on the 1st of September, and the last proof was read on the 9th of January, 1900; copies were received on the 13th of March.

The preparation of the Report for 1899 was taken up on the 1st of September and was complete on the 30th of June, 1900. It was sent to the printer on the 6th of July, 1900.

The half-yearly reports, July 1 to December 31, 1899, were written up for the Annual Report for 1900 between March 23 and May 3.

B. BULLETINS.

No new bulletins were published during the year, but a second edition of No. 36, "Table of Depths for Channels and Harbors, Coasts of the United States," was sent to printer on the 12th of February. On the 5th of March there was likewise sent to the printer a second edition of Bulletin No. 40, "Coast Pilot Notes of the Fox Island Passes, etc., Alaska."

C. COAST PILOT.

The following volumes were published during the year:
Supplement to the United States Coast Pilot, Atlantic Coast, Part IV.
Supplement to the United States Coast Pilot, Atlantic Coast, Part VIII.
Supplement to the United States Coast Pilot, Atlantic Coast, Part VI.
Supplement to the United States Coast Pilot, "Rules of the Road, etc."
Supplement to the United States Coast Pilot, Atlantic Coast, Parts I–II.
United States Coast Pilot, Atlantic Coast, Part IV, Third Edition.

D. TIDE TABLES.

The usual edition of the Tide Tables for the year 1901 was published, and a separate volume covering the Atlantic coast for the same period was also published for the first time.

E. NOTICES TO MARINERS.

The usual monthly notices to mariners, which contain the corrections to be put on existing charts, were sent out, and about 4 700 copies were distributed each month.

F. SPECIAL PUBLICATIONS.

Special Publication No. 3, an atlas of the Philippine Islands, was sent to the Public Printer on the 17th of November.

Special Publication No. 4 was submitted to the Superintendent on the 5th of September, 1899. It was edited and the illustrations were prepared between the 1st of January and the 28th of February, and the manuscript was sent to the printer on the 10th of March. The first proof was received on the 13th of April and the last on the 14th of August, and volumes were delivered on the 6th of October.

Special Publication No. 5.—This is a reprint of projection tables already published, the edition of which, however, was exhausted, and which it was necessary to republish for the use of the Survey and the public. It was sent to the printer on the 10th of March, 1900.

VII. OFFICE OF INSPECTOR OF WEIGHTS AND MEASURES.

ANDREW BRAID, *Assistant in charge of Office of Weights and Measures, July 1 to Oct. 27.*
S. W. STRATTON, *Inspector of Standards, Oct. 28 to June 30.*

Personnel.

Name.	Occupation.
L. A. Fischer	Adjuster.
F. A. Wolff, jr	Verifier.
N. P. Lake	Adjuster's helper (Oct. 28 to Apr. 16).
W. S. Rich	Adjuster's helper (Apr. 16 to June 30).
Otto Storm	Mechanician.
Jas. A. McDowell	Watchman.

The work of the Office of Standard Weights and Measures was divided into two general sections. The first dealt with the comparison of mass, length, and capacity; with the calibration and adjustment of the instruments used in such comparisons; and with the solution of problems which arose in connection with standards. The second section, which was assigned to electric measures, included the construction and comparison of standards, the calibration of measuring apparatus, and the solution of problems which arose in connection with such work.

SECTION I.

During the past year the usual number of thermometers, weights, tapes, and other length measures were verified for the Executive Departments and for private individuals and institutions. Part of the set of standard weights and measures for the State of Maine was put in order and compared, and the preparation of a set of metric standards for Porto Rico was begun.

At the request of the street commissioners of Boston, Mass., a 100-foot bench standard, built for the use of the city surveying department, was graduated in feet and meters and standardized. This work was accomplished in a satisfactory manner and at a trifling cost to the city compared with its value. Engineers and surveyors of that vicinity are now provided with ready means of verifying their tapes and chains, the accuracy of which is of prime importance in public and private surveys.

For the past ten years all length comparisons, except of tapes and base bars, have been made in the comparing vault under the sidewalk in front of the Coast and Geodetic Survey building. This temporary wooden structure had become useless owing to dampness, and for sanitary reasons it had to be torn down in July, 1899, thus leaving the Office without facilities for making comparisons of length measures from 1 to 0·1 meter. Accordingly the construction of a comparator having the desired range was begun, and the piers for it were built in the balance room of the Butler Building.

The following is an abstract of the work done by this division for outside parties during the year:

Thermometers compared	65
Single weights verified	20
Sets of weights verified	8
Tapes compared	69
Sugar flasks graduated and tested	772
Polariscope tubes adjusted and verified	04
Leveling rods compared	9
Magnetometer deflection bars verified	3
Sets of capacity measures verified	3
Standard meter compared	1
Barometer tested	1
Cubic-foot standards verified	2
Half-bushel measure verified	1
Quartz-control plate compared	1
Spring balances tested	2
100-foot and 30-meter bench standard graduated and standardized	1
Requests for information complied with	75
Total number of calls	1 337

SECTION II.

The legalization of the international electric units by Congress, in 1894, made it the duty of the Office of Standard Weights and Measures to provide facilities for the official verification of electric standards and measuring apparatus. Preliminary steps to provide the Office with the necessary facilities were taken soon after July, 1897, when the appointment of a verifier for that purpose was authorized. Considerable work was accomplished, and in March, 1900, the electricians were notified, through the principal technical journals, of the readiness of the Office to undertake the verification of certain kinds of measuring instruments in terms of the provisional standards adopted.

To avoid the delay which would naturally arise from the construction of primary mercury standards, it was decided to refer, for the present, all measurements of resistance to the mean value of a number of wire coils, known in terms of the best existing mercury standards. The general excellence of the Reichsanstalt type, the extremely small temperature coefficient, and thermo-electromotive power with respect to copper, and their permanency, led to the selection of manganin coils of the type mentioned.

A large number of Clark standard cells were set up with the purest material obtainable in the market, and a number were set up with material purified in this Office. The intercomparisons made indicate a most satisfactory agreement of all the cells on hand, well within 0·005 per cent. The mean electromotive force of the three dozen or more cells furnishes, therefore, a standard of reference which can be relied upon within this limit.

The Office is practically equipped to undertake the verification of a limited amount of the following classes of apparatus:

Resistance standards.—Coils of the following denominations: 1, 2, 5, 10, 100, 1 000, 10 000 ohms. Low-resistance standards for current measurements of the following denominations: 0·1, 0·01, 0·001, 0·0001 ohms. Resistance boxes; potentiometers, and ratio coils.

Standards of electromotive force.—Clark standard cells, and other standard cells.

Direct-current measuring apparatus.—Millivoltmeters and voltmeters up to 150 volts. Ammeters up to 50 amperes.

VIII. FIELD OPERATIONS.

A. COAST PILOT.

The Coast Pilot party, during the year, was engaged in both field and office work. During the month of August on board the steamer *Endeavor*, the party was collecting data in Long Island Sound and vicinity.

In the month of March, while the party was engaged in office work in Washington, Mr. John Ross took the field in order to obtain material for a report on the ports and waterways along the Atlantic coast, between Chesapeake Bay entrance and St. Augustine, Fla. This information was needed for the revision of Coast Pilot, Part VII.

B. GEODESY.

1. RECONNAISSANCE.

a. Middle Division.

Reconnaissance, that necessary part of geodesy before extended triangulation can be carried out, was executed in different parts of the United States, and also in the outlying territory. In Nebraska Assistant Granger continued the reconnaissance of the ninety-eighth meridian northward until sufficient points had been obtained for a complete season's work of observation of angles.

On the same scheme of work, that is to say, the triangulation along the ninety-eighth meridian, Assistant Forney executed reconnaissance in Texas. This work was carried on, for the purpose of determining available points for the triangulation which was to follow, and also for the location of certain base lines, which were demanded in order to verify the triangulation.

b. Division of Alaska.

In order to determine the availability of Scammon Bay as a harbor for deep-sea vessels, a reconnaissance was made, during the season of 1900, by Assistant Putnam. This required the determination of astronomic latitudes and longitudes, as well as the measurement of an azimuth. Much unfavorable weather was experienced. The determinations depend entirely upon observations of the sun.

c. Outlying Territory.

Before taking up the triangulation, topography, and hydrography of San Juan Harbor, Porto Rico, and of the islands in this vicinity, Assistant Boutelle made a reconnaissance in each of these different localities. This work brought to light a number of new facts, and aided materially in the prosecution of the subsequent work. Assistant Nelson, who was charged with the triangulation, base measurement, and other geodetic work on the island of Porto Rico, also made a reconnaissance for the particular needs of his work. It devolved upon Assistant Forney to make a reconnaissance for a triangulation across the island of Porto Rico, connecting the work near Ponce with that at San Juan, and a reconnaissance was made which covered the locality.

2. BASE LINES.

a. Middle Division.

Six base lines were selected and located by Assistant Forney on the ninety-eighth meridian triangulation, between the northern boundary of Texas and the Rio Grande. These were situated in the neighborhood of Bowie, Stephenville, Lampasas, Seguin, Hidalgo, and Alice, Tex.

b. Division of Alaska.

In order to begin a triangulation in the vicinity of Scammon Bay, Assistant Putnam measured a base line on the flats south of the Khun River, near its mouth, from which a rough triangulation was extended along the south side of the bay to Cape Romanzof. In order to control the triangulation of the Kwiklowak pass of the Yukon River four base lines were measured, having an average length of about 2 000 meters and a distance between the bases of from 10 to 30 miles. Four base lines were measured by Assistant Faris in his work at the mouth of the Yukon and along the adjacent coast. A great many of the lines forming the sides of the triangulation connecting these bases were only from 300 to 500 meters long. The length of the bases ranged from about 300 to 1 600 meters. A base line about 2 000 meters long was measured on the northwestern shore of Golofnin Bay by Assistant Pratt.

c. Outlying Territory.

A base line was measured at Great Harbor, Culebra, by Assistant Boutelle, and from this a triangulation was extended over the island and to the outlying rocks to the westward. A base line was measured by Assistant Nelson in the neighborhood of Boqueron, on the west coast of Porto Rico.

3. TRIANGULATION.

a. Eastern Division.

The work undertaken by Assistant French, on the coast of New Jersey, for the purpose of bringing the charts of this locality up to date, involved the execution of triangulation, which was carried on as the necessities of the case required during the entire season. Triangulation was executed on Chesapeake Bay, from the entrance of Eastern Bay to the Miles River, by Extra Observer Donn, and the triangulation of Miles River was pushed southward from Deep Water Pond. Between the 15th of September and the 24th of October the work was completed as far as the line Royal to Oak. The unfinished topography of the Miles River to the northward over the Wye River required a tertiary triangulation, which was executed by Extra Observer Donn during the season. Assistant Flemer carried on the triangulation on the west shore of Chesapeake Bay, from Bay Ridge to Curtis Point, including that of South River. The upper part of Chesapeake Bay was taken up by Assistant Vinal, and the triangulation expanded from the head of the bay to Port Deposit, and in Northeast River to the head of navigation. In the prosecution of his hydrographic work Assistant Welker executed a triangulation at the head of Eastern Bay. Toward the close of the fiscal year Assistant Welker took up the triangulation of Chesapeake Bay below the mouth of the Potomac River. In order to make a resurvey of the old main channel into Charleston Harbor, S. C., it was necessary to determine a number of points. The triangulation for this purpose was executed by Assistant Fairfield during the month of June, and the results were furnished to Assistant Vinal, who was charged with the hydrographic survey.

b. Middle Division.

From the 1st of July till the 28th of October, 1899, Assistant Granger continued his work on the ninety-eighth meridian, and during this time occupied seven primary stations. During the month of June Assistant Granger continued his work on the ninety-eighth meridian in the State of Nebraska. This work was in progress at the end of the fiscal year, and was being carried northward. Starting from the transcontinental triangulation, at the stations Wilson and Heath, Assistant Eimbeck carried the triangulation along the ninety-eighth meridian southward. Three stations were occupied during the season, from July 1 to November 23.

c. Western Division.

The triangulation around Rich's Passage and Port Orchard was executed by Assistant Dickins during the month of April. In the survey of Seattle Bay, by Assistant Gilbert, a secondary triangulation, based on the line Alger to Freeport was made. In the execution of hydrography from Point Penole to Marin Islands, triangulation was done by the party in charge of Assistant Westdahl. The primary triangulation of southern California was completed by Assistant Mosman. This now extends to the Mexican Boundary, and the work may be subsequently developed westward from any of the figures along the coast.

d. Division of Alaska.

Triangulation was executed in Alaska in the various localities occupied by the Coast and Geodetic Survey parties. By Assistant Putnam, at the mouth of the Yukon and on Scammon Bay; by Assistant Faris, at the mouth of the Yukon; by Assistant Pratt, in Golofnin Bay; by Assistant Ritter, on Copper River, and by Assistant Dickins, in making connection between Chatham and Rosario straits.

e. Outlying Territory.

Triangulation in Porto Rico was done by Assistant Boutelle, by Assistant Forney, and by Assistant Nelson. Assistant Hodgkins, operating on the steamer *Blake*, made a trigonometric connection between the island of Culebra and the longitude station established some years ago at Port Christian, St. Thomas, West Indies. All the triangulation executed by Assistants Boutelle and Hodgkins depends upon a base line near the head of Culebra Harbor, measured by Assistant Boutelle.

In making hydrographic and topographic surveys in the Hawaiian Islands, Assistant Perkins executed triangulation in the vicinity of Kahului Harbor and Kamalalaea Bay, Maui, Hilo Bay, Hawaii, and Kaunakakai Harbor, Molokai. This triangulation is all based upon the Hawaiian Government work previously executed.

4. ASTRONOMIC DETERMINATIONS.

During the month of October Assistant Sinclair, cooperating with Assistant McGrath, determined the longitude of Maricopa, Ariz., from the base station at El Paso. In connection with Assistant Putnam's work at the mouth of the Yukon and on Scammon Bay, seven latitude stations, seven longitude stations, and six azimuth stations were occupied. Observations were made for latitude and azimuth by Assistant Flynn, under the direction of Assistant Faris, near the Kawanak Pass of the Yukon River Delta. Astronomic observations were made by Assistant Pratt, at Cape Nome and in Golofnin Bay. Owing to continued cloudiness, however, only solar observations could be obtained. Azimuth observations were made by Assistant Forney, at station Latimer, in Porto Rico. An azimuth station was made at Great Harbor, Culebra, by Assistant Boutelle, and also by Assistant Nelson in the Boqueron Valley, Porto Rico. Azimuth observations were made at several points in the Hawaiian Islands, by Assistant Perkins, in connection with his magnetic work. The longitude of the International Geodetic Latitude Station, at Gaithersburg, Md., was determined during the month of August, by Assistants Smith and McGrath.

C. HYDROGRAPHY.

GENERAL STATEMENT.

Hydrographic operations have been continued during the year on the eastern and western coasts of Alaska, and in the outlying territory. By far the greater part of the work has been inshore hydrography, but a portion of the work of Alaska was so far from land as to be classified under the term "offshore work."

1. OFFSHORE WORK.

The steamer *Patterson*, under the command of Assistant Pratt, was engaged in hydrography in Bering Sea, between St. Michael and Cape Romanzof. The soundings were made beginning with the three-fathom curve.

2. INSHORE WORK.

a. Eastern Division.

Hydrography was executed on the Monomoy Shoals and off Boston Entrance, Massachusetts. A hydrographic survey was made during the early part of the fiscal year of the area extending from the west side of Governors Island, New York Harbor, to the Battery, and up the East River beyond Coenties Reef. A drag procured from the United States Engineers was brought into requisition, and by this means a sunken wreck was found off the South Ferry slip lying in about 30 feet of water, and having about 17 feet over it at its highest point.

The investigation of certain reported shoals and obstructions in the Delaware River was undertaken by Assistant Young. Signals were erected in the latter part of May, and the hydrographic work was carried on until the close of the fiscal year.

Hydrography was executed at the head of Chesapeake Bay, including the Susquehanna River, to Port Deposit, and the Northeast River to the head of navigation. Assistant Welker, in command of the steamer *Bache*, made supplemental surveys in the Patapsco River. Hydrographic operations were carried on in Bush River, Sassafras River, and Elk River by the steamer *Endeavor*, under command of Assistant Yates. A resurvey of the old main channel into Charleston Harbor was executed by Assistant Vinal on his return from Porto Rico.

b. Western division.

A survey of Rich's Passage, Port Austin, Wash., was made by Assistant Dickins, commanding the steamer *Gedney*. Soundings were made in the vicinity of San Francisco, from Point Penole to Marin Islands, from October to December, 1899. A hydrographic survey was also made by Assistant Westdahl, commanding the steamer *McArthur*, of the bar outside the Golden Gate.

c. Division of Alaska.

In connection with his general plan of operations in Alaska, Assistant Pratt, commanding the steamer *Patterson*, made a detailed hydrographic survey of Golofnin Bay. A hydrographic reconnaissance was executed in Scammon Bay and at the mouth of the Yukon in the Kwiklowak Pass by Assistant Putnam. Assistant Faris did hydrography in the neighborhood of St. Michael and in the Kwikpak and Kawanak passes. The mouth of the Copper River was explored hydrographically by Assistant Ritter.

d. Outlying Territory.

The operations carried out during the year in Porto Rico involved the execution of considerable hydrography. This was executed by Assistant Boutelle, commanding the schooner *Eagre*, in the harbor of San Juan and on the west shore of Culebra Island, by Assistant Vinal, commanding the schooner *Matchless*, in the harbor of San Juan, and by Assistant Hodgkins, commanding the steamer *Blake*, in the sound east of Culebra, including Mangrove Harbor.

In the Hawaiian group hydrography was executed by Assistant Perkins, commanding the steamer *Pathfinder*, at the port of Kahului, in Kamalalaea Bay, in

Kaunakakai Harbor, and between the islands of Maui and Kahoolawi. At Hilo a hydrograpic survey was also made by him, covering the harbor, the reef, and the approaches out to the 100-fathom curve.

D. HYPSOMETRIC.

1. EASTERN DIVISION.

Precise leveling was executed by Assistant Ferguson from Toledo to Cincinnati, Ohio, and from Covington to Corinth, in Kentucky.

2. MIDDLE DIVISION.

Aid Tilton continued leveling operations during the year from Cortland to Norfolk, Nebr., and on a side line 20 miles in length westward from Grand Island to the triangulation station Shelton. During the spring and early summer of 1900 the line was carried from Norfolk, Nebr., to Sioux City, Iowa. A side line 7 miles in length, to Hadir, Nebr., was also executed.

3. WESTERN DIVISION.

Assistant Winston continued the line of the previous season, beginning north of Denver and going as far as Rock Creek, Wyo., by way of Cheyenne.

E. MAGNETIC.

Magnetic observations were made and a number of valuable results were obtained in different localities. First of all may be mentioned the work carried out in the States of Rhode Island, Maryland, District of Columbia, Virginia, North Carolina, West Virginia, Ohio, Kansas, Colorado, Texas, and New Mexico. This was done under the immediate direction of Assistant Bauer, inspector of magnetic work, and comprised over 100 stations. Second, the work of Mr. D. L. Hazard in South Carolina, Georgia, Florida, Alabama, Kentucky, and Tennessee, including about 40 stations. At all these the regular series of determinations, including declination, dip, and intensity, were observed, and in many cases meridian lines were established. Assistant Preston continued the series of annual observations at Cherrydale, Va. Assistant Baylor occupied a number of county seats in Maryland, and also made magnetic observations at Cape Charles City, in connection with the total solar eclipse of May 28. Other observations in connection with the eclipse were made by Assistant Putnam at Wadesboro, N. C. About thirty stations were occupied in North Carolina by Assistant Baylor between July 1 and December 20. This work was done under the joint auspices of the Coast and Geodetic Survey and the North Carolina Geological Survey. Meridian lines were established from morning and afternoon sun observations, and the lines were marked with granite posts. While engaged in astronomic observations at Gaithersburg, Md., Assistant Smith began magnetic determinations during the month of November. These were continued weekly until the 4th of April, after which date the observatory was turned over to the party of Assistant Bauer. The programme included the regular observations for declination, dip, and intensity. Dip observations were continued weekly until the 22d of May, but the other elements were not observed after the middle of April. Three magnetic stations were occupied by Assistant Putnam in connection with his work at the mouth of the Yukon, in Alaska. Two additional ones were occupied by Assistant Faris in the same general locality. Five magnetic stations were occupied by Assistant Perkins in Hawaii, of which three, namely, Hilo, Lahaina, and Honolulu, were old stations previously occupied by Assistant Preston.

F. TIDAL.

1. TIDE OBSERVATIONS.

Tide observations were made in connection with hydrographic work by Assistants Vinal, Welker, and Yates in Chesapeake Bay; by Assistant Vinal in Charleston Harbor; by Assistant Dickins at Rich's Passage, Washington; by Assistant Westdahl in San Francisco Bay; by Assistants Pratt, Putnam, Faris, Ritter, and Dickins in Alaska; by Assistants Vinal and Hodgkins in Porto Rico, and by Assistant Perkins in Hawaii.

Automatic tide gauges have been in operation at New York, Philadelphia, Washington, and Fernandina on the eastern coast, and at San Francisco and Seattle on the western. Besides these a number of observations have been furnished by other parties, notably the United States Engineers and the Mississippi River Commission. Records from several foreign ports have also been received.

The tide indicators at Fort Hamilton, N. Y., and Reedy Island, Delaware, have continued to give satisfaction.

2. CURRENT OBSERVATIONS.

Current observations were made at Kahului Bay, Hawaii, by Assistant Perkins. The currents were studied by means of bottles, each carrying a flag, and so weighted that only an inch of the neck showed above the water. These were set adrift outside the mouth of the harbor, and for a considerable distance along the outer edge of the reef, and observations made upon them to determine the velocity and direction of the current.

Over 200 current stations were made by Assistant Pratt, incident to his hydrographic work in the North Bering Sea.

G. TOPOGRAPHIC.

1. EASTERN DIVISION.

In connection with the hydrography at Monomoy Shoals and Boston Harbor, topography was executed by Assistant Hodgkins, commanding the steamer *Blake*, during the summer of 1899. Similar work was done by Assistant French along the New Jersey coast, in connection with the revision of charts. Considerable topography was completed during the year on Chesapeake Bay; by Assistant Bowie at the north end of the bay, as far as Port Deposit and Northeast; by Extra Observer Donn in the vicinity of Kent Island and on the Miles and Wye rivers; by Assistant Flemer from Bay Ridge to Curtis Point; by Assistant Nelson on the Sassafras River and its tributaries; and by Assistant Vinal on the Elk River. On his return from Porto Rico, Assistant Vinal stopped at Charleston, S. C., where topographic work was done in connection with the hydrography of the old channel.

2. WESTERN DIVISION.

Topography in the vicinity of Seattle was executed by Assistant Gilbert in September. During the year three sheets were finished by Assistant Morse, in the vicinity of San Francisco.

3. DIVISION OF ALASKA.

The topography executed in Alaska was as follows: By Assistant Pratt, at Cape Dyer and on Golofnin Bay; by Assistant Putnam, on Scammon Bay and at the Kwiklowak mouth of the Yukon; by Assistant Faris, in the vicinity of St. Michael and at the mouth of the Yukon; by Assistant Ritter, on the Copper River.

4. OUTLYING TERRITORY.

The neighborhood of Great Harbor, Culebra, was surveyed topographically by Assistant Boutelle. Assistant Nelson carried on the same class of work, beginning in the neighborhood of Ponce and continuing along the coast to Mayaguez. The shore line of the harbor of San Juan was rerun and the topographic details mapped one-half mile back from the shore by Assistant Vinal. Assistant Hodgkins surveyed, during the season, a portion of the shore line of Culebra and the adjacent islands. In connection with his hydrographic work, Assistant Perkins executed shore-line topography in the Hawaiian Islands.

E. SPECIAL DUTY.

GENERAL STATEMENT.

Besides the regular work of the Survey, which is much the same in successive years, a number of special investigations are usually desirable and necessary. During the year several of these investigations led to important results, and it is proposed in this place to give a short account of the work and the results accomplished.

1. INSPECTION OF CHART AGENCIES.

With a view to getting information to improve the character of the charts, there was sent out during the previous fiscal year a circular to shipmasters and other nautical experts. The paper proposed certain questions to which answers were requested. Sixty-one replies came, and much information from the point of view of the public as to the character of the charts was obtained. Without attempting to give a summary of the replies to this circular, it may be said that the large majority suggested no essential change in the published chart. The information brought out led to instructions being issued to Assistant Bradford to make an inspection of the chart agencies along the coast, and to acquire all possible information from mariners and other parties interested in the subject. Assistant Bradford made a tour of the coast, visiting 45 places along the Atlantic and Gulf coasts. Conferences were had with officers of chambers of commerce and boards of trade. Valuable information on the subject of charts and chart making was obtained.

2. GRADUATION OF BENCH STANDARD.

At the request of the street commissioners of Boston, Mass., a graduation in feet and meters was made on their 100-foot bench standard.

3. BIBLIOGRAPHY OF THE SURVEYS OF MASON AND DIXON'S LINE.

A bibliography of the surveys of Mason and Dixon's line was prepared. This required a great amount of research, and fourteen towns and cities were visited in Pennsylvania, Maryland, and Delaware. Numerous libraries and city offices were examined, and many calls were made at newspaper offices and on historians.

4. SANITARY CONDITIONS IN PORTO RICO.

Availing himself of a sojourn on the islands of Porto Rico and Culebra, the surgeon of the schooner *Eagre* made a study of the sanitary conditions of both islands, and has submitted an interesting and valuble report thereon. Vital statistics for Porto Rico are given for the month of August, and a mortality table is furnished from 1890–1899, classifying all deaths under nine heads, from which it appears that nearly one-half of the deaths were from tuberculosis.

Of the island of Culebra the report speaks very favorably. The climate differs from Porto Rico by being somewhat cooler and less rainy. The general health of the people is good, but, as in Porto Rico, the prevalent diseases are consumption and rheumatism.

5. MISSISSIPPI RIVER COMMISSION.

While engaged on the survey of the Brunswick outer bar, Georgia, Assistant Marindin, as a member of the Mississippi River Commission, was called upon to attend the seventy-ninth session, at St. Louis. A tour of inspection was made from the last-named place to New Orleans.

6. PHILIPPINE ISLANDS.

While in command of the steamer *Pathfinder*, engaged in hydrographic and topographic work in the Hawaiian Islands, Assistant Perkins was detached to proceed to Manila and report on the conditions prevailing in that section as regards the work of this Bureau.

He reached Manila on the 4th of June, and remained until the 15th of July. The results of his studies are given in a series of letters and reports. His investigations covered the field of longitudes, tides, magnetism, triangulation, and topography.

7. SEISMIC OBSERVATIONS.

While engaged on his regular work on the Copper River, Alaska, Assistant Ritter had opportunity to observe a number of earthquakes, a list of which has been submitted with his season's report.

8. CONNECTIONS BETWEEN GRAVITY STATIONS IN EUROPE AND AMERICA.

Assistant Putnam received instructions on June 11 to make the necessary pendulum observations at Washington, London, Berlin, and Paris to suitably connect these primary stations. The work was done at the request of the International Geodetic Association, and at the close of the fiscal year the work had been completed at Washington and at Kew Observatory, in England. The party expenses were paid out of the funds of the Association.


UNITED STATES
COAST AND GEODETIC SURVEY
SKETCH OF GENERAL PROGRESS
JUNE 30 1900
Eastern Sheet
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
GULF OF MEXICO
ATLANTIC OCEAN
MAINE
NEW YORK
PENNSYLVANIA
OHIO
INDIANA
ILLINOIS
IOWA
WISCONSIN
MICHIGAN
MINNESOTA
KENTUCKY
TENNESSEE
NORTH CAROLINA
VIRGINIA
ARKANSAS
MISSISSIPPI
LOUISIANA
ALABAMA
GEORGIA
FLORIDA
CUBA
YUCATAN
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO


CO
SKETCH
105°
100°
95°
90°
85°
50°
45°
40°
35°
30°
NORTH DAKOTA
Bismarck
SOUTH DAKOTA
Deadwood
Pierre
MINNESOTA
St. Paul
St. Peters
Duluth
LAKE SUPERIOR
WISCONSIN
Fond du Lac
Milwaukee
Dubuque
MICHIGAN
LAKE MICHIGAN
LAKE HURON
Saginaw
Grand Rapids
Lansing
Detroit
Toledo
NEBRASKA
Yankton
Omaha
IOWA
Des Moines
Davenport
Rock Island
CHICAGO
Peoria
ILLINOIS
Keokuk
Quincy
Springfield
INDIANA
Fort Wayne
Logansport
Indianapolis
Terre Haute
OHIO
Columbus
CINCINNATI
Atchison
Topeka
Kansas City
KANSAS
MISSOURI
Evansville
Lexington
KENTUCKY
Cairo
TENNESSEE
OKLAHOMA
Guthrie
INDIAN TER
ARKANSAS
Little Rock
Helena
Memphis
Huntsville
Atlanta
Macon
MISSISSIPPI
Vicksburg
Jackson
Natchez
ALABAMA
Montgomery
Mobile
Pensacola
Dallas
Shreveport
LOUISIANA
Baton Rouge
NEW ORLEANS
Waco
TEXAS
Austin
San Antonio
Houston
Port Arthur
Galveston
Port Lavaca
Rockport
Corpus Christi
Eagle Pass
Laredo
Matamoras
Rio Grande
Monterey
GULF OF MEXICO
MEXICO
Tampico
Vera Cruz
Frontera
Campeche
Progreso
Cape Catoche
C. San Antonio
YUCATAN
Belize

9. COLLECTION OF DATA RELATIVE TO THE EARLY SURVEYS OF THE BOUNDARY OF CALIFORNIA.

In compliance with instructions of March 24, Assistant Edmonds undertook the collection of data relative to the early surveys of the southeastern boundary of California, and visited the offices of the United States surveyor-general at San Francisco and Sacramento, Cal., and at Reno and Carson City, Nev

10. INTERNATIONAL LATITUDE SERVICE.

The International Geodetic Association having undertaken the establishment of six latitude stations near the thirty-ninth parallel of north latitude, three of these stations were located within the United States. One was established at Gaithersburg, Md., one at Ukiah, Cal., and a third, which was not entirely at the expense of the Association, but merely subsidized, was located at the Cincinnati Observatory. The work at Gaithersburg, Md., and at Ukiah, Cal., is done under the general supervision of the Superintendent Coast and Geodetic Survey, acting for the association, and the expenses at these stations are paid by him out of funds furnished by the association. By authority of the Honorable Secretary of the Treasury, an Assistant of the Coast and Geodetic Survey, Mr. Edwin Smith, was detailed to carry out the work at Gaithersburg. At Ukiah, Cal., it was necessary to employ an observer, and the charge of the work was given to Mr. Frank Schlesinger. A detailed account of the methods of observation, and other considerations of a theoretical nature, will be found in Appendix No. 5 of this Report.

11. COMPARISON OF MAGNETIC INSTRUMENTS IN EUROPE.

In order to have a thoroughly reliable comparison of the Coast and Geodetic Survey magnetic instruments with those used in the European observatories, Assistant Bauer was charged with the task of carrying this project into effect. He left the United States in September and returned on the 19th of December. During this time he visited England, France, Germany, and Russia, and compared the instruments taken with him with the best standard instruments of these countries.

12. INVESTIGATION OF HYDROGRAPHIC METHODS.

Assistant Yates was charged with the examination of some of the principal hydrographic methods employed in England and Continental Europe. Leaving the United States in April, he was engaged until the close of the fiscal year in this work.

13. LOCATION OF CABLE.

It having been decided to lay a submarine cable between West Chop Light-House and Nobska Light-House, Vineyard Haven, Mass., an officer of the Coast and Geodetic Survey was detailed to determine its location at the time it was put down.

14. INVESTIGATION OF METHODS EMPLOYED IN THE MARCONI SYSTEM OF WIRELESS TELEGRAPHY.

Prof. S. W. Stratton, Inspector of Standards, Office of Weights and Measures, was directed to report to Admiral Farquhar, U. S. N., commanding the North Atlantic fleet, late in October, to witness the test by the Navy Department of the Marconi system of wireless telegraphy. Experiments were made on October 31 and November 1, communication being kept up between the U. S. steamers *New York* and *Massachusetts* and the shore station at Navesink, at distances varying from 1 to 35 miles.

15. CAPE CHARLES CITY SPEED TRIAL COURSE.

The Coast and Geodetic Survey steamer *Endeavor*, at the request of the Navy Department, laid out a speed trial course, in September, at Cape Charles City, Va.

16. LOCATION OF BUOYS ON CAPE CHARLES CITY SPEED TRIAL COURSE.

At the request of the Navy Department, an assistant of the Coast and Geodetic Survey was detailed, on March 26, to assist in the location of buoys at the ends of the trial course off Cape Charles City, Va.

17. CRUISE OF THE PATHFINDER.

The Coast and Geodetic Survey steamer *Pathfinder*, which was completed just before the beginning of the fiscal year, made the trip from Washington, D. C., to San Francisco, Cal., under the command of Assistant Perkins. The trip proved to be a successful and rapid one. A full description of the voyage, written by the commander, and accompanied by a chart showing positions and dates, is given in another part of this Report.

18. BRUNSWICK OUTER BAR.

A resurvey of the outer bar at Brunswick, which, according to law, was to be made by an officer of the Coast and Geodetic Survey under the direction of the Secretary of War, was executed by Assistant Marindin, between August and December, 1899. Assistant Marindin reported to the Secretary of War, through the Chief of Engineers, and received, on August 12, instructions to make the survey under the provisions of the river and harbor act of June 3, 1896, and as amended by the river and harbor act of March 3, 1899. The work continued until the middle of November, when the party returned to Washington. A report was submitted to the Secretary of War on the 4th of December.

19. ALASKA PROVISIONAL BOUNDARY.

On December 20, 1899, Assistant Superintendent O. H. Tittmann was appointed commissioner of the United States for the purpose of marking the temporary boundary line between Alaska and British Columbia, as defined by the modus vivendi agreed to by the United States and Great Britain under date of October 20, 1899.

After several conferences with the British commissioner, Mr. W. F. King, in Ottawa and Washington, the plan of work was adopted, and Mr. Tittmann left Washington on May 12.

Assistant O. B. French was assigned to duty under Mr. Tittmann's direction, as United States engineer, to execute the necessary field work. The Commission reached the field of work early in June and the work was in progress at the close of the fiscal year.

APPENDIX No. 1.

REPORT 1900.

DETAILS OF OFFICE OPERATIONS.

TABLE OF CONTENTS.

APPENDIX NO. 1.

DETAILS OF OFFICE OPERATIONS.

OFFICE OF THE ASSISTANT IN CHARGE.

Andrew Braid ....Assistant in Charge.

The Assistant in Charge of the Office is charged with the direct supervision of the routine work of the different divisions of the Office. Letters written by the division chiefs pass through the hands of the Assistant in Charge for approval and transmission to the Superintendent for his signature.

A considerable part of the work of the Coast and Geodetic Survey Office is the furnishing of data to the field parties and information to the general public. The letters from the general public may request information in regard to any detail covered by the work of the service.

The following persons were employed under the immediate direction of the Assistant in Charge:

Name.	Occupation.
Geo. A. Fairfield	Clerk.
A. B. Simons	Do.
Miss S. S. Hein	Clerk (July 1 to Nov. 3).
Miss Kate Lawn	Writer.
C. W. Jones	Do.
C. H. Jones	Chief messenger.
Attrell Richardson	Messenger.

A. COMPUTING DIVISION.

Personnel.

Name.	Occupation.
C. A. Schott	Chief of Division (July 1 to Dec. 31).
J. F. Hayford	Chief of Division after Jan. 1, 1900.
E. H. Courtenay	Computer.
M. H. Doolittle	Computer (July 1 to Dec. 31, and June 13 to 30).
Miss L. Pike	Computer (July 1 to Dec. 31).
A. L. Baldwin	Computer.
W. H. Dennis	Do.

A. COMPUTING DIVISION—Continued.

Personnel—Continued.

Name.	Occupation.
C. R. Duvall	Computer (Nov. 1 to June 12).
H. S. Davis	Computer (Feb. 13 to June 30).
J. H. Millsaps	Writer (Jan. 5 to June 30).
TEMPORARY FORCE.	
A. T. Mosman	Assistant (Jan. 26 to May 31).
Isaac Winston	Assistant (Jan. 29 to May 14).
O. W. Ferguson	Assistant (April 2 to May 31).
E. B. Latham	Assistant (April 24 to June 22).
F. M. Little	Assistant (June 11 to June 23).
J. E. McGrath	Assistant (July 1 to July 31, and Nov. 10 to Nov. 18).
W. H. Burger	Aid (Jan. 3 to June 9).

Assistant Charles A. Schott, who was appointed Chief of the Computing Division in 1855, and whose active service in the Coast and Geodetic Survey dates back to 1848, was relieved of the charge of this Division on the 1st of January, 1900, and this duty was assigned to Assistant J. F. Hayford.

During the first half of the fiscal year, while Assistant Schott remained in charge of the Computing Division, work was done on the transcontinental triangulation, the report for which was submitted on the 5th of September, 1899. After this date, until the 1st of January, attention was given to the preparation of a report on the oblique arc along the Atlantic coast. The work carried on by the different computers was largely of a routine nature, and consisted in the revision of star places, geodetic operations, abstracts of horizontal directions, etc.

During the last half of the fiscal year, as before mentioned, the Computing Division was in charge of Assistant J. F. Hayford, and the work continued much on the same lines as had been previously followed. The work of this Division, as stated by Mr. Hayford, falls naturally into four classes: (1) Supplying information of various kinds to field parties and to persons outside the Survey; (2) final computations or revisions of computations in connection with recent field operations; (3) computations which are necessary to reduce older fieldwork to a standard datum; (4) the preparation of results for publication.

Some idea of the amount of work involved in the first class may be had from the statement that during the month of February alone 180 descriptions of stations, many of them including sketches, and all accompanied by a statement of geographic positions, were furnished to various parties.

The two prominent pieces of work which were pushed with energy during the last half of the fiscal year were the computation of the triangulation in southeastern Alaska and the adjustment of the precise level net. The combined length of the level lines, of which the results were published for the first time in Appendix No. 8, Report for 1899, is over 2 800 kilometers. Of this, 1 300 kilometers was leveling done in 1899, and 1 500 kilometers was old leveling in which the office computations were either incomplete or had not been commenced on January 1, 1900.

B. DIVISION OF TERRESTRIAL MAGNETISM.

Personnel.

Name.	Occupation.
L. A. Bauer	Chief of division.
D. L. Hazard	Chief computer.
W. H. Davis	Clerk (Jan. 19 to June 30).
J. A. Fleming	Aid (temporary duty).
R. L. Faris	Assistant (temporary duty).

The establishment of a Division of Terrestrial Magnetism has brought about increased office duties in this line. During the fiscal year the final report on the magnetic survey of Maryland was made. The preparation was begun of magnetic declination tables for the use of surveyors.

The field computation of the current magnetic observations were revised. A new discussion of the secular variation of declination at stations where new values were available was also made. Original records were prepared for binding, including about 200 volumes.

The values of annual changes in declination, dip, and horizontal intensity were collected for all stations reoccupied since 1880. Two chapters were written for the report of the Magnetic Survey of North Carolina, one on the secular variation, the other on the distribution of the magnetic declination. Copy for the printer was prepared for the report just mentioned.

Miscellaneous computations and revisions were also carried on, and a list of the magnetic declinations at about 3 000 places, for publication in the Tide Tables for 1901, was prepared. Much time was devoted to the study of the plans of foreign magnetic observatories, and the preparation of plans and specifications for a magnetic observatory to be erected at Cheltenham.

C. TIDAL DIVISION.

Personnel.

Name.	Occupation.
L. P. Shidy	Chief of Division.
R. A. Harris	Computer.
J. C. Hoyt	Computer (appointed Sept. 23).
Artemas Martin	Computer.
D. S. Bliss	Do.
Margaret W. Fawcett	Computer (Aug. 2 to Oct. 31).
Alice G. Reville	Clerk.
Mary E. Campbell	Writer (July 1 to Feb. 28).
Virginia E. Campbell	Writer (appointed Jan. 23).
Mary A. Grant	Writer.
Fred A. Kummell	Tide observer (Nov. 6 to Jan. 3).
Frank H. Brundage	Aid (July 17 to Aug. 19).

The annual volume of Tide Tables for the year 1901 was prepared. Full predictions for Manila, P. I., have been introduced for the first time, thus making seventy-two tidal stations and two current stations for which full predictions are given. The harmonic constants used for predicting some of the ports have been greatly improved, a number of additional subordinate stations were introduced, and better values given for many old stations.

Nonharmonic reductions were made for thirty-seven stations, the equivalent of about five years of continuous records of high and low waters.

Harmonic analyses were completed for several short series of hourly heights, and several series of a year each have been partially analyzed, the total work being equivalent to the complete analysis of one year of continuous record.

A beginning was made in collecting together the harmonic tidal constants for the world, and although not completed at present, the list contains 248 stations, for which 503 years of harmonic analysis have been made.

The following tidal records were received during the year:

From the Maritime Exchange, at Philadelphia, Pa., one year's automatic gauge record at Reedy Island Quarantine Station, Delaware.

Three months of automatic gauge record at Great Fox Islands, Virginia, made in 1895.

From the United States engineers, records at the places named below and for the time stated: Fort Carroll, Patapsco River, Maryland, more than two years; Fort Sumter, Charleston Harbor, South Carolina, nearly four years; St. Simons Light, Georgia, one year; Brunswick Outer Bar, Georgia, one year and three months; Galveston, Texas, 3 years; Galveston Bar, Texas, one year; Galveston Entrance, Texas, one year; Morgans Point, Galveston Bay, Texas, one year.

From the Mississippi River Commission, the record at Biloxi, Miss., for three years.

From the commandant of the Puget Sound Naval Station, Bremerton, Wash., the record at that place from July 1 to January 15.

Tracings from the record of the automatic tide gauge at Honolulu, H. I., were received for the calendar years 1897, 1898, and 1899.

From the three foreign ports named below, tidal records were received for the periods specified: Manzanillo, Mexico, one month; Valparaiso, Chile, one year; Port Chalmers, New Zealand, one year.

A tracing for one month from the record of the automatic gauge at Recife Arsenal, Pernambuco, Brazil, was obtained.

In the last Annual Report some account was given of an attempt to partially explain the origin of the principal tides upon a rational basis. This work has since been continued by Dr. R. A. Harris, who has prepared Part IV—A of the Manual of Tides, which is published as Appendix No. 7 to this Report under the title "Outlines of Tidal Theory."

Fifteen years of automatic tide gauge records have been tabulated as hourly heights of the sea, ready for harmonic analysis. The plane of reference has been determined for 37 stations in San Francisco and San Pablo bays, California, by comparison of their observations with simultaneous tides at Sausalito, or the Presidio.

Tide notes were prepared for 205 stations on 64 charts. Requisitions from 17 field parties were filled, requiring descriptions of 208 bench marks, tidal data for 225 stations, and current data for 68 stations. Tidal information was called for by 121 persons not connected with the Survey, the response to which required the preparation of 237 descriptions of bench marks, current tables for 50 stations, and tidal data for 635 stations.

There were received, examined, and registered in the Tidal Division an aggregate of about thirty-one years of record from automatic tide gauges, together with 121 original and 113 duplicate volumes of tidal observations made by 17 hydrographic parties, and the record of the currents at 8 stations. About five years of tabulated hourly heights of the sea, with the times and heights of high and low waters, were also received.

D. DRAWING AND ENGRAVING.

Personnel.

Name.	Occupation.
W. W. Duffield	Chief of Division.
John H. Smoot	Clerk (July 1 to June 12).
James M. Griffin	Do.
George Newman	Messenger.
Hans Bowdwin	Laborer.
Edwin H. Fowler	Chief draftsman.
Harlow Bacon	Draftsman.
Chas. H. Deetz	Do.
F. C. Donn	Do.
E. P. Ellis	Do.
P. von Erichsen	Do.
D. M. Hildreth	Do.
Jas. P. Keleher	Do.
A. Lindenkohl	Do.
H. Lindenkohl	Do.
Charles Mahon	Do.
E. J. Sommer	Do.
E. M. Sunderland	Draftsman (July 1 to July 15).
J. T. Watkins	Draftsman (July 12 to May 31).
Williams Welch	Draftsman (July 1 to Nov. 21).
R. J. Christman	Do.
F. W. Hart	Do.
S. B. Maize	Do.
W. H. Davis	Engraver.
H. E. Franke	Do.
R. H. Ford	Do.
P. H. Geddes	Do.
Geo. Hergesheimer	Do.
W. H. Holmes	Do.
H. M. Knight	Do.
Wm. McKenzie	Do.
H. R. McCabe	Engraver (July 1 to Nov. 20).
W. F. Peabody	Do.
A. H. Sefton	Do.
E. H. Sipe	Do.
H. L. Thompson	Do.
W. A. Thompson	Do.
W. A. Van Doren	Do.
F. G. Wurdemann	Do.
Theo. Wasserbach	Do.
F. Geoghegan	Engraver (appointed Dec. 8).
D. N. Hoover	Foreman of printing.
C. W. Buckingham	Printer's helper.
W. M. Conn	Do.
R. J. Fondrèn	Do.
Eberhard Fordan	Plate printer.
C. J. Harlow	Do.

D. DRAWING AND ENGRAVING—Continued.

Personnel—Continued.

Name.	Occupation.
C. J. Locraft	Plate printer.
J. L. Smith	Plate printer (July 1 to Dec. 12).
E. F. Campbell	Do.
John H. Brown	Laborer (July 1 to July 3).
R. F. Le Mat	Extra laborer.
Frank Thomas	Laborer.
L. P. Keyser	Electrotyper and photographer.
Thomas Roy	Assistant electrotyper.
E. W. Ford	Clerk (July 24 to Sept. 1).
M. Gilmore	Messenger (Nov. 1 to Nov. 5).
U. Houston	Messenger (Nov. 6 to Dec. 5).
W. H. Hoopes	Laborer (Feb. 14 to May 8).
H. Murry	Laborer (appointed Jan. 8).
J. B. Quinlan	Clerk (Sept. 20 to Sept. 23).
Max Trostler	Extra laborer (May 15 to May 31).
R. J. Trostler	Extra laborer (June 25 to June 30).
T. E. Vaughn	Messenger (Aug. 22 to Oct. 10).
TEMPORARY FORCE.	
F. F. Weld	Aid (Dec. 8 to Jan. 4).
R. L. Severs	Aid (Dec. 19 to June 30).
C. W. Noble	Aid (July 13 to July 21).
R. J. Christman	Draftsman (Feb. 20 to May 21).
F. W. Hart	Draftsman (Aug. 24 to Sept. 12).
W. C. F. Nespital	Draftsman (Dec. 28 to Jan. 25).
V. Sournin	Draftsman (June 11 to June 30).

The Drawing and Engraving Division is one of the important divisions of the Office. The work was divided into four sections, namely, the Drawing, Engraving, Printing, Photographing and Electrotyping sections. Each one of these had its own particular work, and all the work was coordinated to bring about the completion of finished charts.

During the year 287 calls for information were made upon the Division, involving areas, shore lines, distances between various points, tracings from original topographic and hydrographic sheets, copies of old and canceled charts, construction of special maps, negatives, blue prints, etc.

1. DRAWING SECTION.

In the Drawing Section a number of new features were introduced during the year which greatly facilitated the work and economized time and labor. Prominent among these features may be mentioned the "history sheets," on which are preserved, in compact form, records of all materials and authorities embodied in new charts. Every detail and authority used upon charts published by this Office is here shown. These sheets enable the Chief of the Division to determine at once the date on which any correction was applied and the authority for such correction. The history sheets are a most important addition to the records of the Section.

Another feature of the records initiated during the year is the card index of original sheets, which contains a history of all sheets and schemes for charts and which shows what is required in the way of inking, lettering, approval, etc., to complete the sheet. As soon as the original sheet is finally approved, or the drawing for a new chart is completed, its card is removed from the index and filed. This feature is found to be a great timesaver and, taken in connection with the history sheets and the standard proof upon which the details of the correction are shown, completes such a record of the charts and sheets as will enable anyone in future years to determine the history of each chart.

There were an unusually large number of charts drawn during the year. A complete record of the occupation of each draftsman is kept on the files of the Office.

The following drawings have been completed during the year for photolithographing and engraving:

Chart No.	Title.	Scale.
549	Patapsco River, Maryland	1–40 000
908	San Juan Harbor, Porto Rico	1–10 000
909	Jobos Harbor, Porto Rico	1–20 000
1000	Cape Sable to Cape Hatteras	Mercator.
1001	Chesapeake Bay to Jupiter Inlet	Mercator.
1002	Straits of Florida and Approaches	Mercator.
4202	Guam Island	1–80 000
6140	Columbia River Entrance	1–40 000
8281	Sitka Sound and Olga Strait	1–40 000
8282	Salisbury Sound to Hooniah Sound	1–40 000
8833	Port Moller, Alaska	1–80 000
8995	Pribilof Islands, Alaska	1–200 000
9008	Dutch Harbor, Alaska	1–10 000
9302	Bering Sea, Eastern Part	Mercator.
9380	Norton Sound, Alaska	1–400 000
9381	Port Safety, Alaska	1–15 000

Three hundred and ninety-three charts were revised, corrected, and verified for new editions or reprints. Forty-six topographic and thirty-five hydrographic projections have been constructed for the use of the Office or field parties, and six projections have been made on copper plates. Three hundred and thirty-one topographic and hydrographic sheets were in hand for lettering, inking, platting, or revision. Clarke's spheroid projection was applied to thirty-one old sheets.

2. ENGRAVING SECTION.

This Section has been under the personal charge of the Chief of the Drawing and Engraving Division. A number of original plates were completed and plates for new editions of charts.

The following original plates were completed:

Chart No.	Plate No.	Title.	Scale.
254	2583	Deep River to Higganum	1–20 000
256	2585	Rocky Hill to Hartford	1–20 000
445	2600	Charleston and vicinity	1–20 000
5002	2507	San Diego to Point St. George	Mercator.
5052	2527	San Francisco to Cape Flattery	Mercator.

The following plates for new editions of charts were corrected:

Chart No.	Plate No.	Title.	Scale.
A	2569	Cape Sable to Cape Hatteras	1-1 200 000
S	2363	San Francisco to Bering Sea	1-3 000 000
T	2632	General Chart of Alaska	1-3 600 000
11	2593	Cape Hatteras to Cape Romain	1-400 000
12	2592	Cape Romain to St. Marys Entrance	1-400 000
19	2208	Mobile Bay to Atchafalaya Bay	1-400 000
20	2150	Atchafalaya Bay to Galveston	1-400 000
52	2552	Montauk Point to New York	Mercator.
104	2516	Penobscot Bay	1-80 000
108	2576	Wells to Cape Ann	1-80 000
111	2393	Nantucket Sound and approaches	1-80 000
120	2613	New York Bay and Harbor	1-80 000
126	1935	Penns Neck to Philadelphia	1-80 000
131	2536	Entrance to Chesapeake Bay	1-80 000
136	2602	Magothy River to head of bay	1-80 000
137	2131	Cape Henry to Currituck Beach	1-80 000
142	2577	Roanoke Island to Hatteras Inlet	1-80 000
147	2624	Core Sound to Bogue Inlet	1-80 000
149	2129	Old Topsail Inlet to Cape Fear	1-80 000
150	1989	Masonboro Inlet to Shallotte Inlet	1-80 000
152	2092	Murrell Inlet to Cape Romain	1-80 000
153	1936	Cape Romain to Isle of Palms	1-80 000
154	1910	Isle of Palms to Hunting Island	1-80 000
169	2187	Newfound Harbor Key to Boca Grande Key	1-80 000
190	2614	Round Island to St. Joseph Island	1-80 000
191	2455	Lakes Borgne and Pontchartrain	1-80 000
192	1941	Chandeleur and Breton Island sounds	1-80 000
202	2339	Calcasieu Pass to Sabine Light	1-80 000
204	2607	Galveston Bay	1-80 000
209	2605	Aransas and Topano bays	1-80 000
250	2456	Eastern Entrance to Nantucket Sound	1-40 000
353	2619	Narragansett Bay	1-40 000
369[4]	2601	Hudson and East rivers	1-10 000
400	2407	Hampton Roads, Va	1-20 000
401[a]	2123	Hampton Roads to Point of Shoals	1-20 000
420	2625	Beaufort Harbor	1-40 000
421	2096	Core Sound and Straits	1-40 000
425	2037	Reeves Point to Wilmington	1-40 000
428	2450	Winyah Bay	1-40 000
431	2472	Charleston Harbor	1-20 000
445	2600	Charleston and vicinity	1-20 000
453	2610	Fernandina Entrance	1-20 000
465	2627	Legare Anchorage	1-20 000
469	2628	Key West Harbor	1-50 000
490	2609	Entrance to Pensacola Bay	1-30 000
520	2610	Galveston Entrance	1-20 000
5052	2527	San Francisco to Cape Flattery	Mercator.
5143	2038	Wilmington and San Pedro harbors	Various.
5525	2563	Mare Island Strait	1-10 000
6100	2276	Cape Lookout to Grays Harbor	1-200 000
6451	2595	Commencement Bay and City of Tacoma	1-20 000
8000	1880	Dixon Entrance to Cape St. Elias	1-1 200 000
8500	1133	Icy Bay to Semidi Islands	1 1 200 000
12	2316	Progress sketch (suspended)	
15	2435	Progress sketch (suspended)	
15	2451	Progress sketch (suspended)	

The corrections on a great number of plates for new editions of charts were commenced and some original plates were unfinished at the close of the fiscal year.

The following recapitulation shows in brief the work done in the Engraving Section:

Plates for new charts completed	6
Plates for new editions of charts corrected	58
New miscellaneous plates completed	3
Plates for new charts commenced	2
Plates for new editions of charts, correction commenced	61
New miscellaneous plates commenced	3
Chart plates corrected for printing	917
Miscellaneous plates corrected for printing	17
Plates in progress, not completed:	
For new charts	11
For new editions of charts	27

3. PRINTING SECTION.

The total number of impressions was about 64,000, which went to the Chart Division. Some others were distributed for proofs, verification, standards, etc.

The following charts have been published by photolithography during the year:

NEW CHARTS.

No.	Title.	Scale.
549	Approaches to Baltimore Harbor	1-40 000
908	San Juan Harbor, Porto Rico	1-10 000
909	Jobos Harbor, Porto Rico	1-20 000
1000	Cape Sable to Cape Hatteras	Mercator.
1001	Chesapeake Bay to Jupiter Inlet	Mercator.
3095	Glacier Bay, Alaska	1-200 000
4202	Guam Island	1-80 000
5002	San Diego to Point St. George	Mercator.
5052	San Francisco to Cape Flattery	Mercator.
8281	Sitka and Salisbury Sounds	1-40 000
8282	Salisbury Sound to Hooniah Sound	1-40 000
8838	Port Moller and Herendeen Inlet	Mercator.
8995	Pribilof Island, Alaska	1-200 000
9008	Dutch Harbor, Alaska	1-10 000
9380	Norton Sound, Alaska	1-40 000

NEW EDITIONS.

No.	Title.	Scale.
244	Salem Harbor and approaches	1-20 000
249	Buzzards Bay	1-40 000
252	New Bedford Harbor and approaches	1-20 000
257	Cornfield Point to Duck Island	1-10 000
264	North Shore, Long Island Sound	1-10 000
270	Little Captain Island to Rye Rock	1-10 000
358	Block Island	1-10 000
369[8]	Hudson River, Fifty-third street to Fort Washington	1-10 000
454*a*	St. Johns River Entrance to Jacksonville	1-30 000
518	Calcasieu Pass	1-20 000
519	Sabine Pass, Texas	1-20 000
910	Porto Rico	1-400 000
3093	Territory of Alaska	1-1 200 000
4100	Hawaiian Islands	1-600 000
5052	San Francisco to Cape Flattery	Mercator.
5476	Pfeiffer Point to Cypress Point	1-40 000
5832	Humboldt Bay, California	1-30 000
5971	Coquille River Entrance	1-10 000
6088	Nastugga Bay, Oregon	1-10 000
8000	Dixon Entrance to Cape St. Elias	1-1 200 000
8174	Port Protection, Alaska	1-20 000
8216	Fenshaw Bay and Cleveland Passage	1-1 200 000

NEW PRINTS.

No.	Title.	Scale.
482	Cuba	1-1 200 000
9370	Cape Dyer to St. Michael	1-300 000

The following charts were published by photolithography, and sent to the Chart Division for distribution:

NEW CHARTS.

No.	Title.	Scale.
5002	San Diego to Point St. George	Mercator.
5052	San Francisco to Cape Flattery	Mercator.

NEW EDITIONS.

No.	Title.	Scale.
T.	General Chart of Alaska	1-3 600 000
445	Charleston and vicinity	1-20 000
6140	Columbia River entrance	1-40 000
6400	Seacoast and interior waters of Washington	1-300 000
8500	Icy Cape to Semidi Islands	1-1 200 000

In addition to the foregoing, the following special publications were published by photolithography:

Topographic sheet No. 2371, Chilkat Valley, scale 1-80 000.
450 copies of three designs for Coast Survey uniforms.
1 100 modus vivendi maps.
615 copies of metric cross section paper.

4. PHOTOGRAPHING AND ELECTROTYPING SECTIONS.

The work in the photographic rooms has been varied. Negatives have been made on glass and paper. Van Dyke prints, as well as blue, silver, bromide, and velox, have been printed. Many of the photographs have been mounted, and a large number of films developed. Thirty-two lantern slides were also made.

About 2 200 pounds of copper were deposited in the electrotyping rooms. Forty basso plates and thirty alto plates were finished during the year.

E. CHART DIVISION.

Personnel.

Name.	Occupation.
Gershom Bradford	Inspector of Charts and Chief of Division.
Miss L. A. Mapes	Chief of chart section.
W. C. Willenbucher	Draftsman.
E. H. Wyvill	Chart corrector.
H. R. Garland	Do.
Neil Bryant	Clerk.
P. V. Dolan	Clerk (July 1 to Sept. 22).
J. B. Quinlan	Clerk (Sept. 23 to June 30).
Miss M. L. Handlan	Buoy colorist.
Edward Belford	Buoy colorist (July 1 to Jan. 4).
A. B. Simons, jr	Buoy colorist (Jan. 8 to June 30).
Archie Upperman	Map mounter.
O. E. McNeill	Messenger (July 1 to June 12).

The Inspector of Charts, in addition to the supervision of the work of the Division, gave personal attention to the final inspection of new charts and new editions in their various stages of progress. The work of the Division was divided into two sections, the Chart Section and the Hydrographic Section.

1. CHART SECTION.

In this section all correspondence was carried on, and the bookkeeping relating to the business of the sales agents was done. Corrections to printed charts were made before they were issued to the different parties requiring them.

Besides the duties just mentioned, auxiliary ones, such as coloring, mounting, etc., were performed.

Bulletin No. 36, a Table of Depths for Channels and Harbors of the United States, was prepared, as well as a new edition of the Title and Notes for Charts. Several schemes for new charts were made, and studies of other charts already existing were made with a view to their improvement.

Omitting the years 1898 and 1899, during which the issue of charts was abnormally large, a comparison with issues during the past ten years shows that during the year 1900 the total issue was 19 per cent larger than the average. The free distribution was 16 per cent larger than the average, and the net sales were greater by 23 per cent, both in copies and in value.

Nine hundred and ninety-four copies of the Chart Catalogue were distributed. A new edition of this Catalogue is in preparation.

Twelve chart agencies were established during the year, while 1 was discontinued, leaving the total number of agencies now existing 171. The following table shows the issue of Coast Pilots and Tide Tables to the agencies:

United States Coast Pilot, Atlantic coast	1 063
Pacific Coast Pilot, California, Oregon, and Washington	44
Pacific Coast Pilot, Alaska, Part I	65
Tide Tables, United States and foreign ports	941
Tide Tables, Pacific coast	5 202

There were delivered to this section for issue 16 new charts and maps, all printed by lithography, viz:

Catalogue No.	Title.	Date.
		1899.
3095	Glacier Bay, Alaska	July 18
8995	Pribilof Islands, Alaska	Aug. 18
		1900.
909	Jobos Harbor, Porto Rico	Jan. 12
4202	Guam Island	Do.
8281	Sitka Sound to Salisbury Sound	Jan. 18
5052	San Francisco to Cape Flattery	Feb. 21
5002	San Diego to Point St. George	Mar. 28
549	Approaches to Baltimore Harbor	Apr. 13
1000	Cape Sable to Cape Hatteras	Apr. 26
908	San Juan Harbor, Porto Rico	May 14
8282	Peril Strait, Salisbury Sound to Hooniah Sound, Alaska	Do.
9380	Norton Sound, Alaska	June 4
9381	Port Safety, Alaska	June 11
1001	Chesapeake Bay to Straits of Florida	June 20
8833	Port Moller to Herendeen Bay	Do.
9008	Dutch Harbor, Alaska	Do.

Forty-nine new copperplate editions of charts and 28 new lithographic editions, 77 in all, were delivered to this section for issue. Among the new charts above noted, Nos. 1000, 1001, 5002, and 5052 are on the mercator projection, and correspond to the charts A, B, Nos. 5000, and 5050, respectively, on the polyconic projection.

The issues of charts during the fiscal year 1899–1900 are shown in the following table:

To whom issued.	No.
Sales agents	33 151
Sales by Office and chart section	1 036
Congressional account	2 101
Hydrographic Office, U. S. Navy	13 789
Light-House Board	2 840
Coast and Geodetic Survey Office	4 753
Executive Departments	5 425
Foreign governments	525
Libraries	1 254
Miscellaneous	778
Total	65 652
Condemned	5 962
Total issued and condemned	71 614

2. HYDROGRAPHIC SECTION.

In the Hydrographic Section the charts were corrected, and the monthly notices to mariners were prepared. This required considerable digesting of material, and the work is so complex that it can not well be described briefly. In this section the sheets as they came from the field were platted and verified and proofs were revised.

The following table gives the statistics in this section for the fiscal year 1899–1900:

Drawings and proofs of charts verified	350
Charts corrected	5 715
Volumes of field records examined	148
Angles platted	44 423
Soundings platted	228 255
Miles of sounding lines platted	3 874
Original sheets prepared	20
Sheets verified	18
Sheets protracted	4
Miscellaneous drawings and tracings made	26
Reductions of hydrography verified	37
Proofs overhauled	39
Miscellaneous information prepared relating to tides, dangers, etc., and the usual correspondence.	

F. INSTRUMENT DIVISION.

Personnel.

Name.	Occupation.
E. G. Fischer	Chief of division.
W. C. Maupin	Clerk.
C. Jacomini	Instrument maker.
W. R. Whitman	Do.
M. Lauxmann	Do.
J. A. Clark	Do,
H. O. French	Carpenter.
G. W. Clarvoe	Do.
C. N. Darnall	Do.
J. W. Hunter	Messenger.

The duties of the Instrument Division consist in the accounting for all instruments and general property, whether in the field, on the vessels, or in storage. It also involves the repair of instruments, the design and construction of new apparatus, and experimental work. New instruments which have been selected for purchase are tested in this Division.

Besides the routine duties already mentioned, the Instrument Division carried on experiments with a new form of lamp, designed for the purpose of furnishing signals for triangulation parties. The light-giving power of the lamp supplied in the instrument shop with an 8-inch reflector appeared to be, at a distance of 10 miles, about five or six times as great as the usual form of signal lamp used on the Survey.

Two new theodolites, Nos. 167 and 168, were completed. To provide the international latitude stations at Gaithersburg and at Ukiah with the necessary apparatus for their observations, two meridian marks were made at the Coast Survey Office during the past year. They consist of two horizontal scales, etched upon opal glass and mounted on longitudinal slides, which are fastened to an iron T-bar. The apparatus enables the observer to frequently check the azimuth of the instrument, which is mounted eccentrically, as well as to determine the value of the two latitude levels without removing them. These meridian marks were made after plans furnished by the International Geodetic Association.

Eight new level rods were begun, to provide for a contemplated increase in the precise level parties. Two new precise levels were constructed and finished in time to be issued to field parties.

A description of these leveling instruments is published in Appendix No. 6 to this Report.

G. LIBRARY AND ARCHIVES.

Personnel.

Name.	Occupation.
Edw. L. Burchard, librarian	Chief of Division.
A. F. Zust	Clerk.
E. K. Foltz	Writer.
William H. Butler	Messenger.

Temporary detail of the following persons was made from time to time, as opportunity offered, to assist in the work of this Division:

B. M. Winters, July 1 to January 15.
J. B. Quinlan, July 1 to September 20.
George Baber, September 26 to October 24, and December 11 to January 6.
W. H. Burger, October 24 to November 14.
R. D. Chase, October 26 to December 9.
E. D. Wilson, November 6 to November 6.
J. A. West, November 8 to November 8.
E. W. Ford, November 9 to February 9.
W. H. Ward, November 20 to December 11.
R. C. Denison, December 7 to December 15.
E. B. Wills, January 29 to April 26.
J. H. Smoot, June 11 to June 30.

1. GENERAL STATEMENT.

The work of the Library and Archives Division may be classed into general matters of routine, accessions, indexing, shelf arrangement, binding, and special work. During the year the books have been examined, with special reference to their serviceableness. Those of little value have been sent to the upper floors, and others have been transferred to the Library of Congress.

About 5 000 pamphlets were classified and added to the book shelves. The new terrestrial magnetism collection, purchased in Europe, was indexed and shelved. One hundred and ninety-nine volumes were collated and sent to the bindery. More than one-half the astronomical records are indexed, entrance being made for each station occupied. Two hundred and five volumes of magnetic records, prepared in the Division of Terrestrial Magnetism, and 87 volumes of tidal books, prepared in the Tidal Division, were bound. Original bibliographic work was carried on in Washington and Philadelphia libraries by the librarian, in connection with the bibliography of the surveys of Mason and Dixon's line.

2. ACCESSIONS.

The accessions to the library are by exchange and purchase. Those of the exchanges which are not useful to the Survey are sent to the Library of Congress. Much more is now being received, however, from geodetic and hydrographic institutions than heretofore. A rare and valuable collection on terrestrial magnetism, chiefly pamphlets and separates, was selected and purchased during the summer of 1899.

The following table gives statistics of the library accessions:

	Purchased.	Donated.	Exchange.	Total.
Books	96	98	202	396
Pamphlets	171	171	343	685
Serials	66	164	263	493
Maps and charts	28	344	734	1 106
Total	361	777	1 542	2 680

3. INDEXING.

The current accessions to the library, the pamphlets on terrestrial magnetism, and some 200 maps of Alaska were indexed. The most important work, however, in this direction, which was begun early last year, was the indexing of the astronomical work. The volumes for Alaska, the Pacific Coast States, the Rocky Mountain States, the Southern States and part of the Middle Atlantic States have been thoroughly examined and entry made in the index for each station and subject.

At the request of the Librarian of Congress a complete list of all serials and periodicals currently received in the Survey library was compiled.

4. SHELF ARRANGEMENT.

A collection of pamphlets, which had heretofore been stored in somewhat large and cumbersome tin boxes, was taken out, labeled and classified, and placed alongside the books, according to the subjects to which they belonged. As fast as new pamphlets are received they are put into temporary pasteboard covers and treated as books. Newspaper clippings on shipwrecks, dangers to navigation, survey work, and a variety of other subjects of interest are placed in book-sized portfolios and arranged by subjects with the books and pamphlets. As a result, all of the literature on any given subject is now to be found classified in its proper place on the shelves.

A number of duplicates and material little used were taken to the top floor of the fire-proof building, and have been put in storage where they are easily accessible if wanted. These include old Coast Pilots, duplicates of the Nautical Almanac, United States legal reports, etc.

5. BINDING.

Two hundred and five volumes, classified by the Division of Terrestrial Magnetism, have been bound, in which form they are more convenient for general use. The Tidal Division arranged tide books for the State of New York. These were bound into eighty-seven volumes, and are arranged on the shelves in numerical order.

6. ISSUES.

An arrangement was effected by which the bulletins of new accessions were circulated among the field officers and ships, and blank forms have been printed for use when the temporary loan of new books and periodicals is desired. Considerable use was made of this privilege.

The Library also acts as an intermediary for loans from the Library of Congress. Works required for official use can be called for and obtained through the Library of the Survey.

7. SPECIAL WORK.

The Librarian having been directed by the Superintendent, in the spring of 1899, to prepare a bibliography of material bearing on Mason and Dixon's line, utilized all of his spare time and opportunities to push this work. Examinations were made at the Pennsylvania Historical Society, Philadelphia, and in the city of Washington.

H. MISCELLANEOUS DIVISION.

Personnel.

Name.	Occupation.
F. R. Green	Chief Clerk (July 1 to Mar. 28).
H. C. Allen	Chief Clerk (Mar. 29 to June 30).
H. C. Allen	Clerk (July 1 to Mar. 28).
E. B. Wills	Clerk (Apr. 26 to June 30).
Thomas McGoines	Messenger.

By direction of the Superintendent, Mr. Scott Nesbit, disbursing agent, performed the duties of chief of this Division during the year. The Division was charged with the purchase and distribution of the supplies required for use in the Office and also such supplies as are furnished to the field parties on requisition, and this duty forms the greatest part of the occupation of the clerical force of the Division.

In addition to the above, the Division was also charged with the distribution of the Reports of the Superintendent and other publications of the Coast and Geodetic Survey.

The following is a statement of the publications received and issued during the year:

The following publications were received from the Public Printer:

Report of the Superintendent of the United States Coast and Geodetic Survey Showing the Progress of the Work During the Fiscal Year Ending with June, 1898	2 000
Appendix No. 1, Report for 1898.—Hypsometry—Resulting Heights from Spirit Leveling between Salina and Ellis, Kans. Observations by I. Winston, Assistant; report by C. A. Schott, Assistant	300
Appendix No. 2, Report for 1898.—Hypsometry—Resulting Height from Spirit Leveling between Ellis, Kans., and Hugo, Colo. Observations by I. Winston, Assistant; report by C. A. Schott, Assistant	300
Appendix No. 3, Report for 1898.—Hypsometry—Resulting Heights from Spirit Leveling between Hugo and Colorado Springs, Colo. Observations by I. Winston, Assistant; report by C. A. Schott, Assistant	300
Appendix No. 4, Report for 1898.—Geodesy—Inquiry into the Value of the Peruvian Arc of 1736–1743 and the need of a Check to its Results. Reported by C. A. Schott, Assistant	100
Appendix No. 5, Report for 1898.—Gravity, Magnetism, and Ocean Densities. Physical Observations made in Connection with the Pribilof Islands Expedition of 1897. Report by G. R. Putnam, Assistant	100
Appendix No. 6, Report for 1898.—Geodesy—International Geodetic Association (Twelfth 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	200
Appendix No. 7, Report for 1898.—Astronomy—Determination of Time, Longitude, Latitude, and Azimuth. By J. F. Hayford, Assistant. Inspector of geodetic work	1 000
Appendix No. 8, Report for 1898.—A Plane Table Manual. By D. B. Wainwright, Assistant	500
Appendix No. 9, Report for 1898.—Physical Hydrography—Problems in Physiography. Salinity and Temperature of the Pacific Ocean. By A. Lindenkohl, United States Coast and Geodetic Survey	100
Tide Tables of the Pacific Coast of the United States for 1900	7 000

Tide Tables of the Atlantic Coast of the United States for 1900	2 025
Supplement to First Edition, United States Coast Pilot, Atlantic Coast, Parts I-II.—From the St. Croix River to Cape Ann	600
Supplement to First Edition, United States Coast Pilot, Atlantic Coast, Part III.—From Cape Ann to Point Judith	700
Supplement to United States Coast Pilot, Atlantic Coast, Part IV.—From Point Judith to New York	1 335
Supplement to First Edition, United States Coast Pilot, Atlantic Coast, Part VI.—Chesapeake Bay and Tributaries	500
Supplement to First Edition, United States Coast Pilot, Atlantic Coast, Part VIII.—Gulf of Mexico, from Key West to the Rio Grande	300
Supplement to United States Coast Pilot, Atlantic Coast, Parts I-II, III, VI, VIII.—Rules of the Road at Sea and in Harbors, Rivers, and Inland Waters (except the Great Lakes and their connecting 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
Bulletin No. 36.—Table of Depths for Channels and Harbors, coast of the United States, including Porto Rico, the Hawaiian Islands, and the Philippine Islands	2 000
Bulletin No. 39, Alaska.—Predicted Times of Slack Water at Seymour Narrows, Discovery Passage, British Columbia, and at Sergius Narrows, Peril Strait, Alaska, from May to December, 1899	3 000
Bulletin No. 40, second edition, with additions and changes.—Alaska. Coast Pilot Notes on the Fox Islands Passes, Unalaska Bay, Bering Sea, and Arctic Ocean as far as Point Barrow	5 560
Special Publication No. 5, Geodesy.—Tables for a Polyconic Projection of Maps, based upon Clarke's Reference Spheroid of 1866, second edition	702
General Statement of the Administration and Work of the Coast and Geodetic Survey, with Historical Sketch, from 1807 to 1898	500
House Document No. 436, Fifty-sixth Congress, first session.—Expenditures in the Coast and Geodetic Survey. Letter from the Acting Secretary of the Treasury transmitting a statement of expenditures in the United States Coast and Geodetic Survey for the fiscal year ended June 30, 1899	250
House Document No. 625, Fifty-sixth Congress, first session.—Letter from the Secretary of the Treasury transmitting, with accompanying communications, a draft of a bill for the establishment of a national standardizing bureau	1 000
Table showing the Height, in meters, corresponding to given Angles of Elevation and Distances, in meters	3 000
Table of Coefficients for Reducing Inclined Sights on Vertical Rod to Horizontal Distance	300
Table of Factors for Computing Differences in Elevation (in feet).—Table of Corrections for Curvature and Refraction (in feet)	300
Table of Factors for Computing Differences in Elevation (in meters) and Table of Corrections for Curvature and Refraction (in meters)	300
Notice to Mariners, Nos. 246 to 258, inclusive, from July, 1899, to June, 1900, both inclusive.—"Chart Corrections during the several months, and Index of Notices to Mariners for the fiscal year 1899," 4 700 copies per month	61 100

The publications issued were as follows:

Annual Reports (covering the years 1851 to 1898)	2 221
Appendices to Annual Reports	1 162
United States Coast Pilot, Atlantic Coast	275
Tide Tables, 1900	227
Tide Tables, 1900, Pacific Coast	158
Pacific Coast Pilot, Alaska	32
Pacific Coast Pilot, California, Washington, and Oregon	33

Bulletins	1 434
Treatise on Projections, Craig	13
Deep-Sea Soundings and Dredgings, Sigsbee	13
Pillsbury's Gulf Stream	56
General Instructions for Hydrographic Parties	28
Tables for Converting Customary and Metric Weights and Measures	81
Notice to Mariners, 246 to 258	60 125
Special Publication No. 1	52
Special Publication No. 2	120
Special Publication No. 5	7
Tidal Researches, Ferrel	2
Rules Governing Routine and Discipline Aboard Ship	6
Report on Weights and Measures, 1857	1
General Properties of the Equations of Steady Motion	1
Regulations, Enlistments, and Discharges	6
Supplement to Coast Pilot Rules of the Road at Sea	6

I. SPECIAL DUTY.

Personnel.

Name.	Occupation.
C. A. Schott	In charge of computation of arc measures, Jan. 1 to June 30.
M. H. Doolittle	Computer (Jan. 1 to June 12).
Miss L. Pike	Computer (Jan. 1 to June 30).
C. R. Duvall	Computer (June 13 to June 30).

Upon being relieved of the charge of the Computing Division on January 1, 1900, Assistant C. A. Schott was directed to continue the discussion of the Oblique Arc along the Atlantic Coast and the work of reducing the California triangulation. Two computers were assigned to assist the Chief, and the whole energy of the Section was devoted to continuing the computation of the Oblique Arc, with the following result:

The triangulation was completely adjusted to fit the six base lines and to satisfy the geometric conditions. The results are in shape for publication. The geographic positions were computed from Connecticut to Louisiana, on the same data as developed for the Transcontinental Triangulation. There are 17 longitude stations, 71 latitude stations, and 55 azimuth stations, in the Oblique Arc. The longitude results are ready for publication. The greater part of the latitude results are also ready, and the azimuths only require transcribing.

In the arc section was read the proof of Special Publication No. 4 "The Transcontinental Triangulation," which was exceptionally laborious.

APPENDIX No. 2.

REPORT 1900.

DETAILS OF FIELD OPERATIONS.

TABLE OF CONTENTS.

TABULAR INDEX OF FIELD WORK.

A. EASTERN DIVISION—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. West Virginia.
11. Maryland.
12. District of Columbia.
13. Delaware.
14. Virginia.
15. North Carolina.
16. South Carolina.
17. Georgia.
18. Florida.
19. Michigan.
20. Wisconsin.
21. Illinois.
22. Indiana.
23. Ohio.
24. Kentucky.
25. Tennessee.
26. Alabama.
27. Mississippi.

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
1	Massachusetts.	Hodgkins.		Hydrographic. Topographic.	119
2	Rhode Island. Maryland. District of Columbia. Virginia. North Carolina. West Virginia. Ohio.	Bauer.	Fleming. Vehrenkamp. Dibrell. Edmunds. Brown. Miller. Bauer. Wallis. Loud. Thompson. Weinrich. Baylor. Hazard.	Magnetic.	120
3	New York.	Boutelle.		Hydrographic.	123
4	New Jersey.	French.	Weld.	Triangulation. Topographic.	125
5	Pennsylvania.	Young.	Phelps.	Hydrographic.	127
6	Maryland.	Bowie.		Topographic.	128

A. EASTERN DIVISION—EAST OF THE MISSISSIPPI RIVER—Continued.

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
7	Maryland.	Donn.	Latham.	Triangulation. Topographic.	130
8	Maryland.	Donn.		Triangulation. Topographic.	133
9	Maryland.	Flemer.		Triangulation. Topographic.	134
10	Maryland.	Nelson.		Topographic.	136
11	Maryland.	Vinal.		Triangulation. Hydrographic. Topographic. Tide.	137
12	Maryland.	Welker.		Triangulation. Hydrographic. Tide.	140
13	Maryland.	Welker.	Flower.	Triangulation.	142
14	Maryland.	Yates.	Mitchell.	Hydrographic. Tide.	144
15	Virginia.	Preston.		Magnetic.	147
16	Maryland. Virginia.	Baylor.		Magnetic.	148
17	North Carolina.	Baylor.		Magnetic.	149
18	South Carolina.	Fairfield.		Triangulation.	150
19	South Carolina.	Vinal.		Hydrographic. Topographic. Tide.	151
20	South Carolina. Georgia. Florida. Alabama. Kentucky. Tennessee.	Hazard.	Miller.	Magnetic.	152

A. EASTERN DIVISION—EAST OF THE MISSISSIPPI RIVER—Continued.

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
21	Georgia.	Marindin.	Ford. Brundage.	Special duty. Triangulation. Hydrographic. Tide.	153
22	New York. District of Columbia. Florida.	Spaulding. Kummel. Weeks.		Tide. Tide. Tide.	155
23	Ohio.	Ferguson.	Noble.	Precise leveling.	156
24	Kentucky.	Ferguson.		Precise leveling.	157

B. MIDDLE DIVISION—BETWEEN THE MISSISSIPPI RIVER AND THE ROCKY MOUNTAINS.

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

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
2	Kansas. Texas.	Bauer.		Magnetic.	120
25	Nebraska.	Granger.		Triangulation.	158
26	Nebraska.	Granger.		Reconnaissance. Triangulation.	159
27	Nebraska.	Tilton.	Burger.	Precise leveling.	161
28	Nebraska.	Tilton.		Precise leveling.	162
29	Kansas.	Eimbeck.	Little.	Triangulation.	163
30	Texas. Kansas.	Forney.		Reconnaissance.	165

C. *WESTERN DIVISION—WEST OF THE ROCKY MOUNTAINS.*

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

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
2	Colorado. New Mexico.	Bauer.		Magnetic.	120
31	Arizona.	McGrath. Sinclair.		Astronomic.	167 178
32	Washington.	Dickins.	Edmonds.	Triangulation. Tide.	168
33	Washington.	Gilbert.		Triangulation. Topographic. Tide.	170
34	California.	Morse.	Edmonds. Baird.	Topographic.	172
35	California.	Rodgers.	Edmonds.	Tide.	174
36	California.	Westdahl.		Triangulation. Hydrographic. Tide.	175
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38	Colorado Wyoming.	Winston.		Precise leveling.	180

D. DIVISION OF ALASKA.

No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
39	Alaska.	Pratt.	Young. Rhodes.	Triangulation. Astronomic. Topographic. Hydrographic. Base lines. Tide.	181
40	Alaska.	Putnam.	Flower. Frisby. Mansfield.	Reconnaissance. Base lines. Triangulation. Hydrographic. Topographic. Astronomic. Magnetic. Tide.	185
41	Alaska.	Faris.	Flynn. Derickson. Phelps.	Base lines. Triangulation. Hydrographic. Topographic. Astronomic. Magnetic. Tide.	196
42	Alaska.	Ritter.	Latham. Denson.	Triangulation. Hydrographic. Topographic. Tide. Special duty.	204
43	Alaska.	Ritter.	Denson.	Triangulation. Hydrographic. Topographic. Tide.	207
44	Alaska.	Dickins.	Edmonds.	Triangulation. Tide.	208
45	Alaska.	Gilbert.	Flynn. Frisby.	Hydrographic.	210
46	Alaska.	Tittmann.	French.	Marking provisional boundary.	80

E. OUTLYING TERRITORY.

No. of operations.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
47	Porto Rico.	Forney.	Bowie.	Reconnaissance. Triangulation. Azimuth.	211
48	Porto Rico.	Hodgkins.	Little. Mitchell.	Triangulation. Hydrographic. Topographic. Tide.	213
49	Porto Rico.	Boutelle.	Weld. Noble.	Reconnaissance. Base lines. Triangulation. Topographic. Hydrographic. Astronomic.	215
50	Porto Rico.	Nelson.	McGrath. Brundage.	Reconnaissance. Triangulation. Topographic. Base lines. Azimuth.	217
51	Porto Rico.	Vinal.		Hydrographic. Topographic. Tide.	219
52	Hawaii.	Perkins.	Flynn. Frisby.	Triangulation. Hydrographic. Topographic. Magnetic. Tide. Azimuth.	220

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No. of operation.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
53	Mississippi River.	Marindin.		Member of Commission.	224
54	Massachusetts.	Fischer.		Graduation of bench standard.	225
55	New York	Stratton.		Marconi system of wireless telegraphy.	226
56	Pennsylvania.	Burchard.		Bibliography, Mason and Dixon's Line.	227

F. SPECIAL DUTY—Continued.

No. of operations.	Locality.	Assistants and aids.		Character of work.	Page.
		Chief of party.	Members of party.		
57	Atlantic coast.	Bradford.		Inspection of chart agencies.	228
58	Virginia.	Yates.	Mitchell.	Speed trial course.	229
59	Virginia.	Young.		Buoys on speed trial course.	231
60	Maryland.	Smith.	McGrath.	Astronomic. Magnetic.	234
61	New York.	Ross.	Graves. Ford.	Coast pilot.	236
62	S. E. Atlantic coast.	Ross.		Coast pilot.	237
63	North Carolina.	Putnam.		Magnetic. Solar eclipse.	238
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65	Porto Rico.	Ullrich.		Sanitary conditions.	241
66	Porto Rico.	Ullrich.		Sanitary conditions.	242
67	Atlantic and Pacific oceans.	Perkins.		Cruise of the Pathfinder.	243
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TECHNICAL INDEX OF FIELD WORK.

TECHNICAL INDEX OF FIELD WORK—Continued.

INDEX OF THE PERSONNEL OF FIELD PARTIES.

INDEX OF THE PERSONNEL OF FIELD PARTIES—Continued.

A. EASTERN DIVISION.

Steamer *Blake*, W. C. HODGKINS, Commanding: MASSACHUSETTS, MONOMOY SHOALS, BOSTON ENTRANCE.

TOPOGRAPHIC.
HYDROGRAPHIC.

THOS. S. MARTIN, *First Watch Officer.*
CHAS. A. THOMPSON, *Second Watch Officer.*
Y. D. GRIFFISS, *Third Watch Officer.*
JAS. A. MCGREGOR, *Fourth Watch Officer.*
H. M. HEPBURN, *Recorder.*
O. STRAUBE, *Recorder.*

SUMMARY OF OPERATIONS.

Monomoy Shoals:	
1	topographic sheet.
1	hydrographic sheet.
208·4	miles sounding lines.
4 974	soundings.
2 586	angles measured.
Off Boston Entrance:	
1	hydrographic sheet.
70·5	miles sounding lines.
4 080	soundings.
1 982	angles measured.

The steamer *Blake*, W. C. Hodgkins, Assistant, Coast and Geodetic Survey, commanding, was at Washington on the 1st of July, 1899, having just returned from her season on the south coast of Porto Rico. On July 12 the vessel left Washington for Boston, Mass., where she was to be thoroughly examined by the United States local inspectors, and where certain hydrographic examinations were to be made. The order was subsequently modified to the extent of directing her to stop at New York City, in order to leave an alco-vapor launch at the builder's works in Jersey City. The vessel arrived at New York on July 16, the launch was landed on the 17th, and the trip to Boston was resumed the same day. She arrived on the afternoon of the 19th.

The contemplated inspection of the ship's hull was made, and the state of the vessel was found to be such that it was recommended that the vessel be docked for further examination. It was decided, however, that this should be postponed until the completion of the work on the Monomoy and Nantucket shoals; and the vessel therefore left for Hyannisport on the 7th of August, and on the 9th began the field work at the localities mentioned.

Fog, which was very prevalent during the period, materially retarded the progress of the work. Hydrography, however, was done on eleven days, during which time 208·4 nautical miles of sounding lines were run. Four thousand nine hundred and seventy-four soundings were made and 2 586 sextant angles observed. In addition to the above the position of the Nantucket Shoals light-vessel was determined by sextant observations made on the vessel, the time being carried from Hyannisport. The hydrography closed on September 14, and the *Blake* then proceeded to Boston. On September 15 an examination was begun of a certain shoal spot reported off Boston Entrance. The *Blake* went into the dry dock on the 17th and came out on the 27th. Work was closed at Boston on the 17th of October, at which date hydrography had been executed on thirteen days. Seventy and five-tenths nautical miles soundings had been run, 4 080 soundings had been made, and 1 932 sextant angles had been measured.

The vessel now proceeded to Baltimore, where she arrived on October 21. On the 26th she was hauled out on Spedden's Marine Railway, at Canton, and the work of tearing out and rebuilding her stern was at once begun.

On December 21 the vessel was run off the railway, and from this date until the 31st of December she lay at the wharf, the carpenters and machinists in the meantime being employed on various minor repairs.

The subsequent work of this vessel will be found under the heading "Outlying Territory."

L. A. Bauer: Rhode Island, Maryland, Virginia, West Virginia, District of Columbia, North Carolina, Ohio, Kansas, Colorado, New Mexico, Texas, Europe.

MAGNETIC.

SPECIAL DUTY.

J. B. Baylor, *Assistant.*	
J. A. Fleming, *Aid.*	July 1 to June 30.
H. W. Vehrenkamp, *Aid.*	July 1 to August 22.
W. C. Dibrell, *Aid.*	June 7 to June 30.
D. L. Hazard, *Chief Computer.*	March 20 to June 30.
C. K. Edmunds, *Magnetic Observer.*	March 11 to June 30.
W. McC. Brown, *Magnetic Observer.*	April 1 to June 30.
J. W. Miller, *Magnetic Observer.*	June 1 to June 30.
Wm. C. Bauer, *Magnetic Observer.*	June 1 to June 30.
W. F. Wallis, *Magnetic Observer.*	June 11 to June 30.
F. H. Loud, *Magnetic Observer.*	June 15 to June 30.
W. Weinrich, Jr., *Magnetic Observer.*	June 25 to June 30.
J. D. Thompson, *Recorder.*	March 22 to June 30.
H. F. Gloetzner, *Recorder.*	March 1 to June 30.
V. Sournin, *Recorder.*	May 25 to June 30.
R. H. Blain, *Recorder.*	February 12 to April 30.
C. W. Dawson, *Recorder.*	April 16 to June 30.

SUMMARY OF OPERATIONS.

108 magnetic stations occupied.
2 sites examined for magnetic observatory.
Constants of magnetometers Nos. 3, 18, and 19 determined.
10 dip circles compared.
4 magnetometers compared.
2 magnetographs compared.
Magnetic instruments compared with those at Kew, Potsdam, Pawlowsk, Parc St. Maur, and Darmstadt.

During the year important work was done under the direction of the Inspector of Magnetic Work. The operations may be conveniently treated under four heads: I. The determination of constants; II. Examination of sites for a magnetic observatory; III. The regular magnetic observations of the party, and IV. Comparisons of instruments.

I. THE DETERMINATION OF CONSTANTS.

The constants of magnetometer No. 3 were determined at the Coast and Geodetic Survey Office, in Washington, by Mr. Hazard; and those of magnetometers Nos. 18 and 19 by Mr. Vehrenkamp, in July and August, 1899.

II. EXAMINATION OF SITES FOR A MAGNETIC OBSERVATORY.

It being desirable to establish a magnetic observatory base station near Washington, examination was made in the vicinity for a suitable locality. The first investigations were made at Gaithersburg, Md., on the lot now occupied by the International Geodetic Association for the observation of astronomic latitude. Various points were selected on this piece of ground and complete examinations made. In addition, the magnetic elements at nine places within a radius of 9 miles of the locality were determined. These places were Waring, Middlebrook, Cross Roads I, Cross Roads II, Redland, Derwood, Hunting, Quince Orchard, and Seneca. These observations revealed marked local disturbances, the values of the declination varying from 0° 51′ W. at Waring, 3 miles northwest of Gaithersburg, to 8° 24′ W. at Derwood, 3 miles southeast of the same place. Even on the International Geodetic Association ground, comprising about 2 acres, values of the declination differing one-half degree were obtained. These observations were made by Messrs. Fleming and Vehrenkamp.

Following this work, Mr. Fleming examined the grounds of the State Reformatory School at Cheltenham, 16 miles southeast of Washington. Three points on the grounds were occupied, and four in the immediate vicinity within a radius of about 1 mile, and a complete determination of the magnetic elements made at each point. The results indicate that the distribution of magnetism is quite uniform over this area, and show that between this point and the one at Gaithersburg the preference should be given to Cheltenham.

III. THE REGULAR MAGNETIC OBSERVATIONS.

Regular magnetic observations were made in the following places:

Rhode Island.—By Mr. Hazard: Boston Neck on August 8 and 9, and McSparran Hill on August 26. These points are in the neighborhood of Narragansett Pier.

Maryland.—Observations were made at the following stations: Centerville, Cheltenham, Corunna, Dickerson, Easton, Hagerstown, and Gaithersburg. Linden, the base station of the magnetic survey of Maryland, was reoccupied by Mr. Fleming on July 5, 6, 7, and 8.

Virginia.—The following stations were occupied and all the magnetic elements determined: Arlington (near Warrenton), Calverton, Milford, Manassas, Culpeper, Charlottesville, Natural Bridge, Staunton, Covington, Greenwood, Orange, Fredericksburg, Rectortown, Strasburg, Winchester, Salem, Monterey, Warm Springs, Goshen, Burketown, Harrisonburg.

West Virginia.—All the magnetic elements were determined at the following places: Morgantown, Kingwood, Romney, Martinsburg, Charleston, Lewisburg, Hinton, Beckley, Fayetteville, Summersville, Clay, Charlestown, Winfield, West Union, Ripley, Princeton, Welch, Falls Post-Office, Moorefield, Baileysville, Oceana, Glebe, Bushy Run, Franklin, Cave Post-Office, Williamson, Logan, Travellers Repose, Madison, Marlinton, Hamlin, Mingo, Addison, Camden.

North Carolina.—In connection with the total eclipse, May 28, magnetic observations (absolute and variation) were made at Rocky Mount and at Wadesboro.

Ohio.—The magnetic declination and intensity were determined at Cincinnati, on the grounds of the observatory, on August 21 and 22, by Mr. Vehrenkamp.

New Mexico.—All three magnetic elements were determined by Mr. Fleming at Lumberton, November 28; Tres Piedras, November 30; Santa Fe, December 2 to 4; Albuquerque, December 5 to 7; Fort Wingate, December 9; Grants, December 11; Socorro, December 13 and 14; Fort Craig, December 16; East Las Vegas, December 18 and 19; Springer, December 22 and 23, and Clayton, December 26.

Colorado.—The three magnetic elements were determined by Mr. Fleming at Denver, November 14 and 15; Pueblo, November 17 and 18, and Conejos, November 21 and 22.

Texas.—A station at Amarillo was occupied by Mr. Fleming on December 31, and magnetic observations made.

IV. COMPARISONS OF INSTRUMENTS.

Between September 8 and December 18, Assistant Bauer was engaged in comparing magnetometer No. 18, and Dip Circle 56–4 440, with the standard instruments at the following European observatories: Kew (near London), Potsdam (near Berlin), Pawlowsk (near St. Petersburg), and Parc St. Maur (near Paris). The dip circle was also compared with Prof. K. Schering's earth inductor, at Darmstadt, Germany.

Besides inspecting the general arrangements and the installation of instruments at the above-named observatories, the observatory at Utrecht was visited, and the compass departments of the Russian admiralty at St. Petersburg, of the German Naval Observatory at Hamburg, and the English Admiralty at Deptford (near London) were inspected.

Schooner *Eagre*, J. B. Boutelle, Commanding: New York.

HYDROGRAPHIC.

V. R. Lyle, *First Watch Officer*.
Geo. Olsen, *Second Watch Officer*.
J. L. Dunn, *Chief Yeoman and Draftsman*.
J. A. Whitney, *Recorder*.

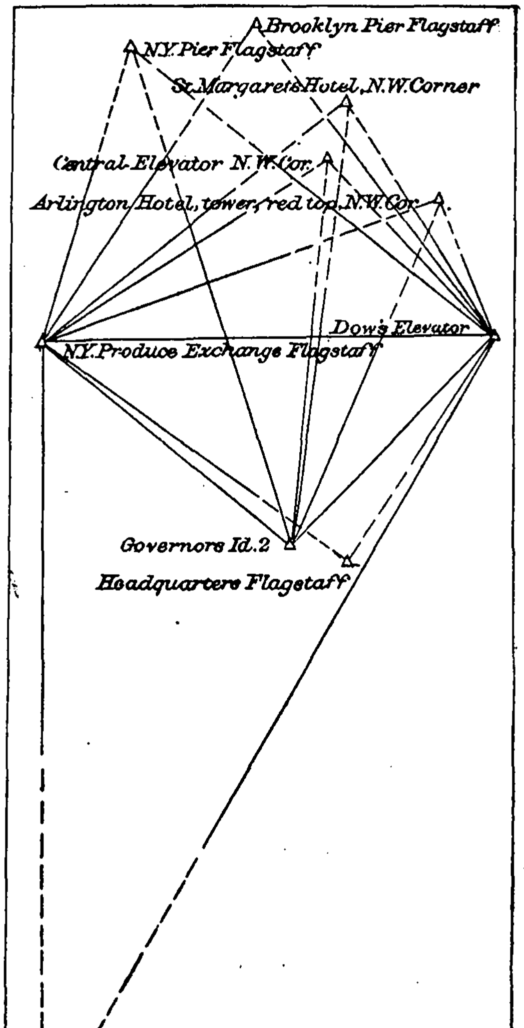
SUMMARY OF OPERATIONS.

East River:
70·3 miles sounding lines.
Off Coney Island:
45·8 miles sounding lines.

On June 29, 1899, J. B. Boutelle, Assistant, Coast and Geodetic Survey, received instructions for hydrographic work in New York Harbor. The party left Washington, D. C., on July 15, 1899, in the schooner *Eagre*, and proceeded to New York, arriving there on July 19. After about a week of rain and fog, hydrographic work was commenced in the East River on July 27, over an area extending from the west side of Governors Island to the Battery, and up the East River to beyond Coenties Reef. Owing to the immense traffic passing through here it was found impracticable to work from a launch or small boat of any kind, and a tug was hired for the purpose.

The above area was first covered by sounding lines, run 50 meters apart, and special search was made for obstructions and for shoal spots off the Battery shown on the chart, but without success. A drag was then procured from Major Adams, United States Engineers, consisting of a flat barge with an attachment of heavy vertical iron pipes on either side and a horizontal pipe about 40 feet long at the bottom, held in place forward and aft by rope guys. This could be set at any required depth and towed over the area to be searched. By means of this drag a sunken wreck was found off the South Ferry Slip, lying in about 30 feet of water and having about 17 feet over it at its highest point. Search with the drag failed to find the 24-foot spots off the Battery shown on the published chart, but a small ledge was developed there with 27 feet over it. The drag

No. 1.



TRIANGULATION IN EAST RIVER
NEW YORK

was then run, set at 30 feet M.L.W., over the channel for entering or leaving East River on what is known as the "Arbuckle Range." The shoalest sounding obtained on this range was 32 feet, and with the drag set at 30 feet no bottom was found over a space from 100 to 200 feet on either side of this range.

Three triangulation points, Governors Island 2, New York Produce Exchange, and Dow's Elevator, were occupied with a theodolite, and the geographic positions determined of the Central Elevator and northwest corner of St. Margaret's Hotel (formerly Arbuckle Flats), which form the "Arbuckle Range," and also of several other prominent objects.

The *Eagre* was then put upon a dry dock in Erie Basin, for inspection and repairs to the hull, and the party was engaged in computing and platting the East River work until September 21, when, at the request of Lieut. Commander J. C. Fremont, supervisor, harbor of New York, an examination was made of the dumping ground off Coney Island. Lieut. Commander Fremont placed the tug *Argus* at the disposal of the party, and sounding lines were run about 200 meters apart over an area indicated by him.

The work in this vicinity was closed, and on September 30 the vessel sailed for Baltimore, arriving there on October 3. The subsequent work of the *Eagre* is described under the heading, Outlying Territory.

O. B. French: New Jersey.

TRIANGULATION.
TOPOGRAPHIC.

F. F. Weld, *Aid*.

SUMMARY OF OPERATIONS.

Revision of charts from Cape May to Sandy Hook.
1 position for light-house determined.
150 square miles triangulation.
53 stations occupied.

The charts covering the coast of New Jersey have, for some time, needed revision. In order to accomplish this, instructions were issued, under date of May 26, 1899, to Assistant O. B. French, to proceed to Cape May and undertake the revision of all the charts from that locality northward to Sandy Hook. The plan proposed was to occupy known triangulation stations with the theodolite, and from them determine subsidiary points to be used in locating new features in the neighborhood; this last location to be made by the best means available, either direct measurement or the observation of angles with the sextant.

Assistant French arrived at Cape May on July 1. He immediately began a reconnaissance, and discovered that a great number of changes had taken place since the map now used was published. The original topographic sheet was photographed in the Office, and a copy was carried to the field, and upon this copy the necessary corrections were made. By this means the Cape May sheet was corrected in a rapid and economical manner, and with all the accuracy necessary for the purposes intended.

Sufficient triangulation points were found to locate subsidiary points for all the work along the coast. In many cases it was necessary to depend on local maps, especially where towns were involved; but these were found to be generally sufficiently accurate for the purpose.

South of Barnegat enough triangulation stations were found for use in this work; but north of the last-mentioned point very few stations could be recovered, and those that were found were so situated that they were of little use in the absence of high signals for observations. It therefore became necessary to carry on a scheme of triangulation from Barnegat light-house to Sandy Hook, a distance of about 50 miles. The stations selected were generally cupolas, church spires, flagstaffs, etc., which made the occupation of many eccentric stations necessary. Care, however, was always taken to locate the exact position of the instrument accurately, so that the observations could be reduced with a sufficient degree of exactness to answer the purpose.

Toward the end of September the health of Assistant French became seriously impaired and he was obliged to relinquish field work. The operations were continued by Mr. F. F. Weld, Aid, Coast and Geodetic Survey, who had joined the party on August 1, and who carried out the scheme, under direction of Assistant French, with complete success. The field work ended in November and Aid Weld returned to Washington on the 12th.

Sufficient data were collected during the season to bring all the topographic sheets along the New Jersey coast up to date, with the exception, however, of a few places on the Western Bay, which was not included in the original programme. South of Bay Head there are few places where material changes occur, and those sheets may be considered as practically up to date. This region was surveyed about thirty-five years ago, and very few artificial features then existing could be found.

The streams, sloughs, and bays lying farther inland remain practically as they were a generation ago. The smaller channels, where the current is sluggish, are filling slowly; but the larger ones, which serve as the immediate outflow to the sea, undergo great modification with every storm. The bars at the mouths of the inlets are generally very shoal, few having more than 2 or 3 feet of water in their deepest channels at low tide.

Assistant French was absent at home from September 23 to December 6. On the latter date he returned to the office in Washington and began preparing the data collected along the New Jersey coast. This lasted until the 12th of May, when he was detailed to the party of Assistant Superintendent O. H. Tittmann, to be engaged in marking the provisional Alaska boundary, as agreed upon in the modus vivendi of October 20, 1899.

While stationed at the office in Washington, Assistant French received orders to locate the position for the West Bank light-house in New York Harbor, in Lower New York Bay. Leaving Washington on the 21st of March, the work was completed on the 29th.

Steamer *Endeavor*, F. A. YOUNG, Commanding: PHILADELPHIA, Delaware River.

HYDROGRAPHIC.

G. S. PHELPS, *Aid.*
A. C. L. ROETH, *Recorder.*
D. B. WAINWRIGHT, Jr., *Observer.*
WM. BAUMANN, Jr., *Draftsman.*

SUMMARY OF OPERATIONS.

254 miles sounding lines.
20 354 soundings.
4 tide stations occupied.

Assistant Young was attached to the party of Assistant J. F. Pratt, on board the steamer *Patterson*, making a hydrographic survey of the Yukon Delta, from the 1st of July to the 31st of October. During the season he located four buoys and two range beacons to mark the channel through the flats off the Apoon Entrance to the Yukon, and was engaged in triangulation in Golofnin Bay and on hydrography in Safety Harbor. The details of this work are set forth in the report of Assistant Pratt.

On the return of the *Patterson* to Seattle, Assistant Young was detached on November 1 from the ship and was employed at the suboffice, making computations of the field work. He also had charge of the suboffice under the direction of Assistant Pratt.

On December 5 he left Seattle for Washington, where he arrived on the 10th. Leave was taken until the 31st. From the beginning of the year to the 11th of March Assistant Young was employed on the computation pertaining to the work of Assistant G. R. Putnam in the survey of the Yukon Delta.

On February 20 he proceeded to Woods Hole, Mass., where a telephone cable was located. This work is described in a special report.

Relieving Assistant Yates of the command of the steamer *Endeavor* on March 12, he proceeded with the ship to Old Point Comfort on the 26th, in order to locate buoys marking the ends of the trial course for ships of the Navy off Cape Charles City. The details of this work are set forth in a special report.

The *Endeavor* returned to Baltimore, where she remained until the 8th of May, undergoing slight repairs. On the latter date she sailed for Philadelphia, having the Inspector of Hydrography and Topography on board. Assistant Young's instructions were to investigate certain reported shoals and obstructions and also to make a general hydrographic survey of the channel from Newcastle to Bombay Hook.

From the 11th to the 20th of May the ship was lying at the wharf at Philadelphia, and the officers were employed in copying descriptions and positions of stations at the Office of the United States Engineers. Signals were erected between May 22 and 27, and from the latter date to the close of the fiscal year the hydrographic work was carried on continuously. A complete hydrographic survey was made during the month of June. This included the channel below Pennsville, the cross lines being 200 feet apart and extending some distance on each side of the channel.

WILLIAM BOWIE: MARYLAND, Chesapeake Bay.

TOPOGRAPHIC.

D. DERICKSON, *Recorder.*
W. E. WILSON, *Rodman.*
LENOX GRANT, *Rodman.*
D. N. HOOVER, jr., *Recorder.*
A. B. SIMONS, jr., *Rodman.*
R. M. LINTON, *Rodman.*

SUMMARY OF OPERATIONS.

49	square miles topography.
1	mile coast line.
69.5	miles shore line of creeks.
158	miles of roads.
2	topographic sheets.

Acting under instructions of June 21, 1899, Assistant Bowie, with his party, took the field on July 6 for the topographic resurvey of the vicinity of Havre de Grace, Md. The headquarters of the party were first located that place, and as the work progressed, successively transferred to Aberdeen, Port Deposit, and Northeast. The shore line of this work had already been run by Assistant Hodgkins during the previous season, so that there now remained only the inland topography.

Between Perrymans station and Havre de Grace the country is low and heavily wooded, so that it was necessary to resort to plane-table traverse lines in order to control the topography. The limits of the work extended from the shore line back to the main country road between Havre de Grace and Port Deposit, on both sides of the river. The topographic features are quite diversified, and the irregular contours rendered the work difficult and made progress somewhat slow.

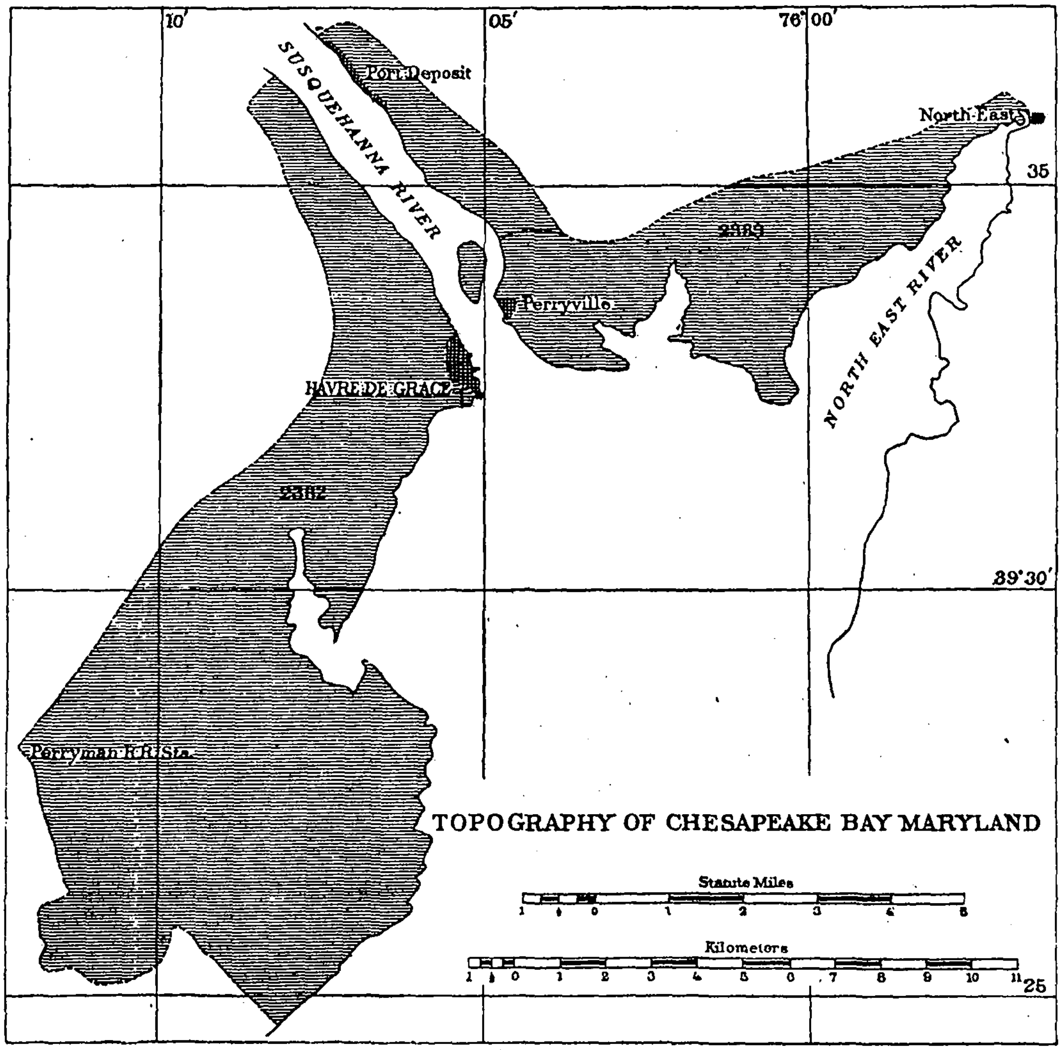
From Perryville eastward as far as Northeast the country is rolling, with contours of regular intervals. All of the triangulation points located by Assistant Perkins in 1898 were recovered. Of the old points established many years ago all were lost except Principio astronomic station, which was found and identified.

Assistant Bowie returned to Washington on November 16. He took leave of absence until December 5, at which time he reported to Assistant R. L. Faris, then engaged in computing his Alaskan work.

On the 23d of December instructions were issued to Assistant Bowie to proceed to Baltimore and locate the new bridges across Curtis Creek and Cabin Branch. This involved the execution of about 2½ miles of topography on the new road connecting the two bridges. The original topographic sheets were taken to the field and the desired features located on the old maps. He returned to the office on the 28th, reporting again to Assistant Faris on the 29th.

The accompanying sketch shows the limits of the topography executed at the head

No. 2.



of the bay and on both sides of the Susquehanna River up to and including Port Deposit.

On the 15th of January Assistant Bowie received instructions to report to Assistant Stehman Forney for duty in the triangulation party about to take the field in Porto Rico.

J. W. DONN: MARYLAND, Chesapeake Bay, Kent Island.

TRIANGULATION.
TOPOGRAPHIC.

R. SEVERS, *Recorder.*
J. S. CALDWELL, *Recorder.*
L. T. EMORY, *Tableman.*

June 20 to December 4, 1899.

SUMMARY OF OPERATIONS.

61 square miles triangulation.
22 stations occupied.
23 geographic positions determined.
70 square miles topography.
25 miles general coast line.
30 miles river shore line.
150 miles creek shore line.
97 miles roads.
2 topographic sheets.

The topography of Kent Island and vicinity was resumed by J. W. Donn, Extra Observer, Coast and Geodetic Survey, near the close of the previous fiscal year. Instructions were issued on June 6, 1899. The party took the field soon thereafter, and work was begun on the 20th. By the close of the fiscal year the shore line on the west side of Kent Island was completed.

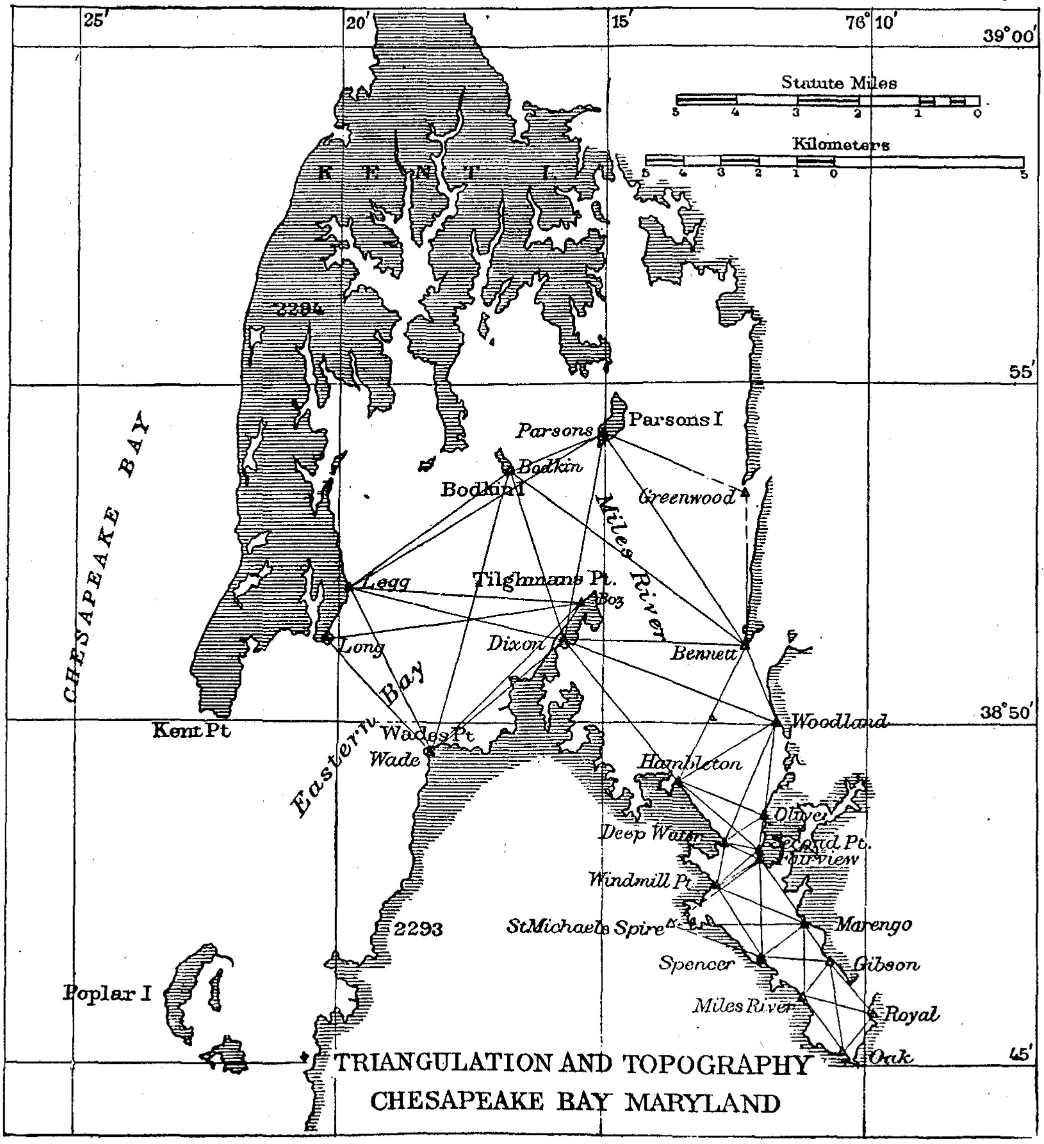
The entire month of July was devoted to the watershed on the western side, and this was completed by the close of the month. The plan adopted by the Superintendent was to carry on topography and hydrography at the same time, the latter being executed by Assistant Welker, on the steamer *Bache.*

In order that advantageous cooperation might be maintained between the two parties, Extra Observer Donn transferred his operations to Wades Point, near Claiborne, about August 1. While awaiting the arrival of the hydrographic party the work was carried on in the region known as Bayside, and at intervals points for the extension of the triangulation up Eastern Bay and Miles River were established. The station Boz, on Tilghmans Point, was found to be impracticable as a turning point for the triangulation, and Dixon was established, a few miles south. From this point the triangulation can be carried up Miles River, and also an advantageous connection made with the preceding work.

The hydrographic party arrived on the 7th of August, and arrangements were immediately made with Assistant Welker for such cooperation as would secure the most economical results. There were few trigonometric points available for the work in Eastern Bay. This condition necessitated laying aside the topographic work for the time being, and made necessary an extension of the triangulation before other work could be done.

Before taking up the triangulation, however, a survey of Poplar Island was made, at the request of Assistant Welker. The triangulation was then continued from the entrance of Eastern Bay to the Miles River, at the same time carrying on the topography of the east shore of Kent Island, from Long Point to Shipping Creek.

No. 3.



The triangulation of Miles River was now pushed southward from Deep Water Point, while the topography of the east and west shores, between Tilghmans Neck and Hambleton and Woodland creeks, was carried on.

Between September 15 and October 24 the triangulation was executed as far as the line Royal to Oak, the topography in the meantime keeping pace with this work, and there was executed the work on Bodkin and Parsons Islands, on Turkey Point, and the shoreline of Eastern Bay from Greenwood to Bennetts Point. The stations occupied in the triangulation are shown on the accompanying sketch, where the trigonometric points are clearly indicated.

Between October 26 and November 30 the shoreline of Eastern Bay, from the mouth of Greenwood Creek to the south point of Shipping Creek, was finished.

The entire work of the season was based upon trigonometric points directly, or upon plane-table determinations by intersections. By this means errors of distortion in the sheets were distributed as evenly as possible. The determination of the details was, therefore, the result of trigonometric work, and not of traverse or plane-table triangulation. The sketch shows the entire season's work and includes the shoreline of Eastern Bay and Miles River, as well as the whole extent of Kent Island except a small portion at the northern end which was executed during the previous season.

J. W. Donn: Chesapeake Bay, Elk Neck, Miles River.

TRIANGULATION.
TOPOGRAPHIC.

E. B. Latham, *Assistant.*
Roscoe Severs, *Acting Aid.*
L. T. Emory, *Recorder.*
W. W. Curtiss, *Tableman.*
John Kenney, *Launchman.*

SUMMARY OF OPERATIONS.

5 square miles triangulation.
6 stations occupied.
6 geographic positions determined.
17 square miles topography.
11 miles river shoreline.
35 miles roads.

Instructions were issued on April 5 to J. W. Donn, Extra Observer, Coast and Geodetic Survey, for the survey of Elk Neck, Maryland. The work was taken up on the 16th and prosecuted continuously until the close of the second week of June. At this time further instructions were given to complete the unfinished topography of the Miles River and to the northward over the Wye River. This work, including both the triangulation and topography, was carried on uninterruptedly until the close of the fiscal year.

J. A. Flemer: Maryland, Chesapeake Bay.

TRIANGULATION.
TOPOGRAPHIC.

G. V. Strong, *Rodman.*
C. L. Watkins, *Rodman.*
E. Vance Miller, *Rodman.*
Wm. W. Curtiss, *Plane-table bearer.*

SUMMARY OF OPERATIONS.

21 square miles triangulation.
14 stations occupied.
17 geographic positions determined.
32 square miles topography.
7 miles general coast line.
35 miles river shore line.
76 miles creek shore line.
53 miles roads.
1 topographic sheet.

Instructions were issued on June 29 to Assistant Flemer to take up the triangulation and topography of the west shore of Chesapeake Bay, from Bay Ridge to Curtis Point, including the triangulation of the South River, with the adjacent topography.

The party located near the mouth of the South River on July 14. The instruments, baggage, and lumber were transferred from Bay Ridge to Arundel-on-the-Bay on the following day. A reconnaissance developed the fact that a number of triangulation points established by Assistant F. W. Perkins during the previous season had disappeared. This necessitated the reestablishment of stations known as "Thomas 2" and "Gowan 2," and from the triangle just north of this line and defined by the points "Hill 2," "Selby," and "Arundel," the triangulation was carried up the river as far as Taylorsville.

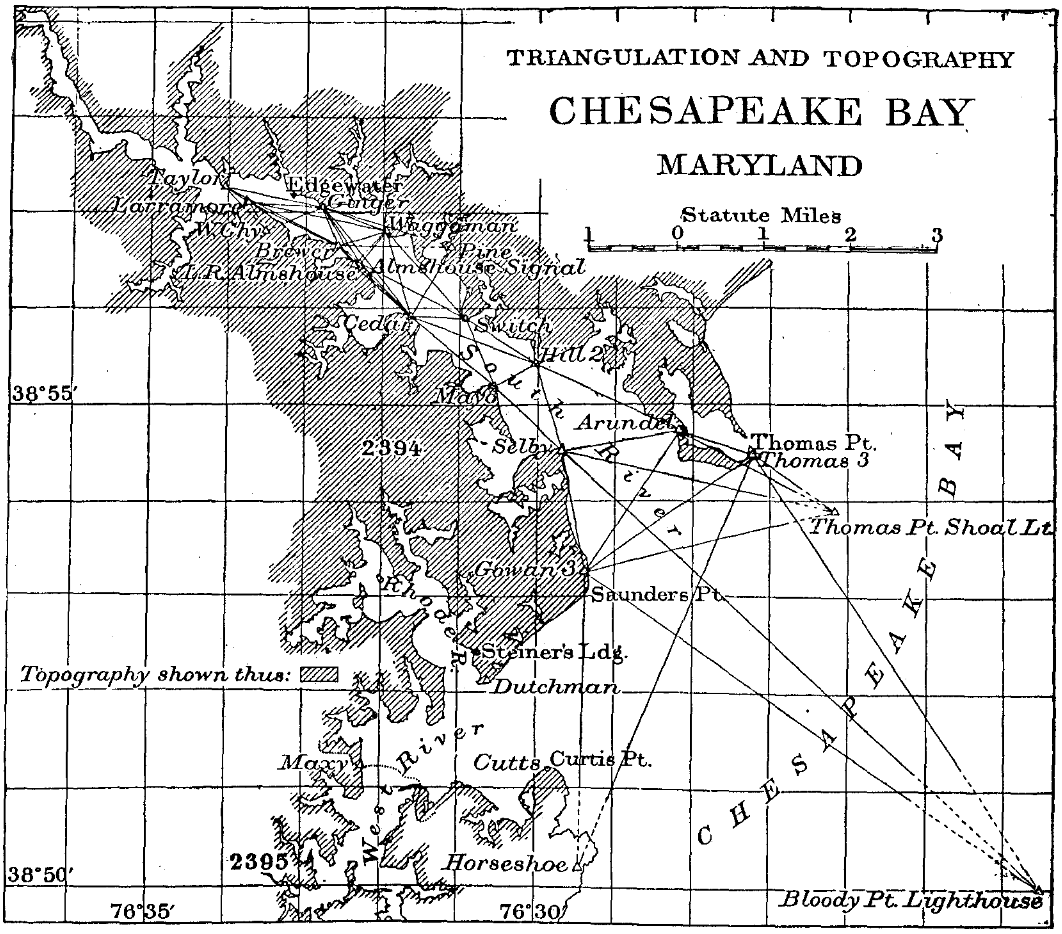
Before making the triangulation the topography was executed from Bay Ridge south to Thomas Point, including the town of Arundel-on-the-Bay, which had recently been laid out. The stations occupied in the execution of the triangulation are shown on the accompanying sketch, as well as the topography based thereon and executed on both sides of the South River. Several concluded points were established, which are likewise shown in the sketch by dotted lines.

The triangulation was completed on August 18, and on the following day the topography was begun. This was carried on continuously until September 9, when the members of the party began to suffer more or less from malarial fever. From the 9th to the 17th two members of the party, including Assistant Flemer, were confined to bed.

From the 14th to the 23d a third member was sick, and on the 15th and 16th all field work was suspended. During the period in which the party was more or less crippled by sickness, the men able for duty were engaged in erecting signals for topographic work in the upper part of the river, so that after sufficient members of the party had recovered to carry on work, it went on more rapidly than before.

On October 18 the party was transferred from Edgewater to Steiners Landing, and the operations were continued in the vicinity of Rhode and West rivers. No triangula-

No. 4.



tion was made here, as the time was short and it was desirable to have the shore line of the latter river for use in hydrographic work later. The topography was controlled by means of a plane-table triangulation, based on stations along the South River. On November 27 the party was disbanded, and on the 28th Assistant Flemer reported at the Office in Washington.

Assistant Flemer was on duty in the Office until March 10, 1900, and during the remainder of the fiscal year was on leave of absence without pay.

JOHN NELSON: MARYLAND, Chesapeake Bay.

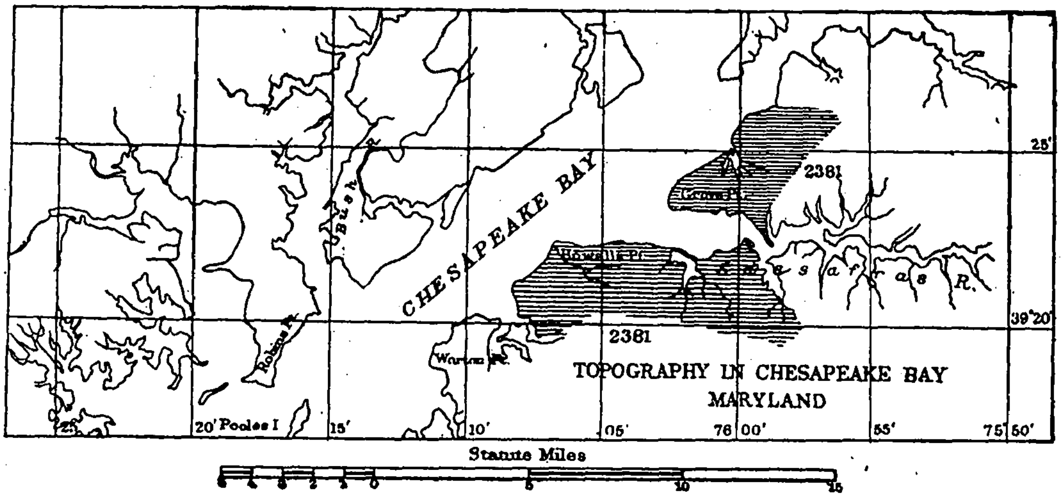
TOPOGRAPHIC.

SUMMARY OF OPERATIONS.

28 square miles topography.
4 miles general coast line.
38 miles river shore line.
84 miles creek shore line.
55 miles roads.
1 topographic sheet.

Instructions were issued on June 21, 1899, to Assistant John Nelson for the execution of triangulation and topography on the Sassafras River and the eastern shore of Chesapeake Bay. A steam launch, *No. 22*, and machinist were secured in Baltimore, and on July 21 the party was completely organized and operations began. The work

No. 5.



continued until October 21, at which time Assistant Nelson was directed to report to the Office in Washington, in order to make preparations for triangulation and topography in Porto Rico.

During the season spent on Chesapeake Bay the topography and shore line of the Sassafras River and its tributaries to a point about 1½ miles above navigation was completed. The area surveyed is shown on the sketch herewith.

Schooner *Matchless*, W. I. VINAL, Commanding: MARYLAND, Chesapeake Bay.

TRIANGULATION.
HYDROGRAPHIC.
TOPOGRAPHIC.
TIDE.

WILLIAM SANGER, *Chief Yeoman, U. S. N.*
SWEPSON EARLE, *Yeoman, U. S. N.*
JOHN W. CLIFT, *Yeoman, U. S. N.*
JAMES E. MARSH, *Chief Yeoman, U. S. N.*
A. J. MISKIMON, *Machinist.*

SUMMARY OF OPERATIONS.

10 square miles triangulation.
22 stations occupied.
43 geographic positions determined.
65 miles shore-line topography, rivers and creeks.
2 topographic sheets.
60 square miles hydrography.
563 miles sounding lines.
8,240 angles measured.
3 tide stations established.
4 hydrographic sheets.

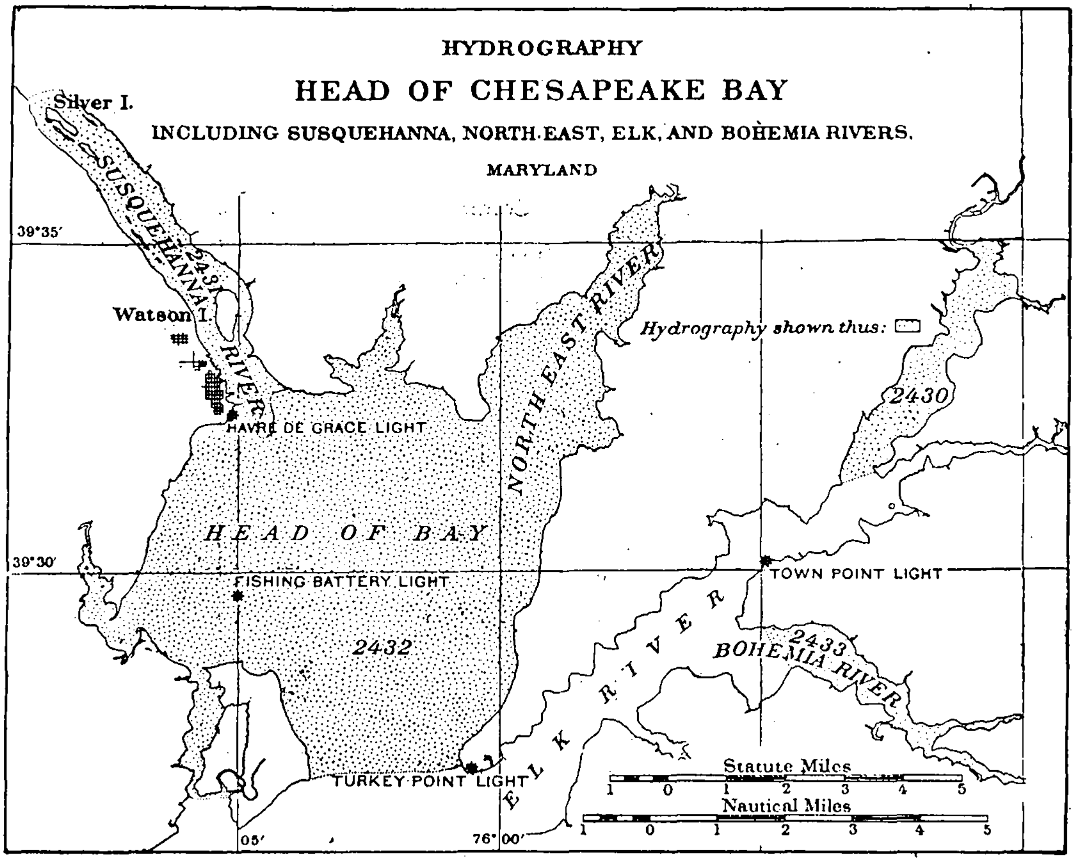
Assistant W. I. Vinal assumed command of the schooner *Matchless* on the 1st of April, 1899, and on the 1st of July he was engaged in a hydrographic survey of the head of Chesapeake Bay, including the Susquehanna River to Port Deposit, and the Northeast River to the head of navigation. This work was finished on August 12.

The party was then moved to Elk River, where the work of 1898, including triangulation, topography, and hydrography, was continued to Elkton, Md. Similar operations were carried on along the Bohemia River and its two branches until the close of the season's work.

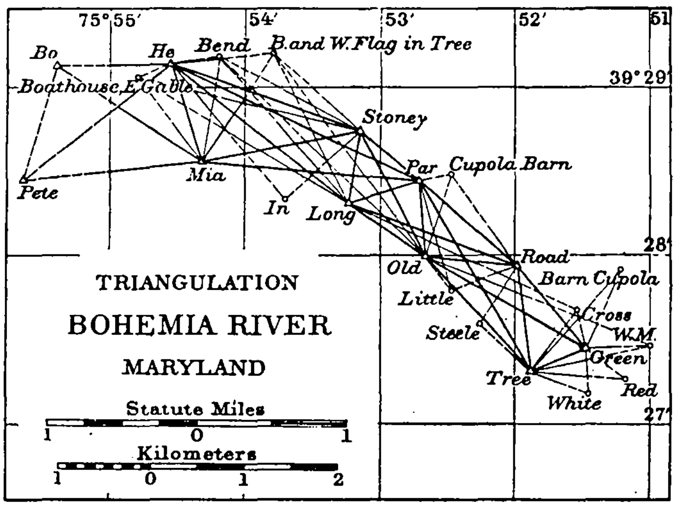
Twenty-two stations were occupied for horizontal angles. Tide gauges were established at Hopper's Wharf, Havre de Grace, and at Frenchtown on the Elk River, and on the drawpier of the bridge crossing the Bohemia River, and these were compared with the standard gauge at Reybold's Wharf, Elk River.

Returning to Baltimore, the party was employed on office work until the end of the calendar year, the necessary repairs being carried out during the same time.

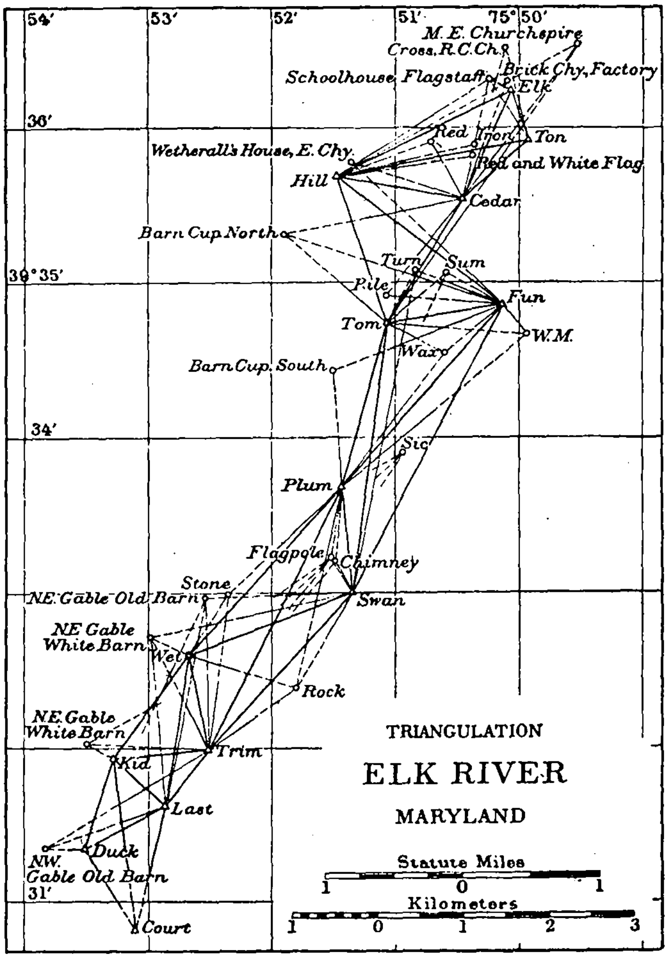
No. 6.


HYDROGRAPHY
HEAD OF CHESAPEAKE BAY
INCLUDING SUSQUEHANNA, NORTH-EAST, ELK, AND BOHEMIA RIVERS.
MARYLAND
Silver I.
Watson I.
SUSQUEHANNA RIVER
2431
39°35′
39°30′
HAVRE DE GRACE LIGHT
HEAD OF BAY
FISHING BATTERY LIGHT
2432
TURKEY POINT LIGHT
NORTH EAST RIVER
Hydrography shown thus:
2430
TOWN POINT LIGHT
ELK RIVER
2433
BOHEMIA RIVER
Statute Miles
1 0 1 2 3 4 5
Nautical Miles
1 0 1 2 3 4 5
05′
76° 00′

No. 7.


TRIANGULATION
BOHEMIA RIVER
MARYLAND
Statute Miles
1 0 1
Kilometers
1 0 1 2
75°55′
54′
53′
52′
51
39°29′
28′
27′
Bo
He
Bend
B. and W. Flag in Tree
Boathouse, E. Gable
Stoney
Par
Cupola Barn
Pete
Mia
In
Long
Road
Old
Barn Cupola
Little
Cross
Steele
W.M.
Green
Tree
Red
White

No. 8.


54'
53'
52'
51'
75° 50'
36'
39° 35'
34'
31'
M. E. Churchspire
Cross. R. C. Ch.
Brick Chy, Factory
Schoolhouse Flagstaff
Elk
Red
Iron
Ton
Wetherall's House, E. Chy.
Red and White Flag
Hill
Cedar
Barn Cup North
Turn
Sum
Pile
Fun
Tom
W.M.
Wax
Barn Cup. South
Sic
Plum
Flagpole
Chimney
Stone
N.E. Gable Old Barn
Swan
NE Gable White Barn
Wet
Rock
N.E. Gable White Barn
Trim
Kid
Last
Duck
NW. Gable Old Barn
Court
TRIANGULATION
ELK RIVER
MARYLAND
Statute Miles
1 0 1
Kilometers
1 0 1 2 3

Steamer *Bache*, P. A. WELKER, Commanding: MARYLAND, Patapsco River, Eastern Bay.

TRIANGULATION.

TIDE.

HYDROGRAPHIC.

C. L. GREEN, *Executive Officer.*
F. H. AINSWORTH, *Second Watch Officer.*
WM. B. PROCTOR, *Third Watch Officer.*
W. G. INSLEY, *Fourth Watch Officer.*
HARRY ELY, *Chief Machinist, U. S. N.*
JAS. J. MURPHY, *Hospital Steward.*
GEO. OLSEN, *Chief Yeoman, U. S. N.*
M. M. GORDON, *Engineer.*
J. A. McGREGOR, *Master at Arms, U. S. N.*
FRANK W. HART, *Draftsman.*

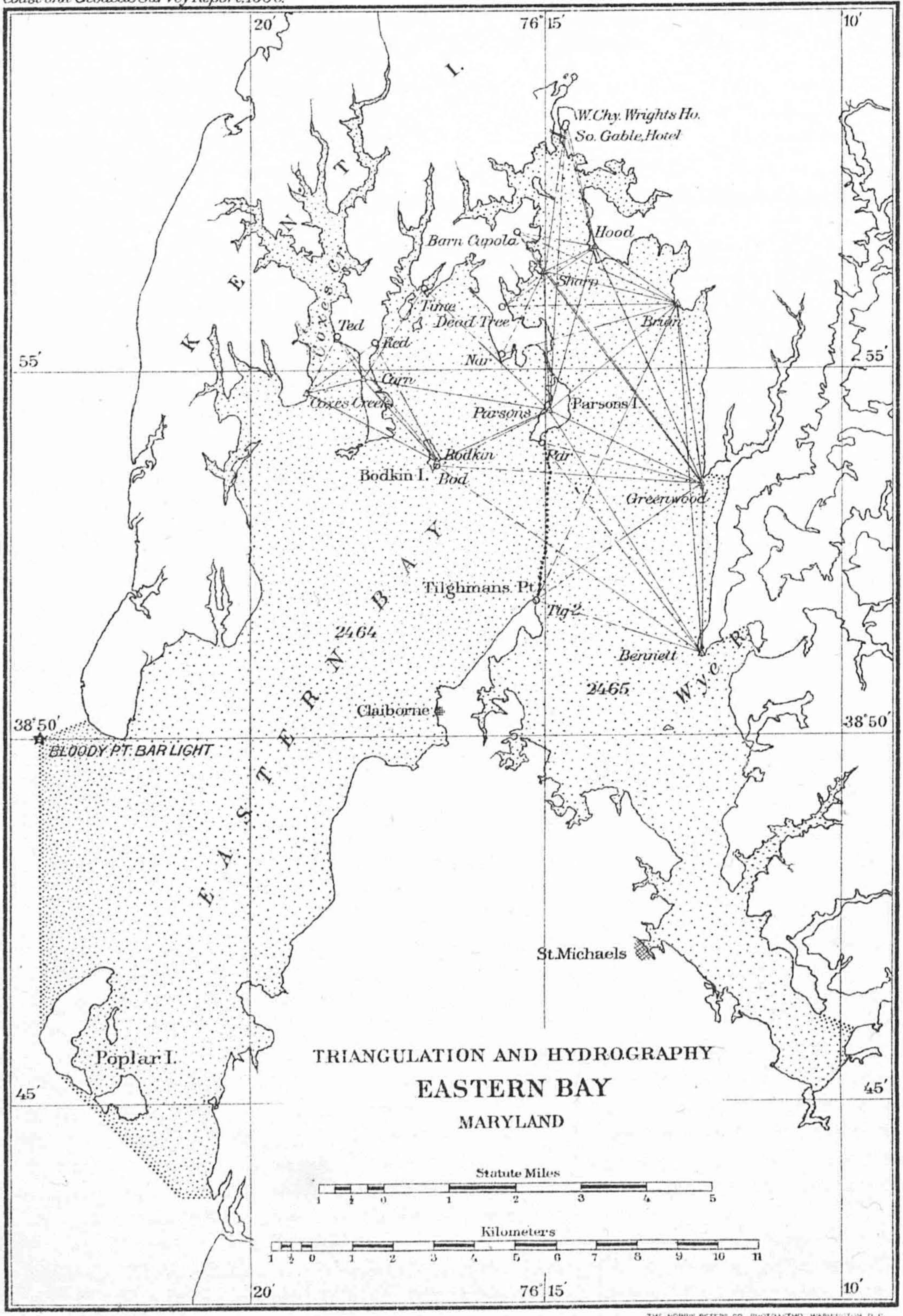
SUMMARY OF OPERATIONS.

Patapsco River:
59 miles sounding lines.
2 199 angles measured.
1 tide station established.
3 hydrographic sheets.
Eastern Bay:
22 square miles triangulation.
9 stations occupied for horizontal angles.
17 geographic positions determined.
75 square miles hydrography.
1 577 miles sounding lines.
24 690 angles measured.
3 tide stations established.
2 hydrographic sheets.

At the beginning of the fiscal year the steamer *Bache* was at Baltimore making special examinations for shoal spots in the Patapsco River, and arrangements for the hydrographic survey of Rock Creek. On the 5th of July these special examinations were completed.

On the same day the steamer *Bache* was moved to Woodall's shipyard for repairs. These were completed on the 25th, and the party proceeded to Sea Girt, where a survey of the entrance to Rock Creek was made. A system of lines was run normal to the shore about 25 meters apart, and another system at right angles to this the same distance apart was executed. The outline of the channel entering the creek was located by the measurement of sextant angles at all principal bends. Work was commenced on July 31 and completed on August 3.

On August 5 the dredged channel from Buoy No. 48 to the Canton elevator, Baltimore Harbor, was located and surveyed by running four lines of soundings parallel with the axis of the channel and crossing the same by a system of zigzag lines.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

During the progress of all the hydrographic surveys thus far mentioned tide observations were made at Fort Carroll staff, and all results were reduced to a plane of reference established at that point. On the 7th of August the steamer *Bache*, with party, moved to Eastern Bay, Maryland, for the purpose of making a hydrographic survey of that locality.

The *Bache* arrived at Eastern Bay on August 7. The locality to be surveyed was projected on two sheets, the lower one extending as far as Tilghmans Point, and the upper completing the locality to the upper end of the bay. Extra Observer John W. Donn, was engaged in topography in this vicinity, and was able to supply the party with the necessary shore line and triangulation for the lower sheet. By August 22 the hydrographic signals had been erected and located, and sounding was commenced.

The main system of lines was rectangular, but in places requiring special development diagonal systems were used in addition. The lines were run approximately 200 meters apart.

The necessary shore line and points on the upper sheet were ready by October 9, and work was immediately begun. These were furnished by Extra Observer Donn, and wherever additional points were found necessary they were either determined by the plane table or by triangulation with the theodolite. The entire geographic position of the survey depends on the base line Wade 2 to Long 2, as furnished by the Office. The triangulation up to the mouth of the Miles River was executed by Extra Observer Donn's party, while north of this point the work was done by the party of Assistant Welker.

Tide gauges for the reduction of the soundings were established at Claiborne and at Deep Water Point, near the mouth of the Miles River. The plane of reference was transferred from the Thomas Point light-house bench mark, established in 1898, to Claiborne Wharf gauge, and from the latter it was transferred to the Miles River gauge, transfers being made by means of simultaneous readings at the gauges. A bench mark was also established at Bloody Point light-house, at the entrance to Eastern Bay.

The party experienced considerable difficulty in procuring supplies, and in view of this fact it was thought best to make Baltimore the base, and make a trip whenever necessary to procure outfit and provisions.

The hydrographic survey was executed on a scale of 1–20 000. About one-half the time was lost on account of unfavorable weather. Before completing the season's work a special examination of the Wye River was made, in obedience to instructions from the Superintendent of November 15. The shore line was tested for about 2½ miles above the entrance by means of plane-table triangulation, and was found to agree, within the desired limits, with that of the published chart. On account of the lateness of the season only one day could be used to make an examination of the hydrography of the river. This was done by using Coast and Geodetic Survey Chart No. 135 as a guide, and checking the same by running a line of soundings through the center of the stream from the entrance of the river up through Back Wye River, through Wye Narrows, and down Front Wye River.

The season's work closed on December 7, and the steamer was then taken to Baltimore and put into winter quarters. The remainder of the calendar year the party was engaged upon the records of the season's work, and the crew in overhauling and repairing the steamer. From December 18 to 31 Assistant Welker was on leave of absence.

Steamer *Bache*, P. A. WELKER, Commanding; VIRGINIA, Norfolk, Chesapeake Bay.

SPECIAL DUTY.

TRIANGULATION.

GEO. L. FLOWER, *Assistant.*
C. L. GREEN, *First Watch Officer.*
C. F. ADAE, *Second Watch Officer.*
GEORGE OLSEN, *Second Watch Officer.*
HENRY S. SMITH, *Third Watch Officer.*
HARRY ELY, *Chief Machinist.*
J. J. MURPHY, *Medical Officer.*
J. E. SHEPHERD, *Medical Officer.*
WM. C. F. NESPITAL, *Draftsman.*
H. I. MCCREA, *Recorder.*

On January 4 Assistant Welker was appointed presiding officer of a board of survey to report on the condition and appraise all the material in the Coast Survey store shed at Woodall's shipyard, in Baltimore. This work was finished on the 31st of March. In the meantime other work was done, consisting in the preparation of engineers' log books and an entire set of new forms for rendering reports, statistics, and accounts of Coast Survey vessels. These new forms were to be used after the transfer of the Navy complement.

On the 1st of May instructions were received to take charge of the suboffice at Baltimore, Md. On the 14th of May the steamer *Bache* was taken from her winter quarters to Lower Canton, at Baltimore, for final overhauling and preparation for field work. In the meantime the office was turned over to the custodian of the building in which it was located, with an inventory of the property contained therein.

During the time the vessel was in winter quarters it was put in good repair by the force on board. Painting was done inside and out; the boiler, engine, launch, and small boats were thoroughly overhauled; numerous other small repairs were made, and all office work relating to the past season's operations, including the work on records, computations, reductions of tides and soundings, etc., was completed, with the exception of the platting of the soundings in Eastern Bay. All supplies and outfit were on board by May 21, and the steamer started for Washington in accordance with instructions of May 14.

On the 26th the vessel left for Norfolk, Va., with a party for the observation of the total eclipse of the sun. She returned on the 29th.

On June 1 the steamer went to Baltimore, and preparations were at once commenced to take up the triangulation and hydrography of Chesapeake Bay below the Potomac River. On June 8 the steamer was taken to the working grounds, and the building of signals for triangulation and hydrography was at once begun. The progress of the work was necessarily slow, as many of the lines of sight were 20 miles long, and the occupation of a single station required many days on account of the impossibility of seeing signals through the hazy atmosphere.

At the end of the fiscal year satisfactory progress had been made. Signals had been erected on the west shore from the mouth of the Potomac to the Rappahannock, and on the eastern shore from Highland Bar light to Tangier Sound light, far in advance of the triangulation. At the close of the fiscal year the vessel was still engaged in this work.

Assistant Welker had leave of absence from the 11th till the 23d of June.

Steamer *Endeavor*, C. C. YATES, Commanding: MARYLAND, Chesapeake Bay.

HYDROGRAPHIC.

TIDE.

H. C. MITCHELL, *Aid.*
D. B. WAINWRIGHT, Jr., *Observer.*
OLE ANDERSON, *Observer.*
A. C. L. ROETH, *Recorder.*
C. E. TERRY, *Recorder.*
A. H. BLACKISTON, *Recorder.*
WM. BAUMAN, Jr., *Draftsman.*

SUMMARY OF OPERATIONS.

Bush River:
8 square miles hydrography.
125 miles sounding lines.
2 293 angles measured.
3 tide stations established.
2 hydrographic sheets finished.
Sassafras River:
6 square miles hydrography.
165 miles sounding lines.
3 198 angles measured.
5 tide stations established.
2 hydrographic sheets finished.
Elk River:
½ square mile hydrography.
20 miles sounding lines.
700 angles measured.
2 tidal stations established.

At the close of the previous fiscal year Assistant Charles C. Yates and party, on board the steamer *Endeavor*, were engaged in the hydrographic survey of Bush River, Maryland. The work continued after the 1st of July until the 17th, when orders were received by Assistant Yates to prepare the vessel for sea duty and for a change of commanding officers.

On July 22 the command of the vessel was turned over to Mr. John Ross, Nautical Expert, at Baltimore, Md., who had received instructions to proceed north and continue the examinations for the Coast Pilot in Long Island Sound. On the 23d Mr. Ross landed the party of Assistant Yates at Bush River and the operations were continued, the party now working on shore and having as an equipment a small launch belonging to the *Endeavor*, and a skiff hired for the purpose of sounding in shoal waters.

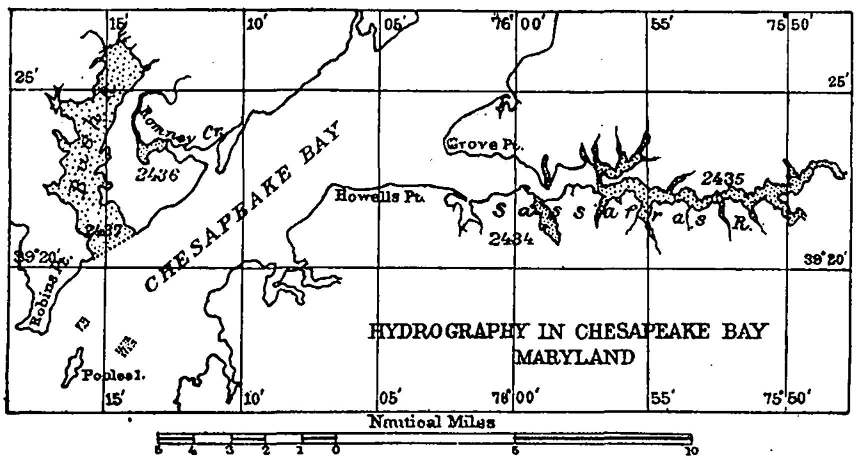
The work proper began on the 26th of July, and was continued without interruption until the 31st of August, at which time it was brought to a successful conclusion. On this same date Assistant Yates resumed the command of the steamer *Endeavor*, at Baltimore, to which point she had just returned from her duties in Long Island Sound. Assistant Yates returned to Bush River, where he disbanded the shore party.

The area covered by the survey in Bush River included all the tributaries from its mouth to the Pennsylvania Railroad bridge. Additional work was done in Romney Creek, and this completed the survey begun by the schooner *Eagre* during the previous season. A study of the survey of Bush River and Romney Creek shows no remarkable features or changes not developed by the original survey of 1889.

From September 8 to September 28 the *Endeavor* was engaged in the location of a speed trial course at Cape Charles City, Va. This work is described under special operations. The vessel returned to Baltimore after the completion of the field work, and was engaged in office work until the 12th of October, at which time the report and accompanying records were transmitted to the Office.

In view of the proposed deep-sea channel along the Sassafras River, from Chesapeake Bay to Delaware Bay, a survey of this region was undertaken on the 13th of October.

No. 10.



From that date until the 29th of November the work went on without interruption. The fact that only 6 square miles were covered, and that the number of soundings taken was more than 21 000 shows the character of the work.

After the completion of the Sassafras River survey, the steamer *Endeavor* spent three days in Baltimore Harbor, and then, on December 3, took up some additional hydrographic development at the mouth of the Elk River, and in the vicinity of Pooles Island. There was much interruption in this work, owing to bad weather, which usually prevails at this season of the year, and it was not until the 17th of December that the operations were completed. The *Endeavor* then went into winter quarters at Baltimore.

In accordance with instructions of the Superintendent the preparation of maps and data relating to changes in the upper Chesapeake Bay, as shown by the surveys of the Coast and Geodetic Survey, was commenced about February 1 at the suboffice in Baltimore. The work was undertaken by Assistant Yates, in conjunction with the director and officers of the Maryland geological survey. It involved the obtaining of tracings, on a uniform scale, of two complete sets of shore line, one from the original survey of 1845 to 1850, and the other from the surveys of 1897 to 1899, as well as two corresponding sets of selected hydrographic cross sections. On March 10, when this work was discontinued, all the necessary tracings of the shore line, together with the necessary data for constructing the hydrographic cross sections, had been collected. Three sets of blueprint copies of the shore-line tracings were obtained. Two of these were sent to the Maryland geological survey, and one to the Office at Washington, at the request of the Inspector of Hydrography and Topography.

From the beginning of the year until the 12th of March, when Assistant Yates was relieved of the command of the *Endeavor*, the office work was prosecuted with vigor, and was only completed with hard work and long hours. During this period the branch office of the Coast and Geodetic Survey was established in the custom-house at Baltimore.

On the 12th of March all office work relating to the vessel was up to date, and all records, sheets, etc., relating to the field work had been sent to the Office.

E. D. PRESTON: VIRGINIA, Cherrydale.

MAGNETIC.

SUMMARY OF OPERATIONS.

1 magnetic station occupied.

Under instructions of the Superintendent of the Coast and Geodetic Survey, Assistant E. D. Preston, in addition to his duties as editor, made a number of magnetic observations at Cherrydale, Va. One set of these was observed in September, 1899, and the other in June, 1900.

J. B. BAYLOR: VIRGINIA, MARYLAND.

MAGNETIC.

SUMMARY OF OPERATIONS.

10 meridian lines established.

From January 2 to May 21, 1900, Assistant Baylor was engaged at the Coast and Geodetic Survey Office upon his report of the magnetic survey of North Carolina. He also made, during this time, magnetic computations, and determined the constants of various magnetic instruments.

On May 4 Assistant Baylor received instructions to resume field work, and from May 21 until the end of the fiscal year he was engaged in laying out meridian lines in the State of Maryland. During this time the following county seats were occupied: Snow Hill, Princess Anne, Denton, Elkton, Ellicott City, Westminster, Annapolis, Prince Fredericktown, Leonardtown, Upper Marlboro, and Rockville. True north and south lines were determined from sun observations, and these lines were marked with granite posts. The magnetic declination was determined with a compass declinometer at each station.

It should also be mentioned that Assistant Baylor made a series of magnetic observations at Cape Charles City, Va., in connection with the total eclipse of May 28, 1900.

J. B. BAYLOR: NORTH CAROLINA.

MAGNETIC.

SUMMARY OF OPERATIONS.

28 magnetic stations.
28 meridian lines established.
28 standards of length marked on court-house floors.

J. B. Baylor, Assistant, Coast and Geodetic Survey, at the beginning of the fiscal year was engaged in magnetic observations in North Carolina. This work was done under the joint auspices of the Coast and Geodetic Survey and the North Carolina Geological Survey. Twenty-eight stations were occupied between July 1 and December 20, of which the following is a complete list:

Kenansville, Duplin County.
Burgaw, Pender County.
Pittsboro, Chatham County.
Carthage, Moore County.
Rockingham, Richmond County.
Monroe, Union County.
Charlotte, Mecklenburg County.
Shelby, Cleveland County.
Lincolnton, Lincoln County.
Rutherfordton, Rutherford County.
Concord, Cabarrus County.
Statesville, Iredell County.
Winston-Salem, Forsyth County.
Mount Airy, Surry County.
Wilkesboro, Wilkes County.
Greensboro, Guilford County.
Wentworth, Rockingham County.
Asheboro, Randolph County.
Troy, Montgomery County.
Laurinburg, Scotland County.
Lumberton, Robeson County.
Elizabethtown, Bladen County.
Whiteville, Columbus County.
Lillington, Harnett County.
Williamston, Martin County.
Henderson, Vance County.
Louisburg, Franklin County.
Graham, Alamance County.

At all of these stations the three elements—declination, dip, and intensity—were determined, and a true meridian line was established from morning and afternoon sun observations. The lines were marked with granite posts, weighing about 400 pounds and about 4½ feet long, embedded about 4 feet in the ground. The tops were dressed to about 6 inches square, and marked as follows:

N. C. G. S.
+
U. S. C. S.

A standard of length, for testing surveyors' chains, was marked on each court-house floor.

W. B. FAIRFIELD: CHARLESTON, S. C.

TRIANGULATION.

GEOGRAPHIC POSITIONS.

JASPER S. BILBY, *Foreman.*

SUMMARY OF OPERATIONS.

4 stations occupied.
14 new points determined.

Assistant Fairfield was attached to the party of Assistant Mosman, at work in the Western Division from July 1 to September 18.

On September 19 Assistant Fairfield left for Los Angeles, Cal., and he arrived in Washington on the 27th, reporting the same day at the Office.

From the date of Assistant Fairfield's arrival in Washington until October 1 he was engaged in miscellaneous duties connected with his field work. He was on leave of absence from October 1 to 19. On returning to the Office he was engaged in miscellaneous computations until the 17th of December, and from this date to the close of the calendar year he was again on leave.

From the 1st of January until the 28th of May, 1900, Assistant Fairfield was engaged in the Office at Washington on computations pertaining to the California-Nevada boundary line. Instructions were issued on the 24th to proceed to Charleston, S. C., to determine some points in the harbor for the resurvey of the old channel. He immediately proceeded to the locality indicated and determined the necessary points, based on the old triangulation stations Fort Johnson, Light-House Creek, and Charleston Light-House. The field computations were completed on June 22 and the geographic positions were furnished to Assistant Vinal, commanding the schooner *Matchless*, after which, on June 24, Assistant Fairfield left for Washington, arriving on the 25th. The time until the close of the year was employed in office work in connection with the field operations.

Schooner *Matchless*, W. I. VINAL, Commanding: SOUTH CAROLINA, Charleston.

TOPOGRAPHIC.

HYDROGRAPHIC.

TIDE.

WM. SANGER, *Chief Yeoman.*
SWEPSON EARLE, *Yeoman, First Class.*
JOHN W. CLIFT, *Chief Yeoman.*
GEORGE OLSEN, *Chief Yeoman.*
R. McD. MOSER, *Recorder.*
F. H. AINSWORTH, *First Watch Officer.*

SUMMARY OF OPERATIONS.

5 miles coast-line topography.
4 miles shore-line leveling for tide BM.
½ square mile hydrography.
9 miles sounding line.
164 angles measured.
681 soundings.
2 tide stations.

On the 2d of June Assistant Vinal, commanding the *Matchless*, in conformity with telegraphic instructions received on the 21st of May, sailed from San Juan, P. R., for Charleston, S. C., where he arrived on the 14th of June. The following day the vessel was permitted to go up to the city, and from this date until the close of the fiscal year the party was engaged in sounding the old channel of the entrance to Charleston Harbor.

D. L. Hazard: South Carolina, Georgia, Florida, Alabama, Kentucky, Tennessee.

MAGNETIC.

J. W. Miller, *Magnetic Observer.*

SUMMARY OF OPERATIONS.

39 stations occupied.

In order to make absolute determinations of the three elements of the earth's magnetism in the Southeastern States, Mr. D. L. Hazard received instructions, on March 16, to prepare for field work. On March 20 he left Washington, and the next afternoon began work at Columbia, S. C. The observations were continued from this date until the 29th of June, when the instruments were turned over to Mr. J. W. Miller, Magnetic Observer, who had been with the party since the 10th of June, and who was then capable of continuing the campaign alone.

At each place at least one complete set of observations was made, and at those marked with an asterisk two sets were made. Special declination readings were taken every ten minutes from 7.30 a. m. to 5 p. m., on Thursdays, at Oglethorpe, Thomasville, Lake City, Fernandina, Palatka, Marianna, Decatur, and Knoxville.

Special declination observations were made at Union Springs on the day of the solar eclipse.

The following is a list of the stations occupied:

Columbia,* S. C.
Augusta,* Ga.
Warrenton, Ga.
Milledgeville,* Ga.
Macon,* Ga.
Oglethorpe, Ga.
Albany, Ga.
Pelham, Ga.
Thomasville, Ga.
Madison, Fla.
Lake City,* Fla.
Baldwin,* Fla.
Jacksonville,* Fla.
Fernandina,* Fla.
St. Augustine,* Fla.
Palatka, Fla.
Gainesville, Fla.
Cedar Keys,* Fla.
Perry, Fla.
Tallahassee,* Fla.
Marianna, Fla.
De Funiak Springs, Fla.
Pensacola, Fla.
Evergreen,* Ala.
Union Springs, Ala.
Montgomery, Ala.
Birmingham,* Ala.
Cullman, Ala.
Decatur, Ala.
Huntsville, Ala.
Chattanooga,* Tenn.
Knoxville,* Tenn.
Caryville, Tenn.
Williamsburg, Ky.
Livingston, Ky.
Richmond, Ky.
Jackson, Ky.
Mount Sterling, Ky.
Morehead, Ky.

Mr. Hazard returned to Washington and reported in the Division of Terrestrial Magnetism on July 7.

H. L. MARINDIN: GEORGIA, Brunswick Outer Bar.

TRIANGULATION.

HYDROGRAPHIC.

TIDE.

HARRY L. FORD, *Nautical Expert.*
FRANK H. BRUNDAGE, *Aid.*
JOHN A. WHITNEY, *Observer.*
GEO. OLSEN, *Leadsman and Observer.*

SUMMARY OF OPERATIONS.

6 square miles triangulation.
2 stations occupied.
2 geographic positions determined.
44 miles sounding lines.
3 088 soundings.
1 826 angles measured.
2 tide stations established.
1 hydrographic sheet.

At the beginning of the year Assistant H. L. Marindin was engaged on office work connected with the resurvey of Sassafras River, Chesapeake Bay. He was so occupied until July 14, when there were transmitted to the Office one original hydrographic sheet, Turkey Point to Bush River, and twelve original sounding books for the above work.

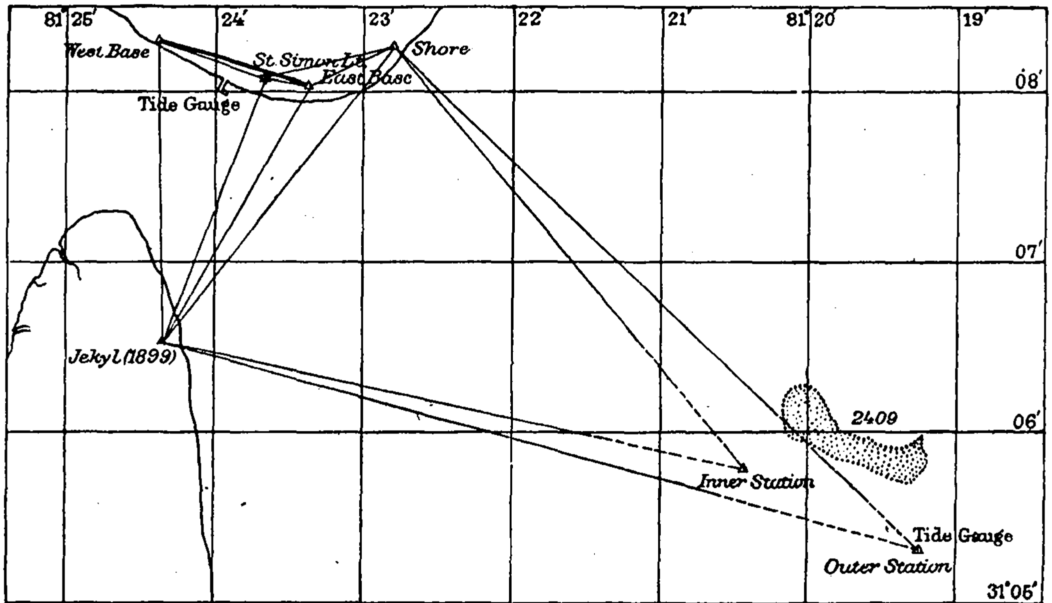
On this date instructions were issued for Assistant Marindin to report to the Secretary of War for duty in connection with the resurvey of the outer bar at Brunswick, Ga., as required by the river and harbor act of June 3, 1896. Supplemental instructions were issued for a conference in regard to the organization of party and the necessary requisition for instruments.

These preliminaries being arranged, Assistant Marindin reported to the Secretary of War, through the Chief of Engineers, and received on August 12 instructions to make a survey of the outer bar at Brunswick, under the provisions of the act stated above, and as amended by the river and harbor act of March 3, 1899.

The orders from the Secretary of War were received on the 15th of August, and on the 17th Assistant Marindin started for Brunswick, having previously made arrangements for the other members of his party to meet him there without delay. On the 29th the party was completely organized and ready to begin work. No steamer suitable for the work could be found at Brunswick, and it was therefore necessary to charter one from Jacksonville, Fla., from which all the soundings were made, and which was used to convey the party from St. Simons Island to the scene of work on the outer bar.

The field of operations lay at a distance of about 5 miles from land, so that it was necessary to have the steamer continually ready to sail at a moment's notice when the weather was favorable for doing the work. The exposed situation and the great accuracy required in this work made it impossible to work continually, as the least breeze from the southeast so disturbed the water that it was impossible to meet the requirements of the instructions. By the middle of October a sufficient number of depths had been measured to indicate the width and depth of the critical parts of the channel. A rough plat was made, which revealed a probable slight deficiency in the depth for a 25-foot channel over a length of about 800 feet. This was between Buoy No. 3 and Buoy No. 6. The information being imparted to Mr. C. P. Goodyear, the contractor, under authority contained in a letter of the War Department dated November 15, 1898, the dredge was set at work and its operations were continued for three days. During the progress of the work it was necessary for Assistant Marindin to attend a meeting of the Mississippi River Commission, to be held at St. Louis on the 4th of November, and to accompany the Commission on its annual tour of inspection down the river as far as New Orleans.

No. 11.



TRIANGULATION AND HYDROGRAPHY, BRUNSWICK OUTER BAR, GEORGIA.

Before leaving New Orleans Assistant Marindin received word from Mr. Ford, temporarily in charge of the work at Brunswick, that the soundings had been completed, and instructions were therefore sent for the party to return to Washington, where they arrived on the 15th of November. Assistant Marindin also arrived on the 15th, and immediately began the preparation of his report on the results of the Brunswick Outer Bar survey. Mr. Ford aided in this work, and the report, together with the finished chart, was completed on the 4th of December and transmitted the same day to the Secretary of War. The cost of this survey was paid by the War Department.

Mr. Marindin was on leave of absence from the 11th of December till the close of the calendar year, with the exception of the 19th and 20th, when, in obedience to instructions from the Secretary of War, he prepared a supplemental report on the means employed by the contractor in deepening the channels over the outer bar at Brunswick, Ga.

J. G. Spaulding, F. A. Kummell, B. W. Weeks.

New York, District of Columbia, Florida.

TIDE OBSERVATIONS.

Automatic tide gauges have been kept in operation throughout the year at the following places: Fort Hamilton, N. Y., J. G. Spaulding, Observer; Washington, D. C., F. A. Kummell, Observer; Fernandina, Fla., B. W. Weeks, Observer.

O. W. FERGUSON: OHIO.

PRECISE LEVELING.

W. C. COLE, *Recorder*.
C. W. NOBLE, *Aid*.

SUMMARY OF OPERATIONS.

365 kilometers leveling line.
121 bench marks established.

A party to be engaged in precise leveling was organized on the 1st of June, 1899, by Assistant O. W. Ferguson. The work proposed was a line from Gibralter, Mich., to Cincinnati, Ohio. Field work began on the 3d of June and was completed on the 28th of November. During this interval the line of precise levels was run between the aforesaid points and continued westward from Cincinnati as far as Lawrenceburg, Ind., 22 miles. This was done in order to make a strong connection with the transcontinental levels along the thirty-ninth parallel. Only one trustworthy bench mark could be found in Cincinnati, and it was necessary to proceed 22 miles westward before another one could be found.

This work is described in Appendix No. 7 to the Report for 1899, and a sketch of the line is given. It is there published somewhat out of chronological order, since it was desirable to give the results of all the correlated leveling work in this portion of the country.

STATES
DETIC SURVEY
RAL PROGRESS
1900
Sheet
SYMBOLS
WASHINGTON
MONTANA
IDAHO
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
LAKE SUPERIOR
IOWA
NEBRASKA
ILLINOIS
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
OKLAHOMA
INDIAN TER.
ARKANSAS
MISSISSIPPI
LOUISIANA
TEXAS
ARIZONA
NEW MEXICO
LOWER CALIFORNIA
MEXICO
GULF OF MEXICO
Helena
Bismarck
Deadwood
Pierre
St. Paul
St. Peters
Dubuque
Milwaukee
Fond du Lac
Omaha
Des Moines
Davenport
Rock Island
Keokuk
Quincy
Springfield
Atchison
Kansas City
Cheyenne
Salt Lake City
Ogden City
Santa Fe
Albuquerque
Prescott
Tucson
El Paso del Norte
Chihuahua
Dallas
Waco
Austin
San Antonio
Eagle Pass
Laredo
Corpus Christi
Houston
Galveston
Port Arthur
Little Rock
Memphis
Helena
Vicksburg
Jackson
Natchez
Baton Rouge
New Orleans
Cairo
Guaymas
Cape San Lazaro
La Paz
Cape San Lucas
Mazatlan
San Blas
Cape Corrientes
Manzanillo
Monterey
Matamoros
Rio Grande
Tampico
MEXICO
Vera Cruz
Frontera
Campeche


UNITED STATES
COAST AND GEODETIC SURVEY
SKETCH OF GENERAL PROGRESS
JUNE 30 1900
Western Sheet
Statute Miles
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
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
INDIAN TER.
TEXAS
MINNESOTA
LOWER CALIFORNIA
MEXICO
PACIFIC OCEAN
Cape Flattery
Seattle
Olympia
Portland
Salem
Walla Walla
Lewiston
Helena
Virginia City
Boise City
Bismarck
Deadwood
Pierre
Cape Mendocino
Ogden City
Salt Lake City
Cheyenne
Denver
Omaha
Atchison
Topeka
Pt. Conception
Santa Barbara
Santa Fe
Albuquerque
Prescott
Tucson
El Paso del Norte
Dallas
Waco
Austin
San Antonio
Galveston
Port Arthur
Corpus Christi
Laredo
Eagle Pass
Matamoros
Rio Grande
Monterey
Chihuahua
Guaymas
Guadalupe I.
Cerros I.
Cape San Lazaro
La Paz
Cape San Lucas
Mazatlan
San Blas
Cape Corrientes
Manzanilla
Tampico
Vera Cruz
MEXICO
125°
120°
115°
110°
105°
100°
95°
45°
40°
35°
30°
25°
20°

O. W. Ferguson: Kentucky.

PRECISE LEVELING.

H. A. Kelley, *Recorder*.
G. C. Baldwin, *Rodman*.
R. C. Howard, *Rodman*.

SUMMARY OF OPERATIONS.

77 kilometers leveling line.
16 bench marks established.

Assistant Ferguson was ordered to Washington on the 29th of November, and he was engaged in Office work until the 19th of December, when he took leave of absence until the 6th of January. On this date he resumed work on the field notes, and completed the reduction and a report of the same on the 13th of March. From this date to the 2d of June he was employed in the Computing Division, and on the 3d, in obedience to orders from the Superintendent, he organized a party at Covington, Ky., to carry on a line of precise levels from this point to Somerset. Field work began on the 6th of June, and the line was completed to Corinth by the end of the year.

B. *MIDDLE DIVISION.*

F. D. GRANGER: NEBRASKA.

TRIANGULATION.

E. E. TORREY, *Foreman.*
D. A. LEWIS, *Driver.*

SUMMARY OF OPERATIONS.

7 triangulation stations.
41 primary directions observed.
50 tertiary directions observed.
1 390 square miles triangulation.
18 geographic positions determined.
15 elevations determined trigonometrically.

The triangulation along the ninety-eighth meridian, in Nebraska, was carried on by Assistant Granger, working north from the station Cameron, where he was on the 1st of July, 1899. A 12-inch theodolite, No. 146, was employed in the observation of horizontal directions. At station Cameron observations were made in 13 positions of the azimuth circle, two series, telescope direct and reverse, being taken in each position. At the following station, Pompey, and at all subsequent ones, the instrument was used in 24 positions, with one series in each position, telescope direct and reverse. At each station observations of double zenith distances and micrometric measurements for differences of height were made. The original intention was to observe the line from Brayton to Elm. This required a signal of 50 feet height at the latter point, and one of 70 feet at the former. On closer inspection of the ground, however, it was found to be impracticable, owing to the limited area of level ground in the vicinity of Elm, to construct a signal of the height required. The point Daily, therefore, was selected, and the quadrilateral Elm-Custer-Brayton-Yale modified by the introduction of an interior station. This obviated the necessity of high signals, and gives a figure equally strong.

The observations being concluded at Brayton, an observing tripod and scaffold were erected at Custer, the instruments and outfit placed in storage at Greeley Center, and the party disbanded. Assistant Granger then proceeded to Washington and reported in person at the Office, where he was employed from November 11 to November 24. Assistant Granger had leave of absence from November 25 to the end of the calendar year.

F. D. GRANGER: NEBRASKA.

RECONNAISSANCE.
TRIANGULATION.

E. E. TORREY, *Foreman*.
D. A. LEWIS, *Driver*.

SUMMARY OF OPERATIONS.

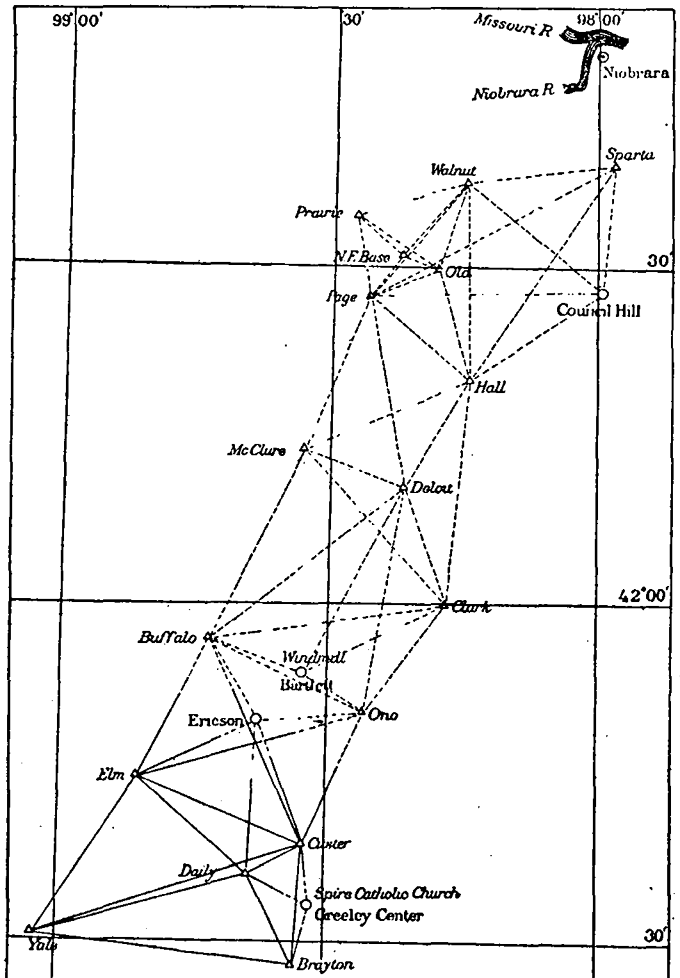
485 square miles reconnaissance.
7 points selected.
1 645 square miles triangulation.
9 stations occupied.
23 geographic positions.
20 elevations determined.

Assistant Granger was on duty at the Coast and Geodetic Survey Office from the beginning of the calendar year until April 9, on which date he proceeded to Greeley, Nebr. His instructions were to organize a party, continue the reconnaissance of the ninety-eighth meridian triangulation northward until sufficient points had been obtained for a complete season's work of observation of angles, and then to return to Greeley and take up the triangulation proper. He was also directed to select a base line in the valley of the Elkhorn River, if suitable topographic features could be found there.

Arriving at Greeley on the 18th of April, the party was organized, and on the 24th proceeded northward toward the Elkhorn River. As some of the points selected in the scheme of 1896 were uncertain as regards intervisibility, it was decided to make an investigation of this phase of the subject and, if necessary, make a rearrangement of the scheme of triangles. This reconnaissance was carried out and a scheme comprising the stations Walnut, Sparta, Council Hill, and Hall as the last quadrilateral, was adopted. Being unsuccessful in his attempt to find a suitable location for a base line at the point previously indicated, an examination was made of the country in the neighborhood of Page station, and here, in a valley, was found a site, 8 kilometers in length, which answered every requirement. The station Page gave the southwest terminal of this base line, and only two stations, Prairie and Old, were required for the base net. Including the base line, the work laid out up to this point fixed 12 stations for the triangulation which could be occupied. It was therefore decided to return to Greeley and take up the measurement of angles.

Arriving at the latter place on May 24, Assistant Granger proceeded to the station Daily, where he arrived and began observations on the 28th. This work was finished early in June. On the 6th the party and outfit were moved to Custer. Observations

No. 12.



TRIANGULATION IN NEBRASKA

were begun on the 8th and closed on the 15th. The party and outfit were then transferred to Ono, where observations were begun on the 28th and were in progress at the close of the year.

During the intervals when the observations were not being made, and for a part of the time while they were being carried on, Mr. E. E. Torrey and Mr. D. A. Lewis, driver, were engaged in erecting signals. When not otherwise employed Mr. Torrey assisted in the observations and Mr. Lewis kept up the records.

B. E. Tilton: Nebraska.

PRECISE LEVELING.

W. H. Burger, *Aid.*

SUMMARY OF OPERATIONS.

384 kilometers leveling line.
64 bench marks established.

On June 30, 1899, Aid Benjamin E. Tilton was attached to the leveling party of Assistant A. L. Baldwin. Mr. Baldwin being instructed to report for duty at Washington, the charge of the operations was confided to Aid Tilton, who prosecuted the work continuously from the beginning of the fiscal year to October 17, when the party was disbanded at Norfolk, Nebr.

The personnel consisted of a recorder, two rodmen, and two hands, which organization was permanent throughout the season. Actual field operations were possible on about twenty-one days per month, the principal causes of delay being bad weather. The line was carried 220 miles from Cortland, Nebr., northward to Norfolk, in the same State; and also a side line was run westward from Grand Island, Nebr., 20 miles, to the triangulation station Shelton.

Three permanent bench marks were placed at or in the vicinity of Norfolk. This, with a Geological Survey bench mark, about 2 miles south of Norfolk, constitute the set of marks established at the end of the season.

Aid Tilton was granted his annual leave on the close of field operations and reported at the Office, in Washington, on November 20. After this date, assisted by Aid W. H. Burger, he continued the revision of field computations relating to the season just closed. This work was completed on the 15th of January, 1900, and the results are printed in Appendix No. 6 to the Report for the year 1899.

A report was submitted on the 25th of January, after which date Aid Tilton began checking the field computations of the leveling work executed by Assistant Winston at different times between 1889 and 1894. This work was completed on the 23d of March, on which date he began work on the adjustment of the level net, and was so occupied until the 24th of April.

B. E. TILTON: NEBRASKA.

PRECISE LEVELING.

SUMMARY OF OPERATIONS.

139 kilometers precise leveling line.
12 permanent bench marks.

On April 4 instructions were issued to Aid Tilton to prepare for field work to complete the line of precise leveling started by him the previous season as far as Sioux City, Iowa.

Leaving Washington on April 25, after taking three days' leave of absence he proceeded to Norfolk, Nebr., arriving on the 1st of May. The party had the same organization as the previous year, namely, a recorder, two rodmen, and two hands.

Field operations were begun on May 8, and the line was completed to Sioux City, a distance of 80 miles, by the 20th of June. Twelve permanent bench marks were left on this line. After finishing the work he proceeded with the party to Norfolk, Nebr., and at once started the line Norfolk to Page, Nebr., to connect the levels with the Page base line. The work was completed to Hadir, Nebr., a distance of 7 miles, by the 30th of June.

WM. EIMBECK: KANSAS.

TRIANGULATION.

F. M. LITTLE, *Assistant.*
JOHN KENNEY, *Foreman.*

SUMMARY OF OPERATIONS.

3 stations occupied.
500 square miles triangulation.

On the 1st of July Assistant Eimbeck began the erection of signals at the stations Wilson and Heath, of the Transcontinental Triangulation along the thirty-ninth parallel. The line joining these two stations was to serve as a basis from which the triangulation along the ninety-eighth meridian was to start. After having placed these stations in order a signal was erected at Bossing. From this point seven primary lines, including the reference mark, were observed. The preliminary preparations, the organization of the party, and the construction of the signals at the stations Sherman and Central occupied the time from July 19 to August 9. Observations began on the 10th, and work concluded on the 13th of September, during which time signals were erected at Little River and Chase, and a large number of observations on secondary points were made and zenith distances measured. On the 14th of September the party proceeded to Sherman, from which six primary and about twenty secondary lines were observed. The necessary preliminary work extended until September 20, and the actual observations began on the 21st, and continued until the 13th of October. From this point the longest line of the season was observed, namely, from Sherman to Wilson, the length of the line being about 32 miles.

The third station was Loder, from which three primary and about twenty-five secondary directions, as well as azimuth distances, were observed. From October 14 to October 19 preparations were made, and the required observations were obtained between the 20th and 30th October. The work for the season closed at Loder, and the instrumental outfit was sent to Salina and placed in storage on the 2d of November.

In the observation of horizontal directions and vertical angles the theodolite and vertical circle were alternately used by mounting them upon the 4-foot iron stand surmounting the frame tripod at each triangulation station.

The observations were executed in strict conformity with the Superintendent's instructions; that is, a single series in each of twenty-four evenly spaced positions upon the limb of the theodolite. The zenith distances upon the primary triangulation points were measured, in general, on eight different days, in the afternoon or just before the horizontal direction observations were taken up. The ordinary frame tripod, such as was used at Bossing and Sherman, having proved unsatisfactory, in consequence of the high winds, Assistant Eimbeck decided to build what he called a "quadripod," and this being employed at Loder proved to be a vast improvement on the previous construction. The twist in azimuth proved to be regular and very small, and the vibrations experienced from high wind were barely perceptible.

The party was disbanded on the 11th of November. Assistant Little and Foreman Kenney left immediately for Washington, and Assistant Eimbeck, after having disposed of the party accounts and made arrangements for storage during the winter, reported to the Superintendent on the 23d of November.

Twenty days' leave of absence was taken between this date and the close of the year, and the rest of the period until June 30, 1900, was devoted to office work in connection with the field operations. During this latter period the series of observations carried on at the Coast Survey Office, in Washington, for the purpose of determining the variation of the coefficient of refraction depending upon the season of the year were continued. The observations were made monthly, during the first twenty days, and consist of about twelve to thirteen days' differential micrometer measures upon four terrestrial objects in the southwestern horizon. During Assistant Eimbeck's absence in the field, July 1 to November 15, these observations were made by Mr. E. G. Fischer, Chief of the Instrument Division.

RECONNAISSANCE.

BASE LINES.

SUMMARY OF OPERATIONS.

3 800 square miles reconnaissance.
50 points selected.
6 base lines selected and located.
10 concrete piers constructed.

After connecting his reconnaissance along the ninety-eighth meridian with the work of Assistant Eimbeck, Assistant Forney proceeded, on July 11, 1899, with his party, to Bowie, Tex., where he arrived on the 12th. After pitching camp, a reconnaissance was made for a base line at this place. One was located with its southeastern terminus 6 miles west of the town of Bowie and its northwestern terminus 1 mile southeast from the town of Bellevue. Each end of the base was marked with a permanent concrete pier capped with a hard limestone block weighing 600 pounds.

On the 25th of July the party left Bowie and traveled by wagon to Stephenville, Tex., arriving on the 30th. The base was located at this point, with its northern terminus on Bunker Hill, 5 miles east of the town of Stephenville, and its ends were marked in a manner similar to that employed at Bowie.

On August 14 Assistant Forney left Stephenville and proceeded to Lampasas, Tex., arriving on the 16th. A base was located with its northern terminus 2 miles east of the town, and the usual permanent concrete piers were constructed at the ends of the line.

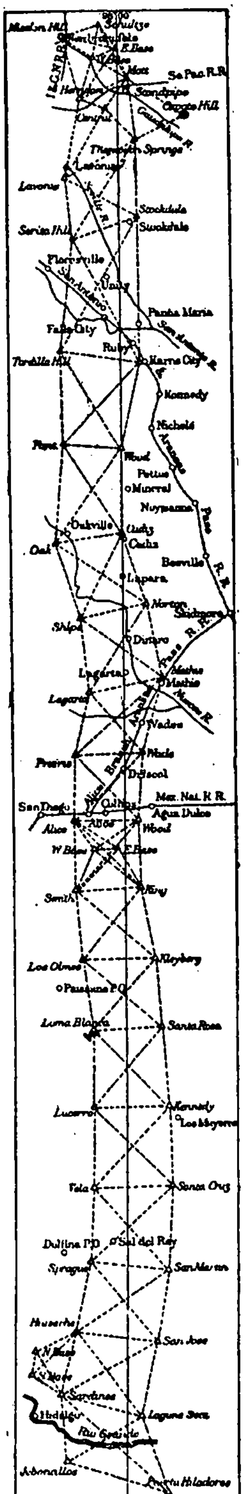
Leaving this point on August 28, the party arrived at New Braunfels, Tex., on the 2d of September. No suitable location could be found here for a base, and on the 12th the party proceeded to Seguin, Tex., where an excellent site for a base was found in Guadaloupe Valley, 9 miles north of Seguin. The line was located and the usual concrete piers were constructed at the ends.

On September 28 the reconnaissance was taken up from this point southward and carried through to the Rio Grande, developing a series of well-conditioned figures forming a chain of 18 unbroken quadrilaterals. The scheme extends 263 miles along the ninety-eighth meridian, with an average length of sides of 16 miles, covering an area of 3 419 square miles. A strong connection was made at the southern end with the line Sardines-Laguna Seca, two of the triangulation stations selected by Assistant Forney in 1894 while making the reconnaissance for triangulation along the Rio Grande.

A base line was located 8½ miles west of north from Hidalgo. It was not practicable at the time to procure material for constructing permanent piers, and the ends were marked by a triangle cut on a mesquite tree.

On November 29, after having completed the reconnaissance,

No. 14.



RECONNAISSANCE. TEXAS

the party left Hidalgo for Alice, Tex., where they arrived on the 4th of December. A base line was selected here, about 7 miles south of the town, and marked with permanent piers of concrete.

Instructions were issued on the 28th of November to Assistant Forney to ship by freight to Washington, D. C., all instruments and such camp equipage as would be useful for future work. Some condemned Coast and Geodetic Survey property was sold at public auction, and on December 20 Assistant Forney proceeded to San Antonio, at which point he was on leave of absence from December 31, 1899, to January 10, 1900. He reported at Washington on January 14.

From Anthony, Kans., to Hidalgo, Tex., covering a distance of 740 miles along the ninety-eighth meridian, eight base lines were laid out, with an average length of 7·5 km., the longest line being 12·8 and the shortest 6·0 km. These lines are placed at intervals of 100 miles apart. Many of the points on these base lines are located near railroad stations, where connection can be made for telegraphic longitude.

C. WESTERN DIVISION.

C. H. SINCLAIR: ARIZONA, Maricopa.

ASTRONOMIC.

SUMMARY OF OPERATIONS.

1 longitude determined.

During the month of July, 1899, Assistant Sinclair was engaged in office work relating to his last season's operations. During August and September and until the 6th of October he was engaged on the topographic sheets illustrating the California-Nevada oblique boundary from Lake Tahoe to the Colorado River. During this time preparations were made for the determination of the difference of longitude between Maricopa, Ariz., and El Paso, Tex.

On October 6 Assistant Sinclair proceeded to El Paso, Tex., in order to make this determination, in cooperation with Assistant J. E. McGrath. Arriving at El Paso on the 12th of October, the observatory erected in 1893 was repaired, the pier was rebuilt, and the necessary preliminary arrangements made for the longitude determination. The ground on which the El Paso station was established in 1892 has since that date been transferred from the General Government to the city, and will soon be converted into a public park.

On account of the delay in preparing the station at Maricopa, no exchange of signals was effected before the 20th of October. Six determinations were made between the 20th and 26th, the observers exchanging positions when the work was half completed. During the latter part of Assistant Sinclair's stay at Maricopa an astronomic latitude was observed with telescope No. 6, by 50 observations on 18 pairs of stars, on October 24, 25, and 26.

All the work for which instructions had been issued having been completed on the 27th, the outfit was shipped to Washington and the observers returned, reporting on the 1st of November.

The longitude work occupied Assistant Sinclair until the end of October. After completing the computations relating to the field work, the topographic sheets of the California-Nevada boundary survey were again taken up and work on them continued until the 29th of November. Leave of absence was then granted him until the close of the calendar year.

In January, 1900, the positions of points on the corrected boundary line, 141 in number, were computed, and work was also continued on the topographic sheets. From this time until the end of the year Assistant Sinclair was engaged in preparing his report on the entire operations connected with the oblique boundary, from its beginning, in 1893, until its close, in 1899. A map was also prepared, on a scale of 1–400 000, showing the Von Schmidt line of 1873, the Coast and Geodetic Survey random line of 1893–1899, the triangulation of the line from Lake Tahoe to the Colorado River, 400 miles, and other miscellaneous data. The report appears as Appendix No. 3 of this Report.

Steamer *Gedney*, E. F. DICKINS, Commanding: WASHINGTON, Rich's Passage, Port Orchard.

TRIANGULATION.

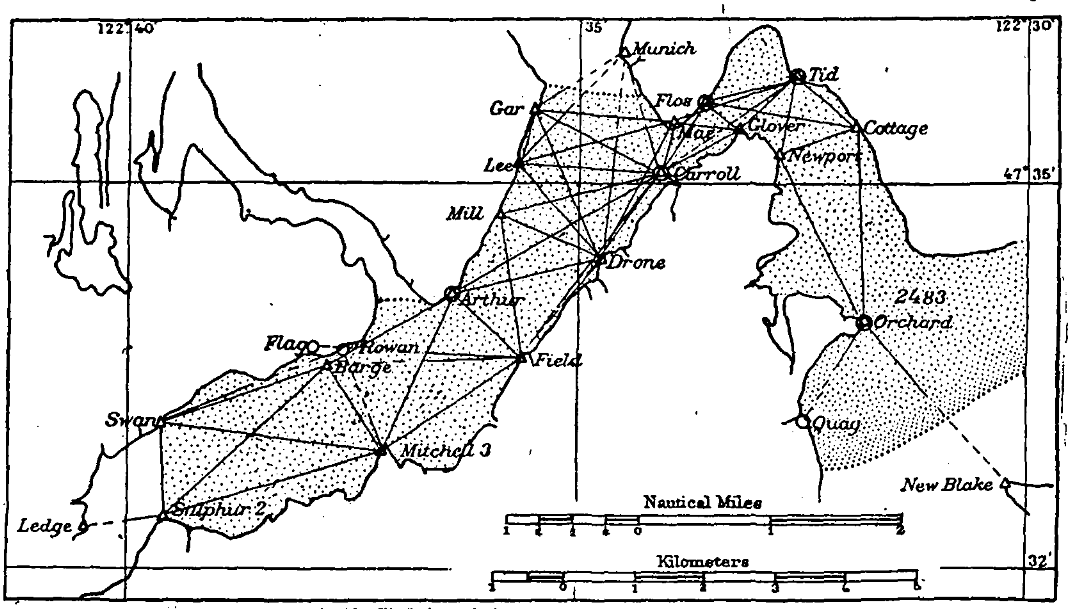
TIDE.

GEORGE F. THOMAE, *First Watch Officer.*
A. H. DUTTON, *Second Watch Officer.*
W. G. APPLETON, *Third Watch Officer.*
I. W. EISLER, *Fourth Watch Officer.*
Dr. W. W. MARKOE, *Hospital Steward.*

SUMMARY OF OPERATIONS.

11 square miles triangulation.
13 stations occupied.
1 249 angles measured.
9 square miles hydrography.
229 miles sounding lines.
10 038 soundings.
3 816 angles measured.
2 tide stations.

No. 15.



TRIANGULATION AND HYDROGRAPHY

RICH'S PASSAGE AND PORT ORCHARD, WASHINGTON

During the winter months Assistant E. F. Dickins was employed at the suboffice in San Francisco, inking the three topographic sheets of the resurvey of San Francisco and San Pablo bays, together with other office duties.

On the 20th of February he received instructions to proceed to Seattle to take command of the steamer *Gedney* and prepare her for work in the Aleutian Islands. Assistant Dickins was unavoidably detained in San Francisco until the 7th of March, when he proceeded north and arrived at Seattle on the 11th. On his arrival it was found that the *Gedney* had been inspected by the United States inspectors and reported as unseaworthy. Assistant Dickins was, therefore, ordered to continue the resurvey of Rich's Passage and Port Orchard, and this work was completed on the 22d of April. Office work was continued at Seattle after this date, and preparations were made to make an examination of the water front of Port Townsend.

On May 26, just as the party was about to proceed to Port Townsend, telegraphic orders were received for the transfer of several members of the party to other duty. For the time being, therefore, it was impossible to proceed with the field work, and office work was resumed.

On June 2, at the request of the contractors and builders of the torpedo boat *Goldsboro*, range signals were erected on the speed trial course. It was now determined to take up the work in Seattle, and preparations were made, but on the 21st telegraphic instructions were received which authorized the repairs of the *Gedney* at the naval station. Having communicated with the commandant, he requested that the vessel be brought over to the station, and on the 25th the work of stripping her was begun.

J. J. GILBERT: WASHINGTON, Seattle.

SUBOFFICE.

TRIANGULATION.

TOPOGRAPHIC.

TIDE.

SUMMARY OF OPERATIONS.

12 square miles triangulation.
8 stations occupied.
45 geographic positions determined.
21 square miles topography.
44 miles coast line topography.
34 miles roads.
2 topographic sheets.

At the beginning of the year Assistant J. J. Gilbert was in charge of the suboffice at Seattle, Wash. In anticipation of instructions to make a resurvey of the city of Seattle, much of his time was devoted to the collection of data, not alone from the city engineer, Mr. R. H. Thompson, but also from Capt. W. R. Ballard, of the West Coast Improvement Company, and f.om Mr. A. H. Kiehl, United States Assistant Engineer, at the military station. Many of these plats were on different scales, which necessitated a general reduction to that chosen, namely, 400 feet to the inch. Compilations and reductions occupied Assistant Gilbert until August 9, when he received instructions to take up the work. Estimates were immediately submitted, and on August 23, the approved estimates being received, the work was taken in hand. The necessary instruments were brought to Seattle from Lopez Island, the steamer *Fuca* was overhauled and brought to Seattle from Port Orchard, and the necessary projections were made.

An automatic tide gauge was kept in operation at Seattle, Wash., under the direction of the Assistant in charge of the suboffice at that place. This suboffice served as headquarters for field officers, temporarily out of the field, and furnished accommodations for the completion of the field records.

Various officers, temporarily on duty at the suboffice, acted as tidal observers, as the occasion demanded.

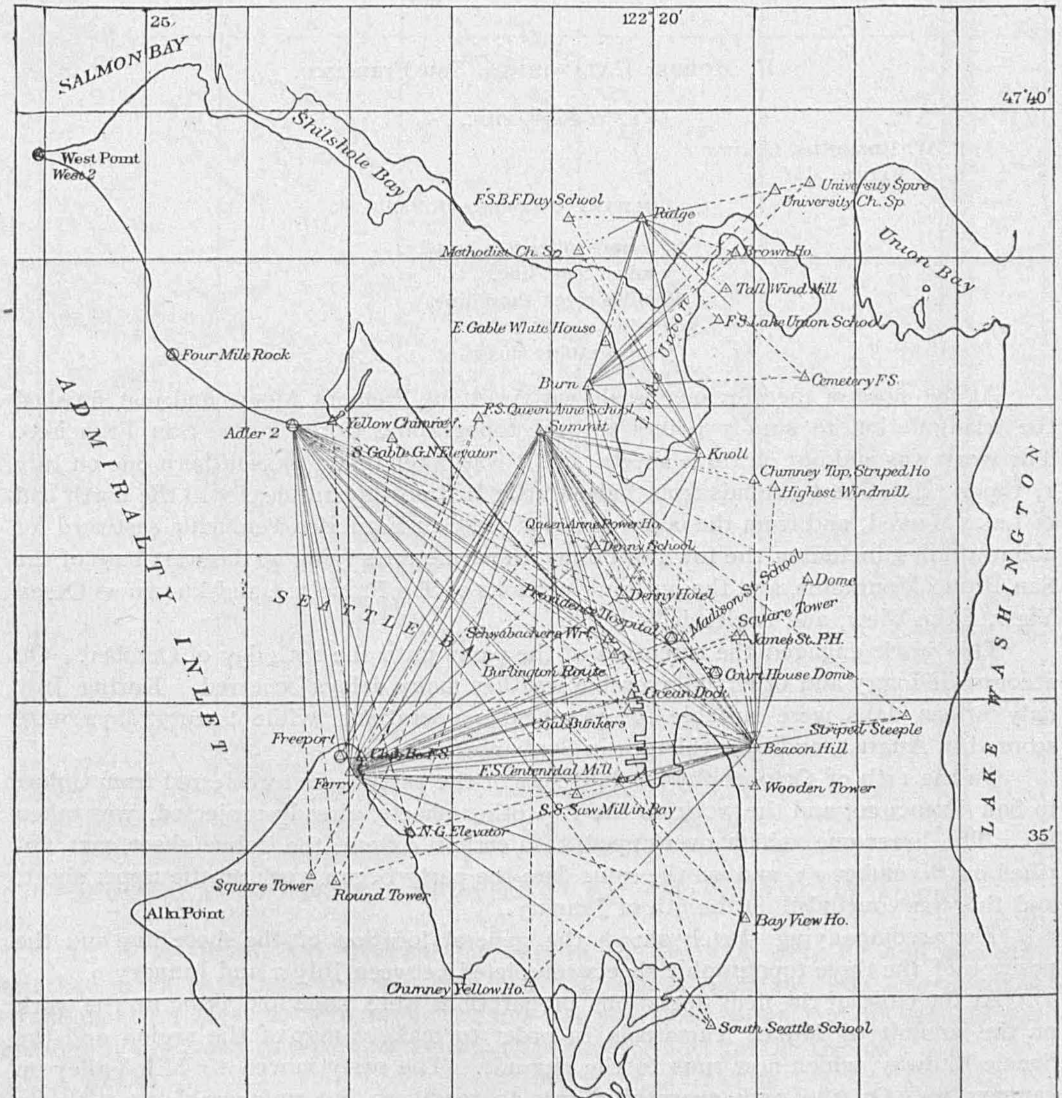
A triangulation was executed, based on the line Alder to Freeport, and many objects along the shores of Seattle Bay and throughout the city were located, and the network was extended across Lake Union as far as the State University building.

On September 25 the topography was commenced, and continued without interruption until the end of the season. Some of the shore line of Lake Union and Lake Washington was obtained from the city plats, and is believed to be nearly correct. Several lines were run locating street corners, which facilitated the use of the city plats.

The contours were taken from the city maps, but were continued beyond the limits of the surveys by sketching and actual determination of heights.

Field work closed on the 31st of October, the party was discharged, and on the same date the Seattle suboffice and the steamer *Fuca* were transferred to Assistant J. F.

No. 16.



TRIANGULATION AND TOPOGRAPHY. SEATTLE BAY, WASH.

Pratt. On November 1 Assistant Gilbert left Seattle for San Francisco, and he was there engaged in office work connected with the Seattle survey to January 1, 1900.

F. MORSE: CALIFORNIA, San Francisco.

TOPOGRAPHIC.

F. W. EDMONDS, *Assistant.*
B. A. BAIRD, *Aid.*

SUMMARY OF OPERATIONS.

61 square miles topography.
3 miles coast line.
66 miles creek shore line.
301 miles roads.
3 topographic sheets.

At the close of the previous fiscal year Assistant Fremont Morse had just finished the triangulation to supply points for the topographic work around San Francisco. The work was laid out on three sheets, and it was taken up on the southern one on July 1, 1899. This sheet extends from False Cattle Hill northward, nearly to the north end of Lake Merced, and from the ocean shore of the San Francisco Peninsula eastward for about 4 miles, including the town of Colma, the cemeteries lying at the west base of the San Bruno Mountains, and the outlying portions of San Francisco, and known as Ocean View, Lake View, and Ingleside.

This work engaged the attention of the party until the 10th day of October. On account of foggy and other unfavorable weather many delays occurred. During July only fifteen days were suitable for plane-table operations, while twenty days were secured in August, and only thirteen in September.

On the 11th of October the headquarters of the party were transferred from Colma to San Francisco; and the work on the two other sheets, already projected, was taken up. The lower one, which overlapped, to a certain extent, the Colma sheet, was finished on December 13, and on the same date the party began work on the upper sheet, and this was concluded on the 9th of January.

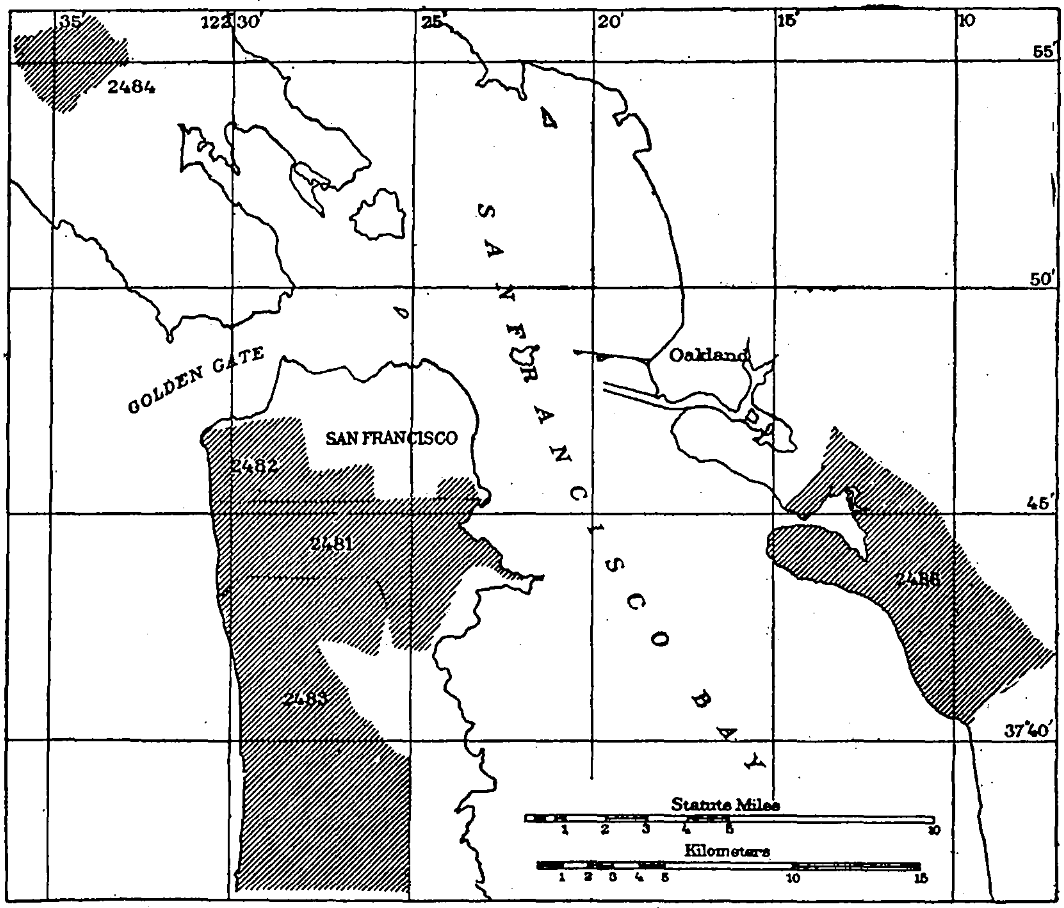
The accompanying sketch shows the general location of the shore line and the position of the three topographic sheets completed between July 1 and January 9.

At the close of the field operations preparations were made for taking up the work on the summit of Mount Tamalpais, in order to make a map of the region and the Scenic Railway, which now runs to the summit. The party moved to Mill Valley on January 10. On the 15th everything was in readiness, but unfavorable weather for two days prevented work. The survey was finished on the 26th and the topography connected with former work in this locality.

In the meantime instructions, dated January 15, had directed Assistant Morse to complete the San Leandro sheets, and accordingly the party was moved across San Francisco Bay and located at the town of San Leandro. The work continued with little interruption until April 24, when the season closed.

Assistant Morse had been on continuous field duty for more than thirteen months. After closing field work, on April 4, Assistant Morse was employed in the office inking six plane-table sheets which he had in hand. This work lasted until the 30th of June.

No. 17.



TOPOGRAPHIC RESURVEY, VICINITY OF SAN FRANCISCO, CALIFORNIA

Mr. B. A. Baird, Aid, reported for duty in the party on May 21, and was still attached to the party on June 30. Mr. F. W. Edmonds, Assistant, was also attached to the party on May 22. He began inking a topographic sheet, and on May 27 was ordered by telegraph to report to Assistant Dickins for duty on the *Gedney*.

A. F. Rodgers: San Francisco.

SUBOFFICE.

TIDE.

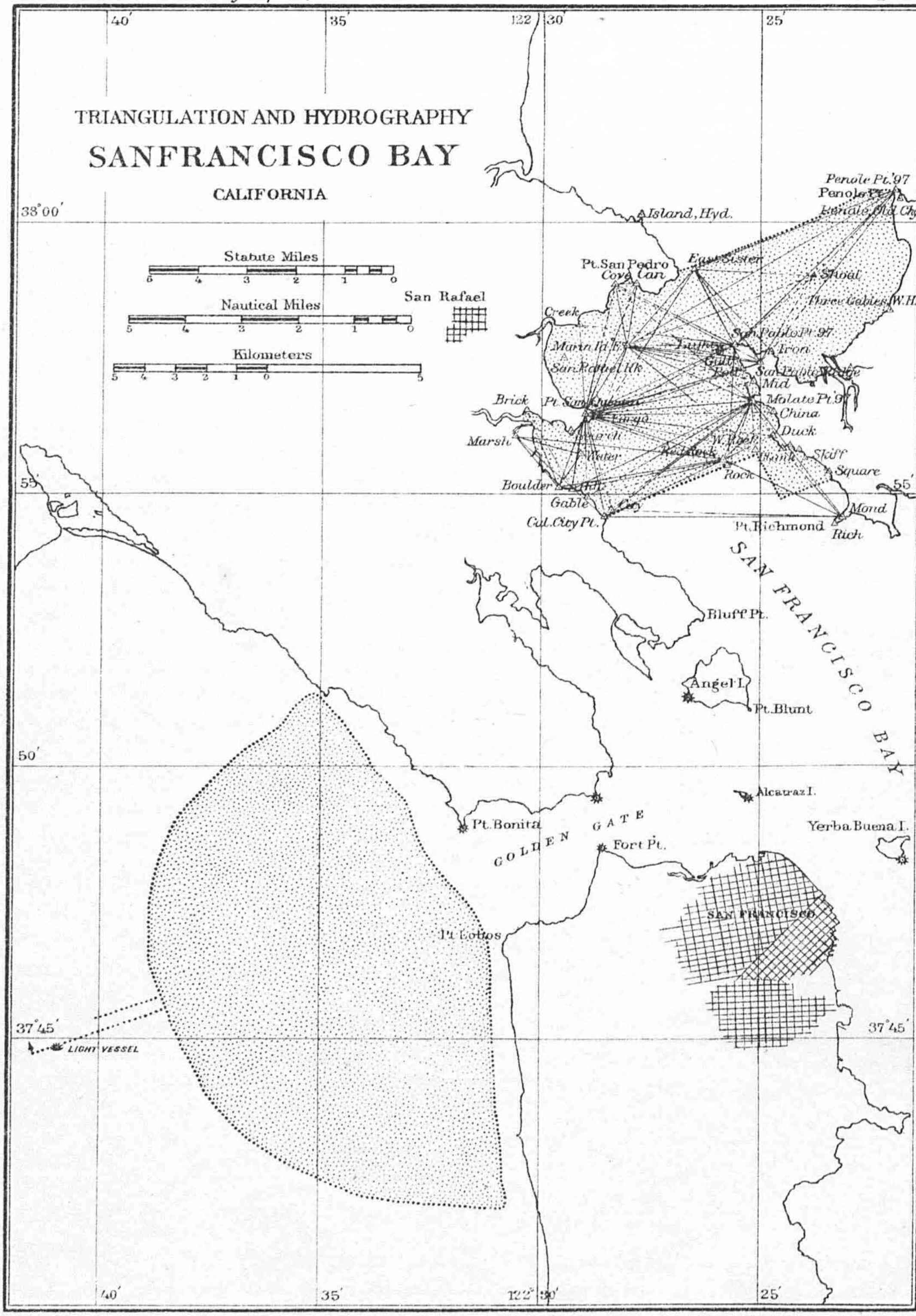
J. J. Gilbert, *Assistant.*
F. W. Edmonds, *Assistant.*

Assistant A. F. Rodgers has been in charge of the suboffice at San Francisco during the entire year. The duties devolving upon him are various, and require an intimate knowledge of the details of the work on the Pacific coast. Among the duties may be mentioned the filling of requisitions for instruments and equipments, and furnishing data to the officers of the Survey and to coordinate branches of the Government, officers of the Engineers, and to civilians. Information is collected in regard to localities and sailing routes in Alaskan waters. Data is prepared for publication in the daily newspapers of San Francisco relating to the sun, moon, and tidal phenomena for current dates.

During the year Assistant Rodgers had charge of the building of a wharf and the construction and installment of a tide indicator on the southern extremity of Alcatraz Island, San Francisco Bay. On February 8 the adjustment of the index of the indicator, to show the surface plane of the water of the bay, was commenced. The index was set by readings of the fixed staff at the Coast Survey tide station at the Presidio. Observations and slight adjustments were continued for about one month, readings at ten-minute intervals being made at the indicator by means of a telescope, from the summit of Telegraph Hill, and compared with simultaneous observations by the tide observer at the Presidio. This indicator is regarded as a substantial aid in navigating the waters of San Francisco Bay. It is also of use to the artillery officers using the range finders at the army posts.

An automatic tide guage was kept in operation at the Presidio, San Francisco, Cal., throughout the year under the direction of Assistant Rodgers, with Mr. H. S. Ballard as tide observer.

During the year the following persons were temporarily employed in the office, under Assistant Rodgers's direction: Mr. C. W. Fitzgerald reported on July 18. He was detached by order from the Superintendent dated November 3, and reported for duty on the steamer *Pathfinder*. Mr. P. M. Newhall reported under orders of November 14, and was on duty until January 3, 1900 Assistant F. W. Edmonds reported on December 6. In April he was temporarily detached, in order to collect data relating to the California-Nevada boundary, and on May 17 he reported to Assistant Fremont Morse. Mr. W. P. Taliaferro reported for duty as writer, and served until the end of the year.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Steamer *McArthur*, F. WESTDAHL, Commanding: CALIFORNIA, San Francisco Bay.

TRIANGULATION.

HYDROGRAPHIC.

TIDE.

B. J. CROWLEY, *First Watch Officer.*
JAMES SULLIVAN, *Chief Machinist.*
R. H. HAWKES, *Hospital Steward.*
L. H. WESTDAHL, *Yeoman, First Class.*
F. G. CRIST, *Chief Yeoman.*

SUMMARY OF OPERATIONS.

12	triangulation stations occupied.
38	geographic positions determined.
65	square miles hydrography.
1 286	miles sounding lines.
22 028	angles measured.
56 929	soundings.
1	tide station.

On the 1st of July, 1899, the steamer *McArthur*, with party on board, was lying alongside the dock at the Union Iron Works, San Francisco. The repairs to the ship, begun some time previous under the direction of Assistant Dickins, had been suspended by telegraphic order from the Superintendent, but they were resumed on July 5 and continued until completion on July 20.

Following this a trial was made and various anchorages in the harbor were examined under the immediate supervision of the Inspector of Hydrography and Topography, who was on board. On July 26 the vessel was laid up in ordinary at Oakland Harbor, and the office work on the San Diego and San Pedro hydrographic sheets was continued.

On August 15 the Superintendent of the Survey made an official visit and inspected the ship and crew. Between the 17th and 25th, under his personal direction, the vessel visited Mare Island Navy-Yard and various portions of the bay on a tour of inspection. Returning to Oakland Harbor on the 25th, office work was continued until the last of September.

Instructions were received by Assistant Westdahl on September 2 for the resumption of the hydrographic survey of San Francisco Bay and approaches as soon after October 1 as the office work then in hand would permit. Pending the arrival and installation of a new boiler for *Launch No. 28*, Assistant Westdahl recommended that the bar work be taken up first, and to this end Assistant Morse was asked to cooperate to the extent of erecting two large signals at certain designated triangulation stations for use in the bar work. These signals were duly erected, but on October 2 telegraphic orders came to do the inside work first, and at the same time Assistant Perkins, in command of the *Pathfinder*, was requested by the Superintendent to turn over temporarily to the *McArthur* one of his launches. The decision in regard to the inside work was most fortunate, since such thick weather prevailed during the months of August, September, and October that little could have been done outside.

On October 9 the ship was moved to McNears Landing, where work was immediately begun on sheet No. 10, from Point Penole to Marin Islands, by the erection and determination of the necessary signals. Actual sounding began on October 23, and continued without interruption until December 22, when the sheet was completed, with the possible exception of some closer work in the examination for sunken rocks to the westward and southward of the Brother Islands.

From October 24 to 28 and from November 6 to 11 two officers and five men from the *Pathfinder* were temporarily transferred to the *McArthur* for instruction in hydrographic work. This enabled Assistant Westdahl to use two parties.

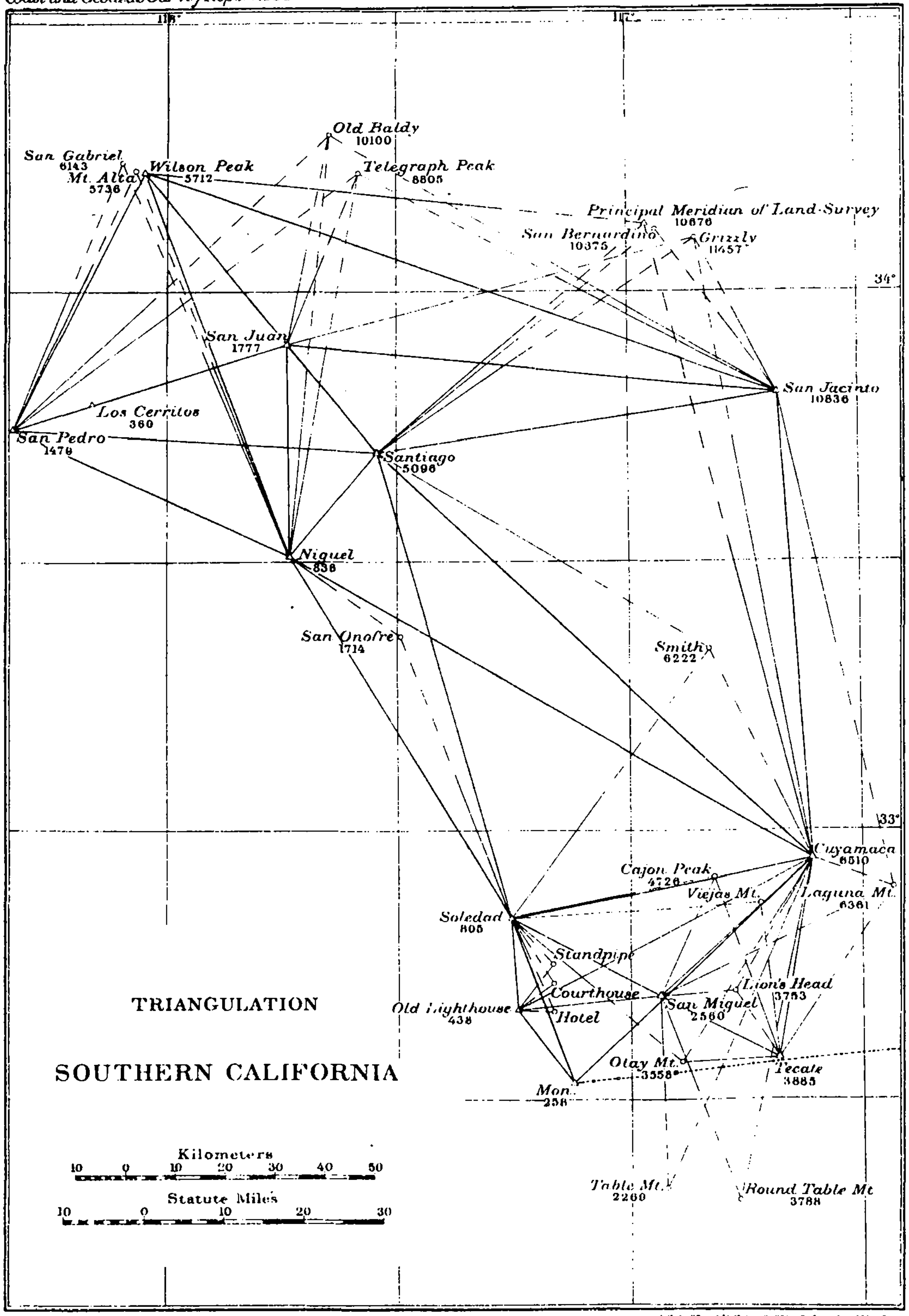
On December 22 the ship proceeded to Oakland, where the boiler was cleaned. On the 29th and 30th she proceeded to San Francisco to fill the bunkers with coal and returned to Oakland, where she remained until the 31st of December.

On the 4th of January, the weather having moderated, the ship proceeded up the bay to begin work on the hydrography from Marin Islands to California City Point. The erection and determination of hydrographic signals was begun the same day. A tide gauge was set up at the Point San Quentin wharf, and the plane of reference established by night and day observation of high and low waters for several days. A comparison could thus be made with the self-registering gauge at the Presidio station. Afterwards tides were observed here only while soundings were being made. Actual work began on January 15 and was continued during every available period until the completion of the sheet on February 28. During January the work was much retarded by stormy weather and strong currents.

Under date of February 1 Assistant Westdahl had been instructed to take up the resurvey of the bar upon the completion of the sheet then under way. On February 28, therefore, the ship was steamed to Oakland Harbor, to prepare for the bar survey. On the morning of March 15 a beginning was made on the bar survey. After locating signals and doing other preliminary work the actual sounding began on the 26th. Everything was in readiness, however, on the 20th, but on account of unfavorable weather nothing could be done until nearly a week later.

In the meantime a staff was replaced at the old tidal station at Sausalito, and observations of high and low waters were made upon it for one week for comparison with the Presidio station. A great deal of fog and hazy weather and periods of rough water retarded the operations of the party. On two occasions when it was impossible to work the boiler was cleaned and the coal bunkers refilled.

At the close of the year the resurvey of the bar was practically completed.


118°
117°
34°
33°
Old Baldy
10100
San Gabriel
6143
Wilson Peak
5712
Mt. Alta
5736
Telegraph Peak
8805
Principal Meridian of Land Survey
10676
San Bernardino
10375
Grizzly
11457
San Juan
1777
San Jacinto
10836
Los Cerritos
360
San Pedro
1478
Santiago
5096
Niguel
836
San Onofre
1714
Smith
6222
Cuyamaca
6510
Cajon Peak
4726
Viejas Mt.
Laguna Mt.
6361
Soledad
805
Standpipe
Courthouse
San Miguel
2560
Lion's Head
3753
Old Lighthouse
438
Hotel
Otay Mt.
3558
Tecate
3885
Mon.
258
Table Mt.
2260
Round Table Mt.
3788
TRIANGULATION
SOUTHERN CALIFORNIA
Kilometers
10 0 10 20 30 40 50
Statute Miles
10 0 10 20 30

A. T. MOSMAN: CALIFORNIA.

TRIANGULATION.

W. B. FAIRFIELD, *Assistant.*
Prof. J. C. L. FISH, *Recorder.*
ARTHUR W. LEWIS, *Recorder.*
PETER A. THOMASEN, *Packer.*

7 424 square miles area covered.
6 stations occupied.
36 geographic positions determined.
8 old stations recovered.
24 elevations determined (trigonometric).
1 elevation determined (spirit leveling).

At the beginning of the fiscal year Assistant Mosman was moving camp from San Juan to Cuyamaca. The journey was made by rail to Lakeside, and from the latter point by wagons to the camp near the triangulation station. From Lakeside to Cuyamaca the distance is about 40 miles, with a rise of about 6 000 feet. At the time this transportation was effected it was exceedingly difficult to procure wagons, as all teams were taken by supply parties for the Cuyamaca mine.

On July 15 camp was ready, and the work of preparing the station site was begun. From the camp to the triangulation point, a distance of about half a mile, there is a rise of about 345 feet, making the transportation difficult and slow. Everything, including instruments, lumber, sand, and water, had to be carried by hand. Before the theodolite could be mounted much work was done in preparing the site, as more than 20 tons of rock were to be handled before the situation could be made fit for the observations. The theodolite and vertical circle were ready for observing on July 22, and the signals and heliotropes were ready on the 25th. The first observations were obtained on the 28th. The usual foggy weather along this portion of the coast very much delayed the observations. Few observations could be obtained in the morning on either Soledad or Niguel, and for days at a time no heliotropes could be seen at these stations, either in the morning or afternoon. Notwithstanding these adverse circumstances, all the primary directions were finished by August 14, and those on Old Light-House and Monument No. 258 on August 19. Tecato was occupied on the 26th and San Miguel on September 2. The instruments were dismounted and all the outfit was at the foot of the mountain by the 6th. On the 7th transportation to the railroad at Lakeside was begun, and on the 10th all outfit was shipped to Los Angeles or San Francisco. On the 15th the mules, wagons, and harness were sold at San Diego, and the party discharged except the recorder and one man, who were kept at Los Angeles a few days to make inventories and ship instruments.

SUBPARTY.

Assistant W. B. Fairfield reported to Assistant Mosman on June 27 at San Juan, and left Los Angeles for San Jacinto on July 5, accompanied by Prof. J. C. L. Fish as recorder and Peter A. Thomasen as packer. On the 8th he hauled the outfit to Strawberry Valley, at the foot of San Jacinto Mountain. Owing to the rough trail and long distance to the top of the mountain, the last pack did not arrive until July 20. The first observations were obtained on the 24th, and they were finished on the 28th. On August 1 moving began, and the last pack went down the mountain on the 8th. On the 9th the outfit was hauled to San Jacinto, and the following day it was shipped by rail to El Toro. On the 15th hauling began from El Toro to the lower end of the trail on Santiago Mountain, and on October 22 the last of the outfit was brought up to the camp. Six days later observations were begun at Santiago triangulation station, and they were finished on September 2. Between the 5th and 7th the outfit was taken down the mountain, and it was shipped by rail on the 9th from El Toro. A part of it went to Los Angeles to be forwarded to Washington, and a part was shipped direct to San Francisco.

Assistant Mosman arrived in Los Angeles on the 16th of September, and was occupied in settling accounts and shipping instruments until the 20th. Assistant Fairfield left for Washington, and Recorder Lewis for Madison, Wis. On the same date, September 20, Assistant Mosman left for San Francisco. After attending to minor matters of a routine nature, he left on the 24th for the East, stopping at Ord, Nebr., from the 3d to the 9th of October in order to visit the party of Assistant Granger, under official orders from the Superintendent. He arrived at Schenectady, N. Y., on October 11. From the 12th to November 2 he was on leave of absence, and on the latter date reported for duty in Washington.

The abstracts and computations pertaining to the work were turned in on January 20. All original and duplicate records had been previously sent to the office.

Assistant Mosman speaks in high terms of the services rendered by Assistant W. B. Fairfield, who was attached to the party from June 27 to the end of the season. Prof. J. C. L. Fish and Mr. Arthur W. Lewis are also highly commended by Assistant Mosman for the energy displayed and the interest taken in the work.

Assistant Mosman was employed at the office until January 25, engaged in computations pertaining to his field work during the past season. At this date instructions were given him to report to the Assistant in charge of the Office for duty in the Computing Division, which duty he performed until the 31st of May.

From June 1 until the 25th he was on leave of absence, and from the latter date until the close of the fiscal year preparations were made to take the field in Kansas, on the triangulation of the ninety-eighth meridian south of the thirty-ninth parallel.

J. E. McGrath: Arizona, Maricopa.

ASTRONOMIC.

Assistant J. E. McGrath was occupied at the beginning of the fiscal year in the Computing Division of the Coast and Geodetic Survey Office, making computations relative to the California-Nevada boundary line. This work continued until the 10th of August.

For one month following this last date he was engaged in determining longitude in cooperation with Assistant Smith of the international geodetic latitude station at Gaithersburg, and making the office computations for the same. He afterwards resumed work on the computation of the California-Nevada boundary work.

On September 18, 1899, Assistant McGrath received instructions to take charge of a cooperating party for the determination of longitude at Maricopa, Ariz., the other party being under the direction of Assistant C. H. Sinclair. The programme contemplated the exchange of signals on three nights between Maricopa and El Paso, Tex., followed by three more nights after the observers had exchanged places.

After numerous preliminary arrangements the parties left for the field on October 6. The town of Maricopa being devoid of all resources, as far as labor and building are concerned, it was necessary to procure assistance from Phoenix, a town near by. It was not until October 19 that everything was in readiness for the proposed observations. On this night the transit instrument was placed in the meridian and secured. On the following evening regular observations for longitude began, and these were continued each evening, without interruption, until October 23.

The observers now exchanged places, Assistant McGrath going to El Paso and Assistant Sinclair coming to Maricopa. The travel was performed on the 24th, and on the evening of the same day signals were again exchanged, and the same programme was repeated for three successive nights. The observations on the 26th closed the work for the entire determination, and on the following day the instruments were dismounted and shipped to Washington. The observatory was turned over to the city commissioner of streets, who has charge of the property on which the building stands.

Assistant McGrath, after taking five days' leave of absence, arrived in Washington on the 6th of November, and on the following day reported at the office for duty. From November 8 to 27 he was employed at the office, first on the computation of the longitude at Maricopa, and afterwards resuming work on the California-Nevada boundary computations.

On November 28 he was assigned to duty in the party of Assistant Nelson, instructed to take up geodetic operations in Porto Rico.

Isaac Winston: Colorado, Wyoming.

PRECISE LEVELING.

H. A. Kelley, *Recorder*.

SUMMARY OF OPERATIONS.

340 kilometers leveling line.
41 bench marks established.

The line of precise levels has been continued from Denver during the past year by the party under Assistant Isaac Winston. Taking the field early in May, at the beginning of the year the party was working northward from Denver.

The greater portion of this region is irrigated, and the atmosphere was extremely tremulous, which to a considerable extent retarded the work. Another unfortunate circumstance was the strength of the wind, which blew with great force most of the time and made it necessary to use guys on the rods during a considerable portion of the season. The work, however, was considerably facilitated by the use of the observing tent, which was constantly used. By permission of the officers of the Union Pacific Railway, velocipede cars were used as a means of transportation, and resulted in a great saving of time and otherwise facilitated the work.

The changes in elevation along the line were very great, and at many points this was so marked that long sights were impossible, even when other conditions were favorable. From Denver to Greeley, 50 miles, the elevation decreases 162 meters, and then increases 336 meters in the following 50 miles. From Cheyenne to Sherman, the highest point of the transcontinental route, the elevation increases 677 meters in about 30 miles. The descent west of Sherman is equally steep over a considerable portion of the route, as far as Laramie.

The work during this season was carried on with modified instruments and methods. The conclusions arrived at by a committee on precise leveling, appointed by the Superintendent to consider the instruments and methods in use, were put in practice, and the result was that the work in the field was much less laborious and the results seemed to be equally accurate.

Assistant Winston speaks in high terms of the contrivance devised by Mr. E. G. Fischer, chief mechanician, Coast and Geodetic Survey, for reading the level from the eye end of the telescope. This is a modification of the device used in France, but is simpler and superior in the result.

Assistant Winston was assigned to office work on the 31st of October. He took up the computations of the field notes of the work just executed, and prepared them for publication. This lasted until the 29th of January, when he reported for duty in the Computing Division, and was engaged there until the 9th of May. On this date he was detached and was assigned to the platting of the field notes made by the party of Assistant O. B. French along the coast of New Jersey for the revision of charts. He was engaged on this work until the close of the year.

D. DIVISION OF ALASKA.

Steamer *Patterson*, J. F. PRATT, Commanding: ALASKA, Bering Sea.

CURRENT.

TIDE.

BASE LINES.

TRIANGULATION.

ASTRONOMIC.

TOPOGRAPHIC.

HYDROGRAPHIC.

F. A. YOUNG, *Assistant.*
H. W. RHODES, *Aid.*
W. A. O'MALLEY, *First Watch Officer.*
GEO. SEELEY, *Second Watch Officer.*
L. M. FURMAN, *Third Watch Officer.*
C. B. LAUGHLIN, *Hospital Steward.*
P. M. NEWHALL, *Recorder.*
A. L. GRACOMINI, *Chief Yeoman.*

SUMMARY OF OPERATIONS.

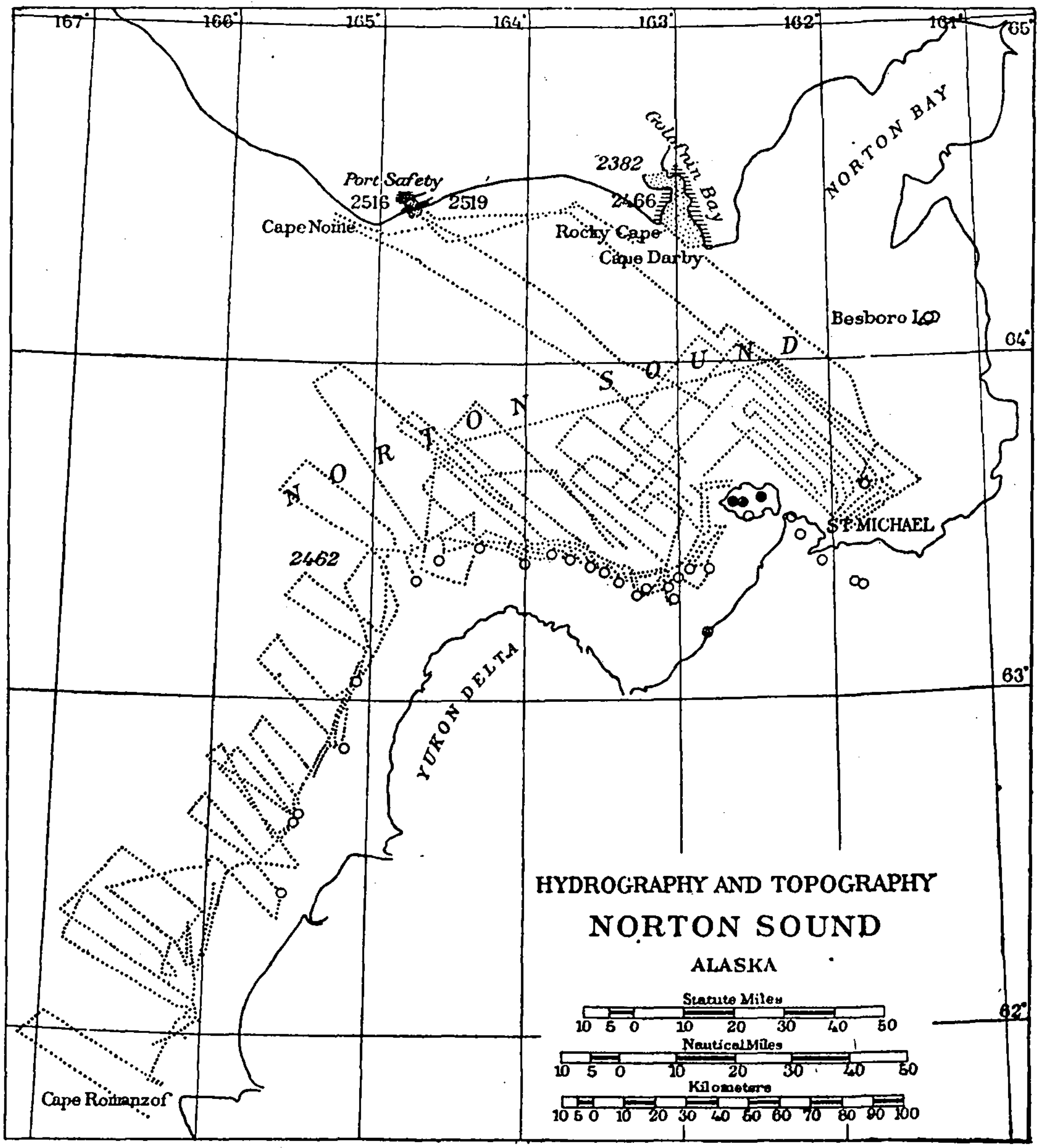
1 base line.
115 square miles triangulation.
8 stations occupied.
30 geographic positions determined.
2 latitude stations.
2 longitude stations.
2 solar azimuth stations.
29 miles coast-line topography.
8 350 square miles hydrography.
3 650 miles sounding lines.
4 129 angles measured.
22 966 soundings.
3 tide stations.
212 current stations.

On July 1 Assistant Pratt, commanding the steamer *Patterson*, was at Seattle, Wash., making preparations to resume work in Alaska.

On the 3d of July, at 2.30 p. m., the vessel sailed for Dutch Harbor, stopping on the way at Port Townsend long enough to put accounts and mail matter in the post-office. Dutch Harbor was reached on the 13th of July, after a passage of 9⅔ days, and a distance covered of 1 668 miles.

When off the Sannak Bank and Islands it was evident from good determinations that there was a very strong set or current to the northeastward. From tentative positions that the party was able to establish, Mount Shishaldin, the great landmark when coming from the southeastward, is out of position on the chart about 6 miles to the northeast.

No. 20.



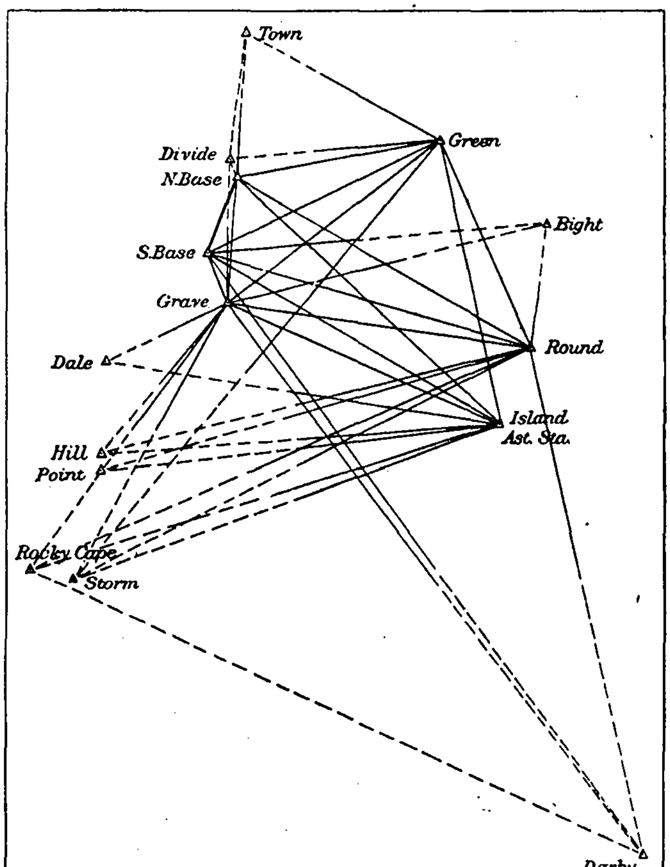
At Dutch Harbor 116·5 tons coal and 4 000 gallons water were taken on board, and on the 15th of July, at 3·30 a. m., the party got under way for St. Michael, where they arrived at 2·30 a. m. on July 19. The distance covered was 782 miles.

On arriving at St. Michael, Assistant Pratt learned that several river steamers were on the flats at the entrance of the Apoön mouth of the Yukon. He immediately dispatched Assistant Young and Recorder Newhall, with the steam launch and material, to establish buoys and beacons in the channels.

On account of the importance of Cape Nome as a landmark an attempt was made to locate it astronomically, but during the three days—July 25, 26, and 27—devoted to the work there, no stellar observations could be obtained on account of clouds. The latitude and longitude were, however, obtained by solar observations with the sextant.

The entire month of August was devoted to sounding, outside the 3-fathom curve, the great Yukon Flats between Stuart Island and Cape Dyer. This is shown on the accompanying sketch. Practically all this work is out of sight of land. About 30 beacons and buoys, in about 18 feet of water, were erected between Stuart Island and Cape Dyer, many of them being 20 or more miles from land. The beacons were 30 feet high above water. About 2 980 miles soundings were run on this piece of work.

No. 21.



TRIANGULATION OF GOLOFNIN BAY, ALASKA

A topographic survey of the outer face of Cape Dyer promontory was made, and sufficient boat work done to develop the approach to Cape Dyer and the entrance to Scammon Bay. The soundings show that there are no lumps, as heretofore supposed, off the mouth of the Yukon, and that the southern portion of this great shoal does not extend offshore quite as far as supposed. The currents in the vicinity of the end of this shoal are quite strong, as much as 2 knots per hour, and their strength and direction depend on the force and direction of the wind and condition of the tide, although it was quite apparent that the flow was in a northeasterly direction the greater portion of the time. Surveying these unknown shoals, with their uncertain and treacherous currents, with a vessel of the size of the *Patterson* was a very risky and exceedingly trying undertaking, but the work went on continuously, day and night, unless interrupted by heavy weather.

In going to and from St. Michael lines of sounding were run, so that the southern half of Norton Sound was covered with hydrographic work. The entrance to Port Safety (see sketch) was next surveyed. This is a small bay or lagoon about 7½ miles east of Cape Nome, and has only recently been known to civilization. This will be an important place in the future, as excellent prospects have been obtained back of it. There is about 6 feet of water on the bar at extreme low tide, with a rise of about 4 feet. Before leaving this place range beacons were erected for crossing the bar and notices to mariners written and posted at St. Michael.

The last locality surveyed was Golofnin Bay. A base line of about 1⅓ miles was measured on its northwestern shore, from which a comprehensive triangulation was expanded abundantly covering the entire outer bay. (See sketch.) An astronomic position was determined at a station on the island on the east side of the bay. Owing to continual cloudiness at night, the position had to be obtained by solar observations with the vertical circle. A magnetic station was occupied on this island for declination and dip. The shore line was run with the plane table, but the adjacent topography will have to be filled in by photo-topographic means, the triangulation stations and some subsidiary ones having been occupied with the topographic camera.

The hydrography covers the entire bay and also the narrows between the two spits at the head of it. The anchorage is quite near to the southern and western spit.

On September 23 enough work had been accomplished for a preliminary chart of the lower and deep-water portion, and the work was closed for the season. On the 24th the *Patterson*, with party, returned to St. Michael, and after waiting seven days for necessary arrangements incident to closing the work in Bering Sea, she sailed on October 3 for Dutch Harbor, taking the steamer *Taku* in tow, under steam.

Arriving at the latter place on the morning of October 8, the *Taku* was moored in the small basin and the *Patterson* continued her voyage on the 11th for Seattle, where she arrived on the 20th of October at 9 p. m. The cruise since leaving San Francisco was about 8 830 miles.

Assistant Pratt remained in command of the *Patterson* during the remainder of the year, and in addition to his duties as commander was assigned the charge of the sub-office at Seattle.

In February he established and marked a trial course near Seattle 1 nautical mile long, to comply with a request from the Navy Department.

During the remainder of the year office work connected with the past season's field work was done, repairs were made to the ship, a crew was enlisted, and all preparations made for another season's work in Alaska.

In spite of many unfavorable circumstances, all preparations for the voyage north were completed by June 18, and on the 19th the vessel sailed for Nome City, Alaska.

At the close of the year the voyage had not been concluded.

Steamer *Yukon*, G. R. Putnam, Commanding: Alaska.

RECONNAISSANCE.

BASE LINES.

TOPOGRAPHIC.

HYDROGRAPHIC.

TRIANGULATION.

ASTRONOMIC.

MAGNETIC.

TIDE.

G. L. Flower, *Assistant.*
E. R. Frisby, *Aid.*
R. J. Mansfield, *Aid.*
Dr. H. M. W. Edmonds, *Foreman.*
P. S. Rose, *Foreman.*
J. H. McEldowney, *Recorder.*
R. McD. Moser, *Recorder.*
W. C. Page, *Recorder.*

SUMMARY OF OPERATIONS.

3 base lines measured.
148 triangulation stations.
123 geographic positions.
7 latitude stations.
7 longitude stations.
6 azimuth stations.
3 magnetic stations.
167 miles coast-line topography.
223 miles river shore-line topography.
175 miles slough shore line.
50 miles reconnaissance.
205 photographs illustrating the country.
15 topographic sheets.
1 024 miles sounding lines.
3 205 hydrographic positions determined.
14 tide stations established.
22 current observations.
10 hydrographic sheets.
9 determinations of density of sea water.

During the month of April, 1899, while engaged in other duty at Washington, D. C., Assistant G. R. Putnam received instructions to prepare for field work in Alaska. The operations contemplated a survey in the neighborhood of the Yukon Delta and in Scammon Bay, some distance to the south. The party, all under the direction of Assistant Putnam, was divided into three parts, of which the first was under Assistant Putnam's direct supervision, and carried on the work from the steamer *Yukon*. This party consisted of E. R. Frisby, Aid; P. S. Rose, foreman; R. McD. Moser, recorder; W. C. Page, recorder; 2 engineers, 1 cook, 1 Eskimo pilot, and 5 sailors and hands, making in all 14 persons. The second detachment was under the immediate direction of Assistant G. L. Flower, accompanied by R. J. Mansfield, aid; J. H. McEldowney, recorder; 1 engineer, 1 cockswain, 1 cook, and 1 hand, making a total of 7 persons. This party operated from the launch *Alpha*. The third was a traverse party under charge of Dr. H. M. W. Edmonds, with 1 rodman, 1 cook, and 1 hand—4 persons in all.

The entire expedition as thus constituted was composed of 25 persons. They sailed from Seattle on the steamer *Roanoke* on the 10th of June, 1899, passed through Akutan Pass on June 18, and arrived at St. Michael Bay on the 24th. The following two weeks were spent in preparing the steamers, launches, and boats for the work of the season, and the party was able to take the field actively on the 9th of July.

The plan of operations was for the *Yukon* to proceed first to Scammon Bay and make an examination, topographically and hydrographically, of this locality. While this work was in progress Mr. Flower established himself at the Kwiklowak mouth of the Yukon, and began the development of that region. When the Scammon Bay work was completed, Assistant Putnam returned to St. Michael for supplies, and went immediately thereafter to the Kwiklowak bar and began hydrographic observations on August 5. On the 9th the launch party of Assistant Flower began work up the Kwiklowak. In the meantime Dr. Edmonds began his traverse line along the Delta coast, northward from the Kwiklowak, of which detailed information will be given later. During the latter part of August and the first part of September the combined parties made a survey of the Kwiklowak Pass and proceeded up the river as far as the vicinity of Andreafski.

The work was closed on September 13, and from this time to October 3 the party was at St. Michael, disposing of the vessels and putting them in shape for the winter. During this time office work was continued as opportunity offered, and the *Patterson* with the party on board sailed on the 3d for Seattle. Arriving there on the 21st of October, the men were discharged and the regular members of the field force were engaged on office work and inventories until the 28th. Assistant Putnam and the other officers reported at Washington early in November, and were engaged during the greater part of the winter on the preparation of the field notes made during the season.

It would be impracticable to give a detailed account of all the operations carried out by a party doing as extensive work in hydrography, topography, and triangulation as was accomplished by the force under Assistant Putnam's direction during the season. But an outline of the work in the different localities can be sketched sufficiently in detail to convey an idea of the results accomplished.

SURVEY AND RECONNAISANCE OF SCAMMON BAY.

In all, fourteen days were devoted to this part of the work, and during this time two southeasterly gales with rain and mist, each lasting several days, were experienced, so that the hydrographic work could only be carried on during six days. As the work in this locality was detached from that in the Yukon Delta, it was necessary to make astronomic determinations of latitude, longitude, and azimuth. Ten chronometers and a meridian telescope were carried for this purpose, but although the latter was set up at three of the temporary headquarters occupied, unfavorable weather prevented any star observations. The determinations, therefore, depend on observations of the sun, nearly all with the 7-inch theodolite, and the deduced positions and azimuths were adjusted

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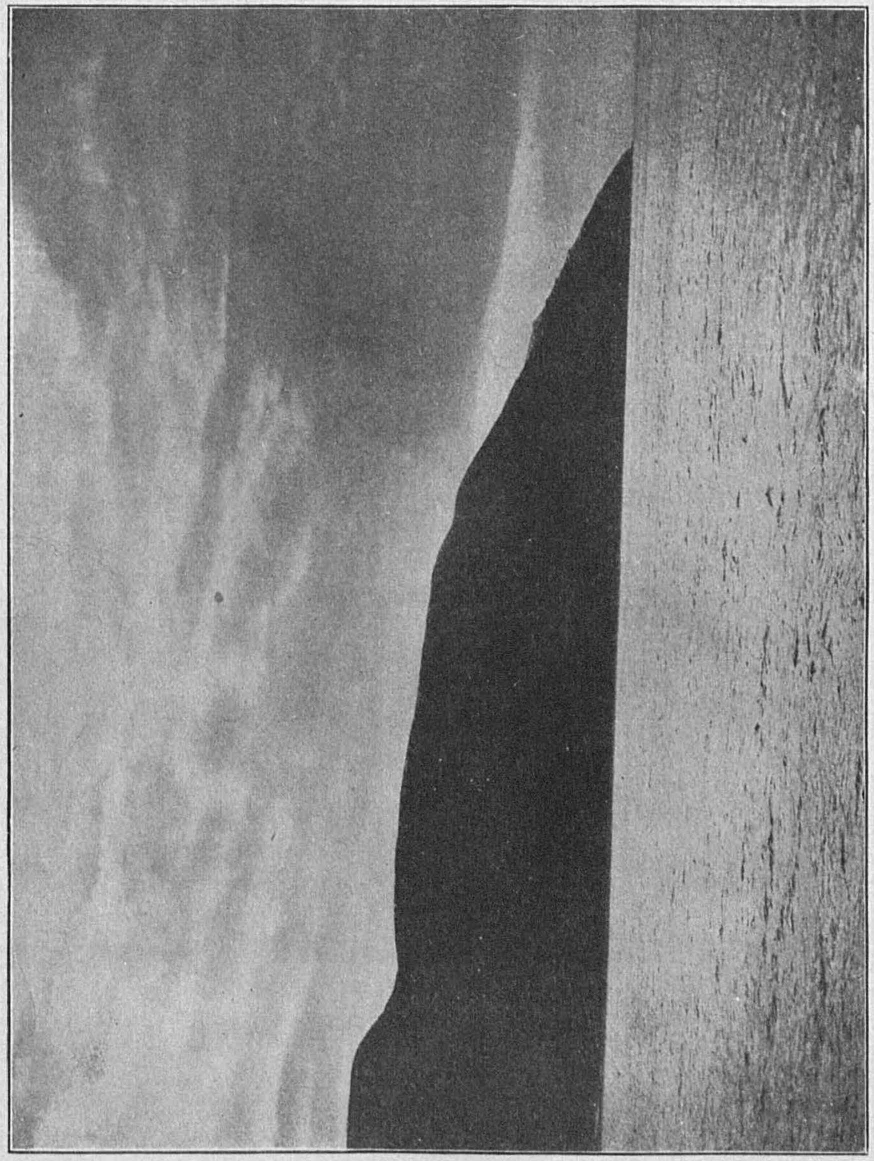

Scammon Bay, looking west from Edmonds Cove.

from these data. The longitude was determined from St. Michael, with time observations made before and after the voyage.

By observing the Kusilvak Mountains and Mount Seward, from the triangulation points near the Yukon mouth, it was possible to compare the results of the systems of triangulation in this locality and that farther up the coast. The result indicated that the positions in Scammon Bay, as roughly determined from the present work, were about 120 meters too far east and 606 meters too far south as compared with the

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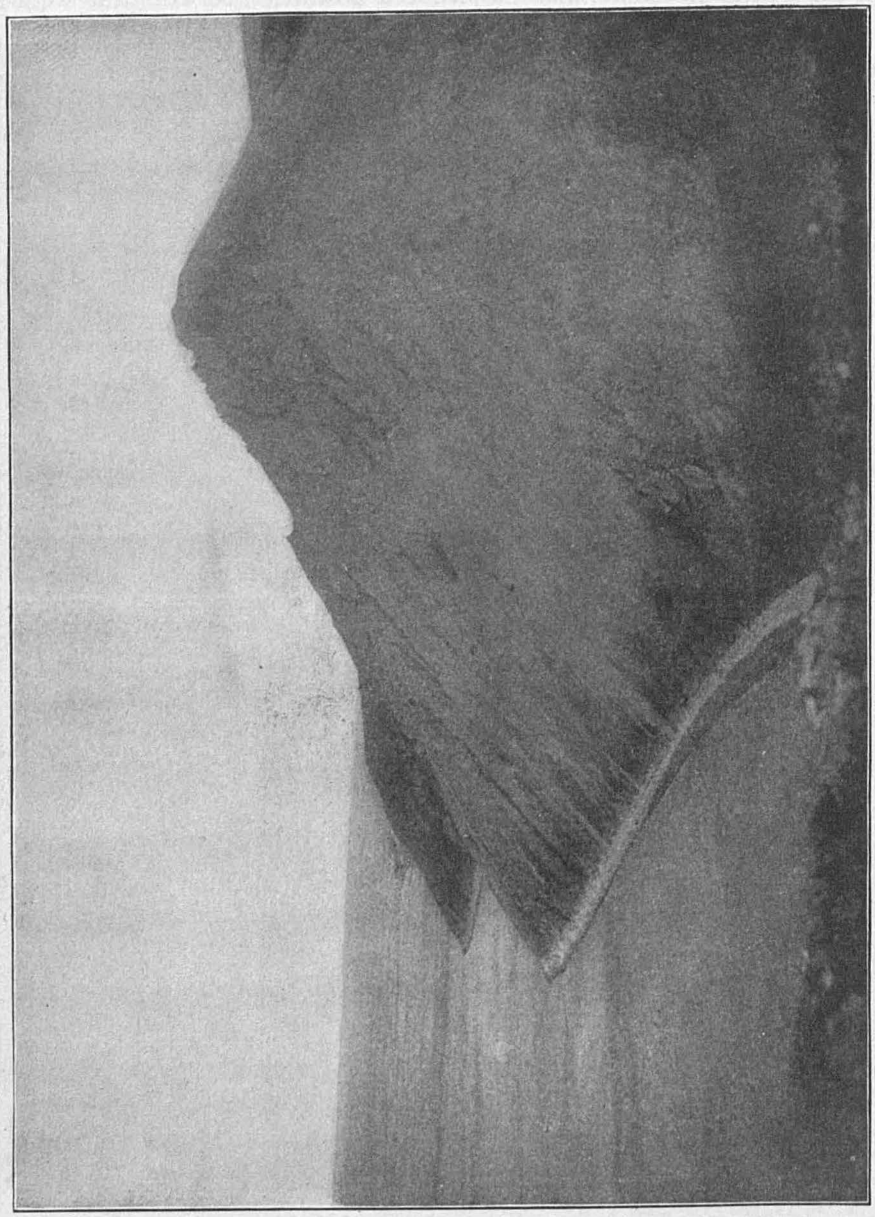

South shore of Scammon Bay, looking east from Windy Cove.

St. Michael data used in the delta, but as the determinations were considered weak on account of the exceptionally bad weather conditions, the positions at Scammon Bay were made to depend entirely on the St. Michael data.

In order to execute the topographic and hydrographic work, a base was measured on the flats south of the Khun River, near its mouth, and a rough triangulation was made along the south side of Scammon Bay to Cape Romanzof. A traverse line was also run along the south shore of the bay from Khun River to the cape, and to a point about 2 miles south of it; also for about 14 miles along the coast toward the Yukon Delta.

Many shoals in the bay were located from elevated stations, whose heights above sea level had been carefully determined. The distances were computed from the measured angle of depression, using the height as a base. The hydrographic work was somewhat hampered by bad weather, but the examination showed that the greater part of Scammon Bay is too shoal to be of much practical value to navigation. Deep water was found immediately south and east of the South Sand Island, but the limited area of this, and the shoals on each side of the channel leading to it, render it probably of little value. There is a narrow channel into the bay and into Khun River, a deep but narrow tidal stream.

Tides were observed at the mouth of the Khun River during the progress of the hydrographic work, as were also a few current observations. There is a double daily tide here, as at the Kwiklowak. Magnetic observations were made at this point, and numerous photographs were taken with topographic and view cameras.

THE CHANNELS AT THE KWIKLOWAK MOUTH.

One of the most important parts of the season's work of this party was the development of the Kwiklowak mouth of the Yukon River. The operations brought out the fact that the pass divides at its mouth into five channels, flowing out in directions varying from southwest to north. Beginning at the south, these are Acharon, the Taku, the Kutmuknuk, the Kwiklowak, and the Nurukomarot. All of these were carefully examined.

The important results of this examination affecting navigation are published in Coast and Geodetic Survey Bulletin No. 40, second edition, 1900.

A self-registering tide gauge was kept in operation at Avogon from July 14 to August 11. This was connected by water levels with the gauge of the previous season, at Kwiklokchun. Tidal observations for the south-channel work were made at Waklarok, and limited observations were also made at three outside points to obtain the relation between the time and range of tides on the bar and at the mouth. Current observations were made in the bar channels.

SOUNDINGS ALONG THE COAST.

The importance of soundings along the coast was fully recognized by Assistant Putnam, and although this work was not included in the original instructions, he availed himself of several trips made between Scammon Bay and St. Michael, as well as from the Kwiklowak mouth to Scammon Bay, in order to obtain information on this point. The results of this work are shown on a hydrographic sheet, but they should be considered rather in the nature of a reconnaissance than as precise information. During this voyage of 200 miles, although keeping close in, with the steamer drawing less than 5 feet of water, the shore of the delta coast was never sighted. Specimens of sea water were taken and their densities determined.

KWIKLOWAK PASS OF THE YUKON RIVER.

In accordance with the original plan, the latter part of the season was reserved for inside work up the Kwiklowak Pass and the Yukon River. Astronomic observations for latitude and time were made with the meridian telescope at Kwiklokchun and Avogon, near the mouth, and at Anuk, about 50 miles up the river. The longitude of Kwiklokchun was determined as a result of two voyages from St. Michael, with 9 and 7 chronometers respectively, in combination with the result obtained in a similar manner during the previous year; and that of Anuk, results from one voyage, with 7 chronometers.

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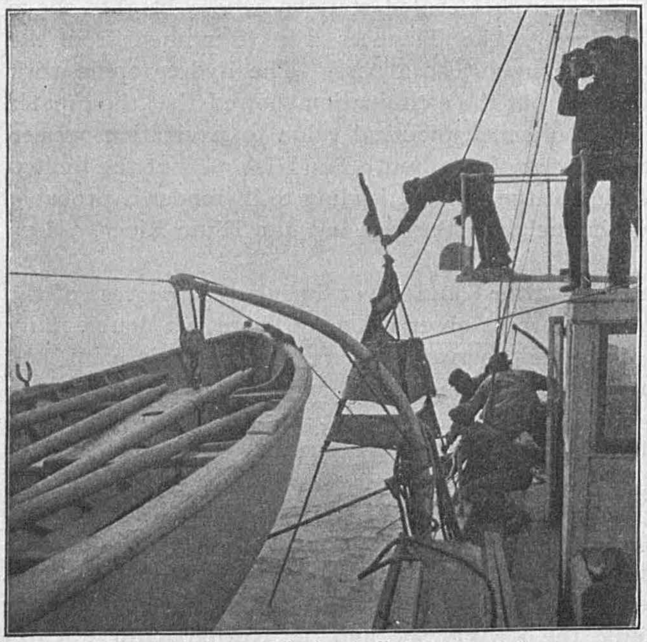

Placing a hydrographic signal off the Yukon Delta.

The triangulation was carried a distance of 87 miles up the Kwiklowak Pass and Yukon River, to within a short distance of the mouth of the Andreafski River. An effort was made to proceed by quadrilaterals or by independent overlapping triangles where practicable, but very little time was spent in cutting lines and none in preliminary reconnaissance. There were 104 triangulation stations established and 5 old ones reoccupied.

The topographic survey up the pass and river was made with sextant, theodolite, and sketch-book. The photographic camera was used, and numerous general views were obtained throughout the delta.

The hydrography was developed by a system of lines run with the steam launch. A good channel was found from the Kwiklowak mouth to near Andreafski.

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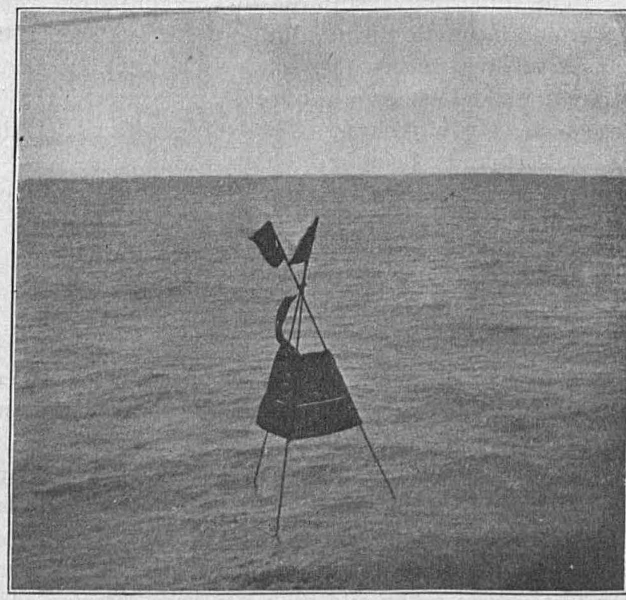
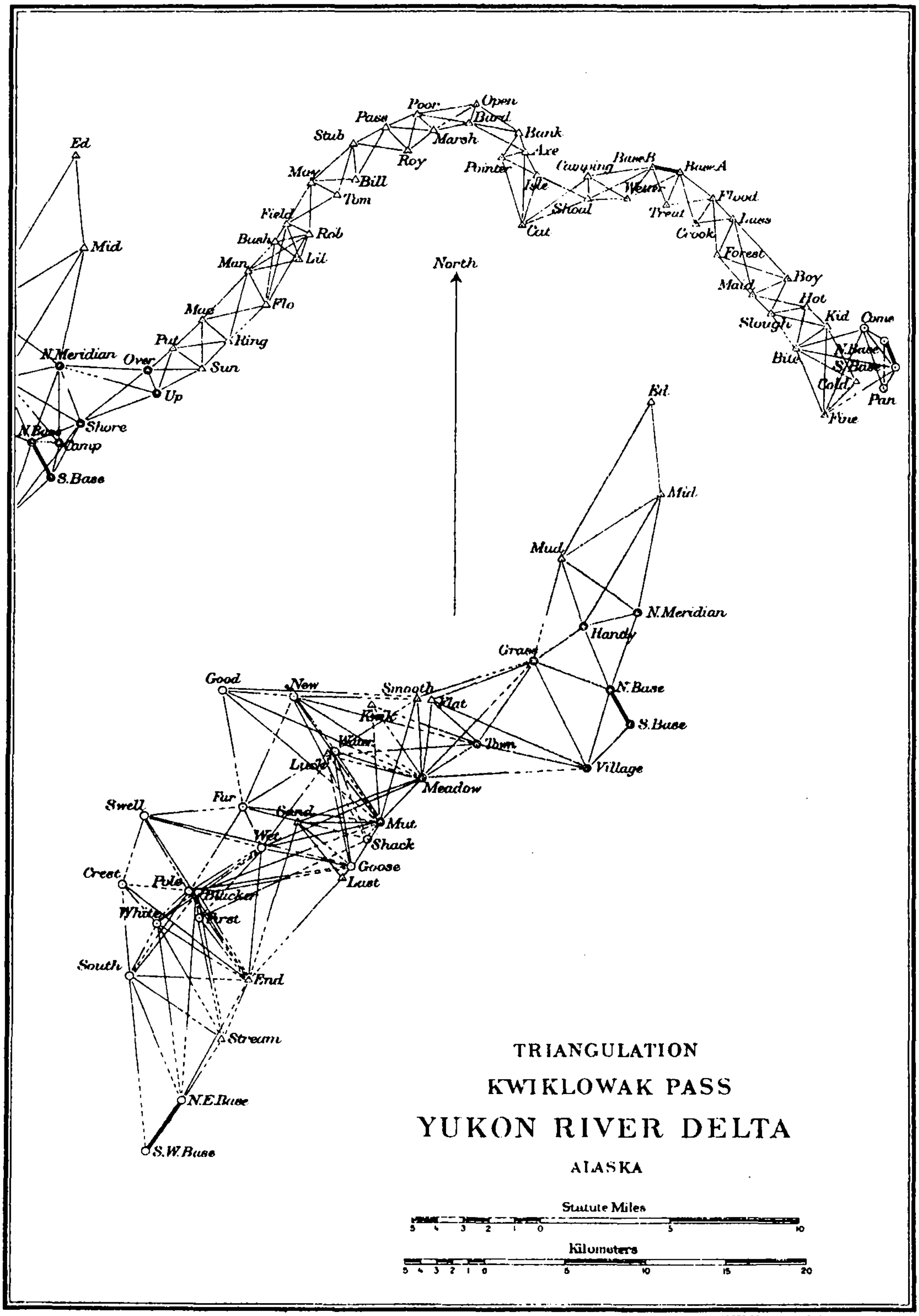
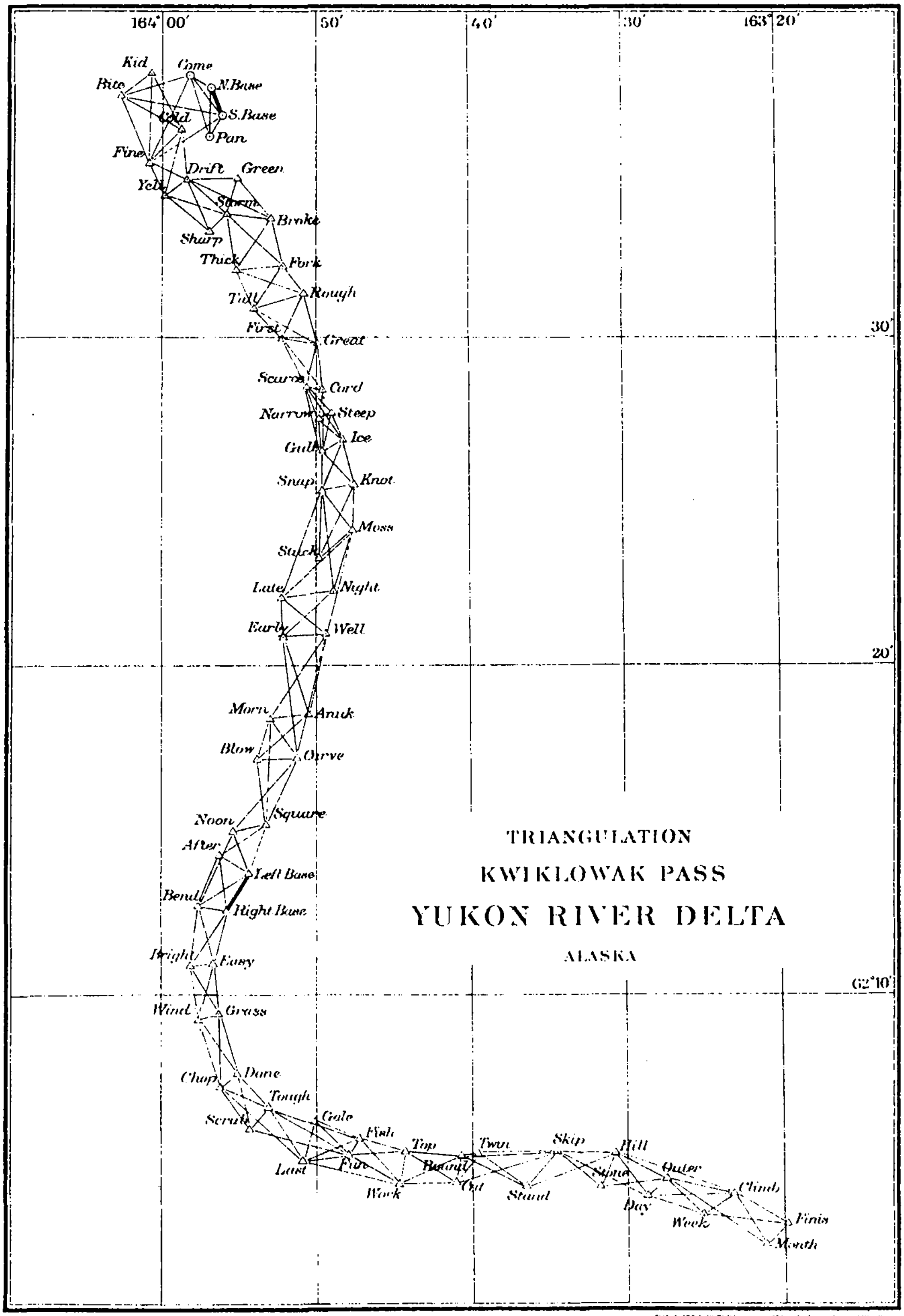
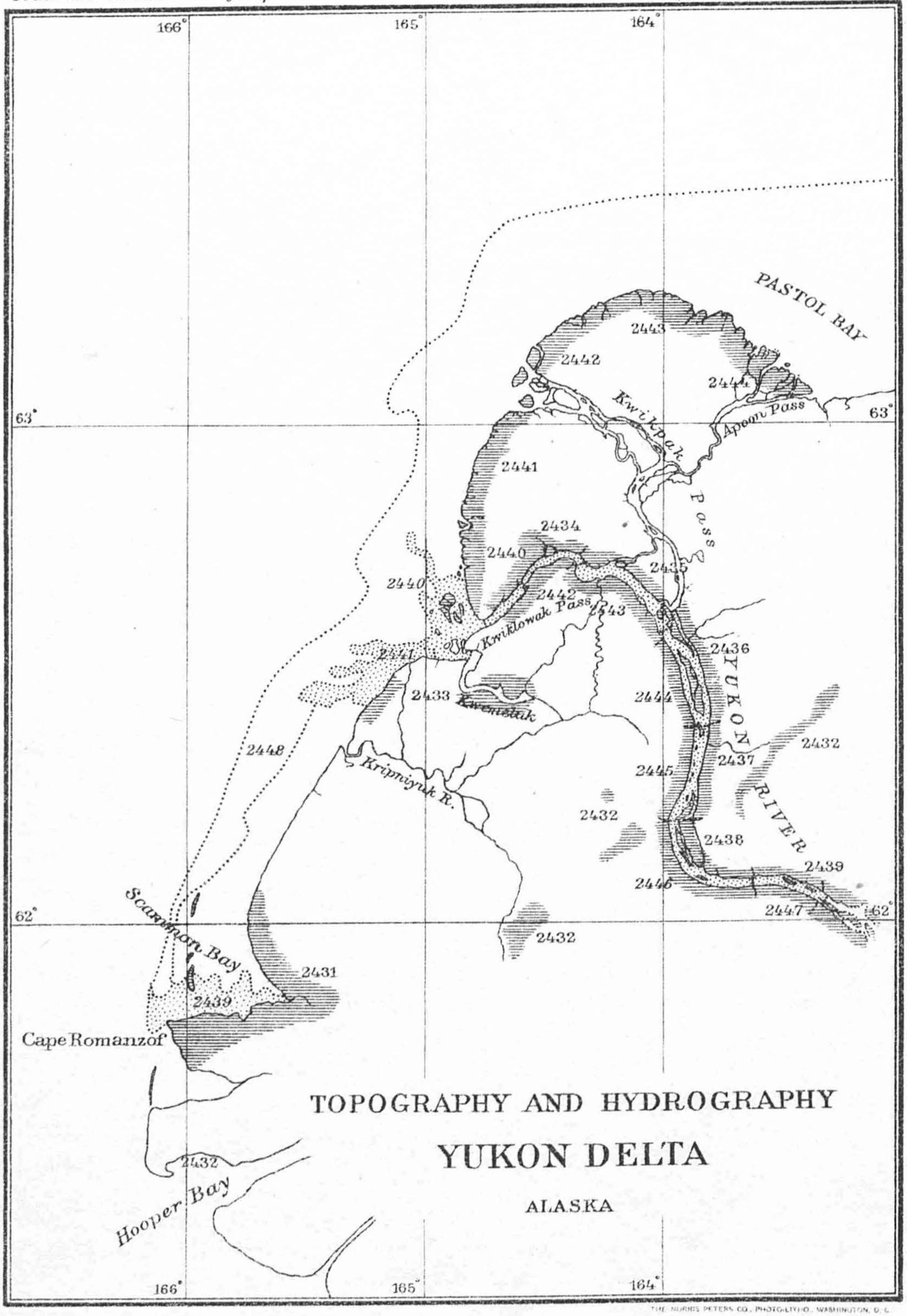


Tripod gas-pipe signal.



THE NORRIS PETERS CO. PHOTO-LITHO. WASHINGTON, D. C.


TRIANGULATION
KWIKLOWAK PASS
YUKON RIVER DELTA
ALASKA
164° 00′
50′
40′
30′
163° 20′
30′
20′
62° 10′
Kid
Come
Bite
N. Base
S. Base
Pan
Fine
Drift
Green
Storm
Broke
Sharp
Thick
Fork
Rough
First
Great
Cord
Steep
Narrow
Ice
Snap
Knot
Moss
Late
Night
Early
Well
Morn
Anuk
Blow
Curve
Noon
Square
After
Left Base
Bend
Right Base
Bright
Easy
Wind
Grass
Chop
Done
Tough
Scrub
Gale
Fish
Top
Twin
Skip
Hill
Last
Work
Cut
Stand
Outer
Day
Climb
Week
Finis
Month



TOPOGRAPHY AND HYDROGRAPHY

YUKON DELTA

ALASKA

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

To obtain an approximation of the discharge of the Yukon, a cross-section and current observations were obtained opposite Azacharak hill, 73 miles from the mouth, where the river is well confined between banks and carries practically all the water.

RECONNAISSANCE OF THE SHORE LINE AT THE MOUTH OF THE YUKON RIVER.

In the course of the work it was found desirable to make a reconnaissance of the shore line in front of the delta, extending from the Kwiklowak entrance on the south to the Apoon on the north. This was undertaken by Dr. Edmonds. He was accompanied by a cook, 1 rodman, and 1 canoeman. The bed of the ocean off the delta is so little inclined that each succeeding tide floods an area of many hundreds of square miles. With the ebb, this vast expanse is completely drained; it then presents to the eye an unbroken surface of mud, and offers the traveler a most uninviting and difficult footway.

Starting from the lower, or Kwiklowak entrance, at a well-established triangulation station, the party proceeded north, measuring the distance by stadia. At the close of the work, six weeks later, after surveying 80 miles of shore line, connection was also made with a point in the main triangulation which extends from St. Michael southward, so that the traverse line is suitably controlled by work depending on astronomic observations.

Assistant Putnam states that this coast had probably never been seen before by a white man. He calls attention to the fact that the shore line, previous to Dr. Edmonds's work, was erroneously placed on our best charts at least 10 miles to the eastward. The many difficulties overcome, discomforts experienced, and valuable geographic knowledge acquired can not be adequately described in a short narrative. The task, to use Assistant Putnam's words, required the greatest endurance, perseverance, and courage, and credit is also due to the men who accompanied Dr. Edmonds.

The following information is extracted from the report cited, which is too extensive for full publication.

Only the lightest draft boats could be used, a small dingey and a canoe being the only ones taken. The tents were light, though large enough to permit the use of temporary bunks, thus placing the inmates out of reach of the floods.

In order to control the azimuths, large signals were established some distance inland, and these were continually observed as long as they were visible. Triangulation was frequently resorted to, in order to cross the small outlets flowing into the sea. In general, it may be stated that there is a distinct grass line separating the sea from the land. In some places banks from 1 to 3 feet high form the dividing line. Canoes can not come close inshore except at high tide, and even the streams can not be entered except under these conditions. When landing at any other time it is necessary to walk for a quarter of a mile or more over the mud, which is generally so sticky that even hip boots, attached with a belt, are drawn from the body. In such cases it is necessary to work barefooted. Every hundred yards or so a slough or stream enters the sea. It was necessary to wade around each of these, requiring a long detour into the ocean before the channel shoaled enough to permit wading.

The readings of the instrument were necessarily made quickly, on account of the unstable condition of the foundation. Favorable stations had to be selected, and spots were occasionally occupied where it took many minutes for the observers to release each other from the mud. In moving camp they waited for high water. As this occurred usually at night, many disagreeable experiences were encountered.

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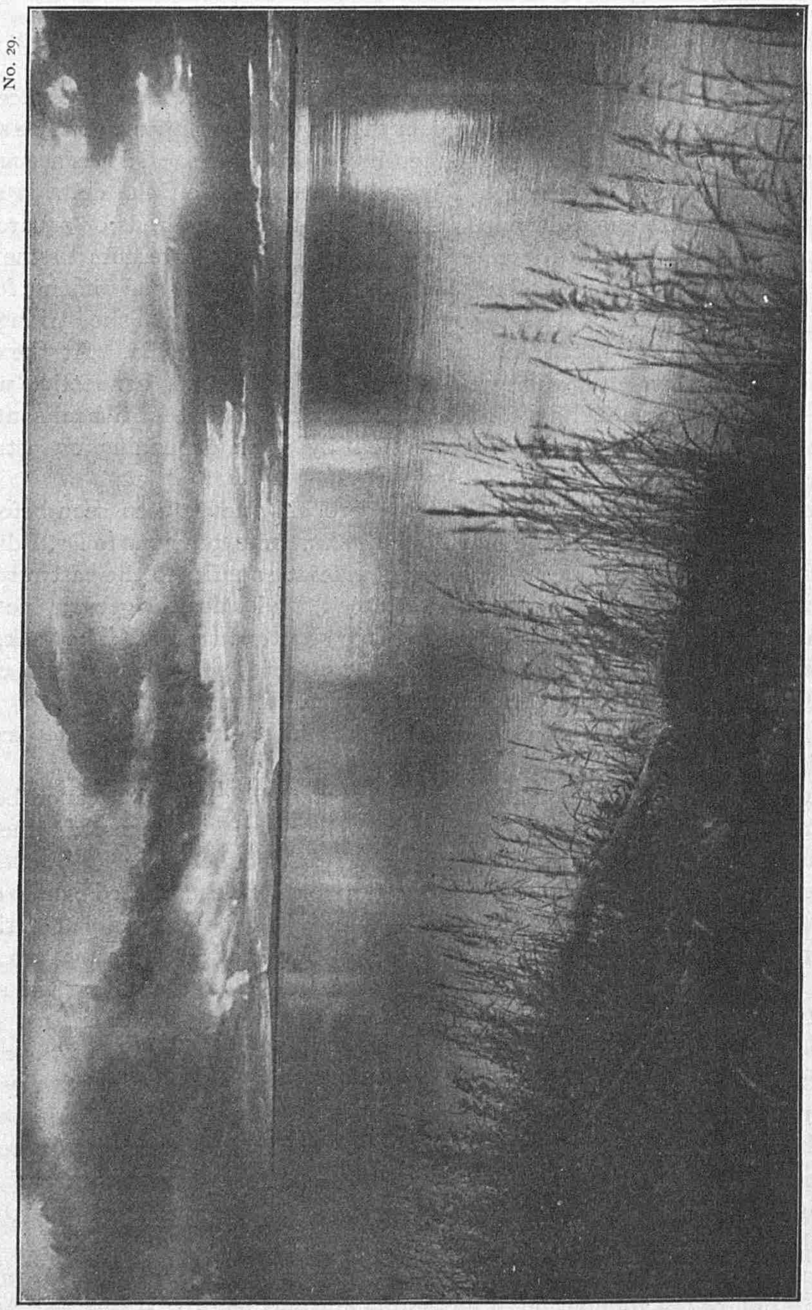
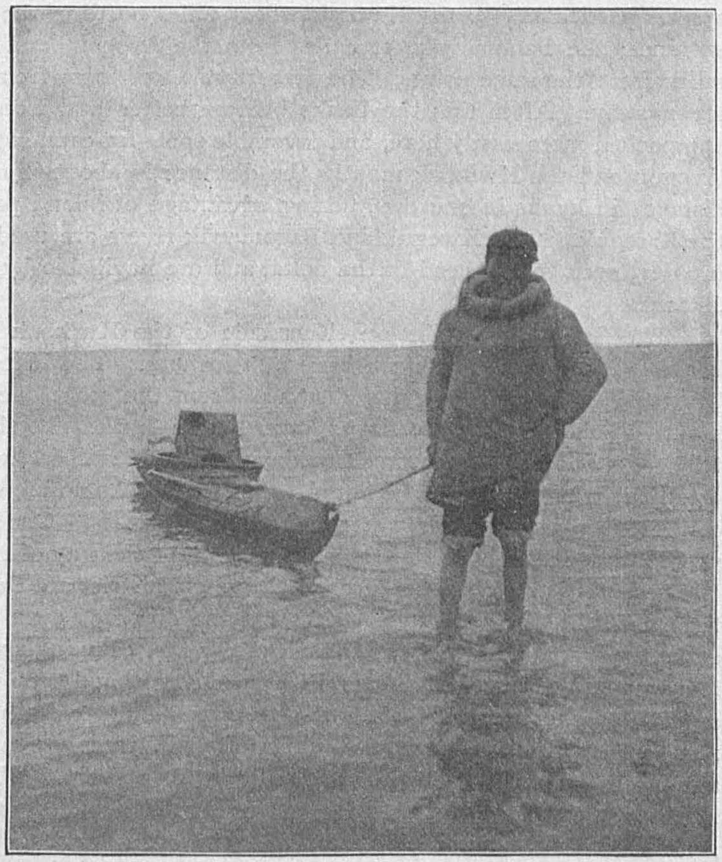


Sunset on the Yukon River.

Both the barometer and tide tables were called into requisition, and work was planned to meet the probable conditions. Fog or darkness sometimes separated the parties, or floods came and swamped the outfit. It was necessary on this account to place everything on staging. At the end of the day's work the party was often completely wet through, and as there was usually little chance to dry clothing it was wrung out and allowed to dry on the body during the night.

Until this year there has been practically no information concerning the character of the coast of the Yukon Delta, and the means of travel along it, either by land or sea. Travelers have lost their way going from the river to St. Michael, and have drifted into the marshy wastes of the delta. The entire country is lonely in the extreme. During the day the muddy flats extend far out from land, and the woeful cry of the loons and exasperating, noisy calls of the geese disturb the peace at night.

No. 30.



One mile at sea off the Yukon Delta coast.

The native travels, preferably, by the river highways, as he there has the advantage of deep water and plenty of driftwood for camping purposes, and he may also take advantage of the incoming tides and currents of rivers. In crossing the face of the delta he awaits the proper tide and favorable breezes for his sailboat, and calm water for the kyak. The "oomiaks," or larger family boats, keep out at sea until opposite the point of destination. The kyak, or single canoe, keeps closer inshore, and takes advantage of the inland passages.

It has been previously supposed that there was a system of islands and sloughs with deeper water, by which it was possible to go along the delta face and not be dependent on the tides. There are, however, but three islands or groups of islands, and the only slough systems that can be taken advantage of are the mouths of the main rivers.

The Yukon Delta coast may be divided into three distinct portions, each having its own characteristics. The first extends from the southern pass a distance of 35 miles to the Kwikpak. The shore line is a low bank from 2 to 3 feet high, with firm hard mud and sand extending 1 or 2 miles seaward. The middle portion, or swampy lands, extends 25 miles from the Kwikpak to the Okshokwhewhik. The remaining portion, from the last-named point to the Apoon, is characterized by jutting points of land, occasional bushes, and patches of deep moss. At high water one can generally keep within a quarter of a mile from shore in light-draft boats, such as Peterboro canoes, and may even at places skirt along the banks. At low water one must here, as elsewhere, keep so far out to sea that even with field glasses only the very largest rivers can be located. Loaded boats can at no time approach sufficiently near at this point to readily distinguish the land.

The largest streams can be entered at any time in light-draft boats. This statement applies particularly to the Kawockawik, 5 miles north of the Avogon or Lower Yukon entrance; the Pagomawik, 17 miles from the Avogon, and the Kwikpak system, 25 miles from the same point. The first 18 miles of coast from the Kwiklowak entrance are marshy. After this the banks become better and wood appears. Land may be approached more easily here, and favorable spots for camping are found. Between the Avogon and the Kwikpak mouths the distance is about 28 miles. Natives travel this distance in kyaks in one day, taking advantage of inland passages near the mouth of the Kweguk. The Kweguk and Pagomawik rivers are used by natives to go into the interior, even to the head of the delta, and are navigable by large boats, except at the entrance.

The first 5 or 6 miles on either side of the Kwikpak are characterized by good banks. Light-draft boats can keep well inshore. The better streams are all marked by stacks of wood at varying distances from the coast line. From here to the lower mouth of the delta is one day's journey in a kyak. To the Apoon it is a two days' trip. To St. Michael requires two days in a good sailboat, with favorable winds. No dwellings whatever are to be found. For five weeks no human being was seen, but the country is a paradise for waterfowl and mosquitoes. One almost stumbles over the geese, and on the rivers they scarcely get out of the way of the boat.

The only prominent features of the whole district are the high conical wood stacks that mark the rivers. These stacks may be observed even when out of sight of land, and are situated a mile or two inland, at the first camping spot. It is not safe to camp lower down the river than at the first wood stack, and even there it is safer to sleep on staging, as after southerly winds the sea comes inland a full mile or more. At low tide, standing at the grass edge, the sea is often invisible. Sea gulls may be seen wading around in an inch or so of water, a mile from shore. The mud is of that peculiar nature which made it necessary during lunch time to march around in circles to prevent sinking, never remaining more than a few moments in one spot.

From the Kwikpak to the good land near Okshokwhewhik but few rivers afford stopping places. Three miles from the Kwikpak there is a branch of the same. At 14 miles the Malitqweengak, at 18 miles the Elongozhewik, and at 22 miles the Oowik. These streams are marked by the aforesaid wood stacks, the Elongozhewik having two. From the time of leaving the Pagomawik, where the last view of the Kusilvak Mountain is obtained, no elevations are visible until, near the Elongozhewik, a distant view of the mountains back of "Hogback," and later on those behind Point Romanzof, is obtained. The last stretch of coast of about 25 miles is the most pleasant. The Apoon approaches the coast somewhat, and many rivers connect with the sea. These are well-defined, have raised banks, and are heavily lined with willows to within a short distance of the shore.

From October 3, on which date the parties were at St. Michael, to November 5, when Assistant Putnam arrived in Washington, the time was employed in settling up the affairs of the party at Seattle and in making the trip. Assistant Putnam was engaged at Washington until May 3, when he was detailed to duty with the Smithsonian Institution expedition to observe the total eclipse of the sun. This duty is reported under the heading Special Duty.

Steamer *Taku*, R. L. FARIS, Commanding: ALASKA, Yukon Delta.

BASE LINES.

ASTRONOMIC.

MAGNETIC.

TIDE.

TRIANGULATION.

TOPOGRAPHIC.

HYDROGRAPHIC.

H. F. FLYNN, *Assistant*.
G. S. PHELPS, *Aid*.
R. B. DERICKSON, *Aid*.
D. W. EATON, *Topographer*.
J. A. FRENCH, *Assistant Topographer*.
CARL E. MORFORD, *Recorder*.
J. E. McGUIRE, *Recorder*.
G. A. HARRIS, *Foreman*.

SUMMARY OF OPERATIONS.

4 base lines measured.
125 square miles triangulation.
254 stations occupied for triangulation.
266 geographic positions.
3 elevations determined of tidal bench marks.
1 latitude station.
2 magnetic stations.
193 square miles topography.
90 miles coast-line topography.
263 miles river shoreline.
92 miles creek shoreline.
9 topographic sheets.
293 square miles hydrography.
1 024 miles sounding lines.
8 800 angles measured.
8 tide stations established.
Miscellaneous current observations.
6 hydrographic sheets.

On the 1st of July Assistant R. L. Faris was at St. Michael, Alaska, with a party of 26 officers and men. The work projected for the season was the topographic survey of St. Michael and Stuart Island, with the hydrography in the neighborhood, and the complete development, topographically and hydrographically, of the Kwikpak and Kawanak passes leading to the mouth of the Yukon Delta. The steamer *Taku* and the steam launch *Delta* were put at the disposition of the party, and on July 10 active work began.

Three subparties were put into the field, Assistant H. F. Flynn, with the steam launch *Delta*, taking charge of the triangulation, topography, and hydrography of the Kawanak and Kwipak passes of the Yukon Delta. The second subdivision was in charge of Mr. D. W. Eaton, topographer, and was engaged in planetable work during the entire season, first on St. Michael and Stuart islands, and on the shore north of St. Michael, and later south of the latter point and in the passes before mentioned.

The third division, with the steamer *Taku*, was in charge of the chief of the party, and began the execution, in July, of the triangulation and hydrography of St. Michael and Stuart islands. In August and September this party was moved to the passes and combined with that of Assistant Flynn, and all worked on triangulation, topography,

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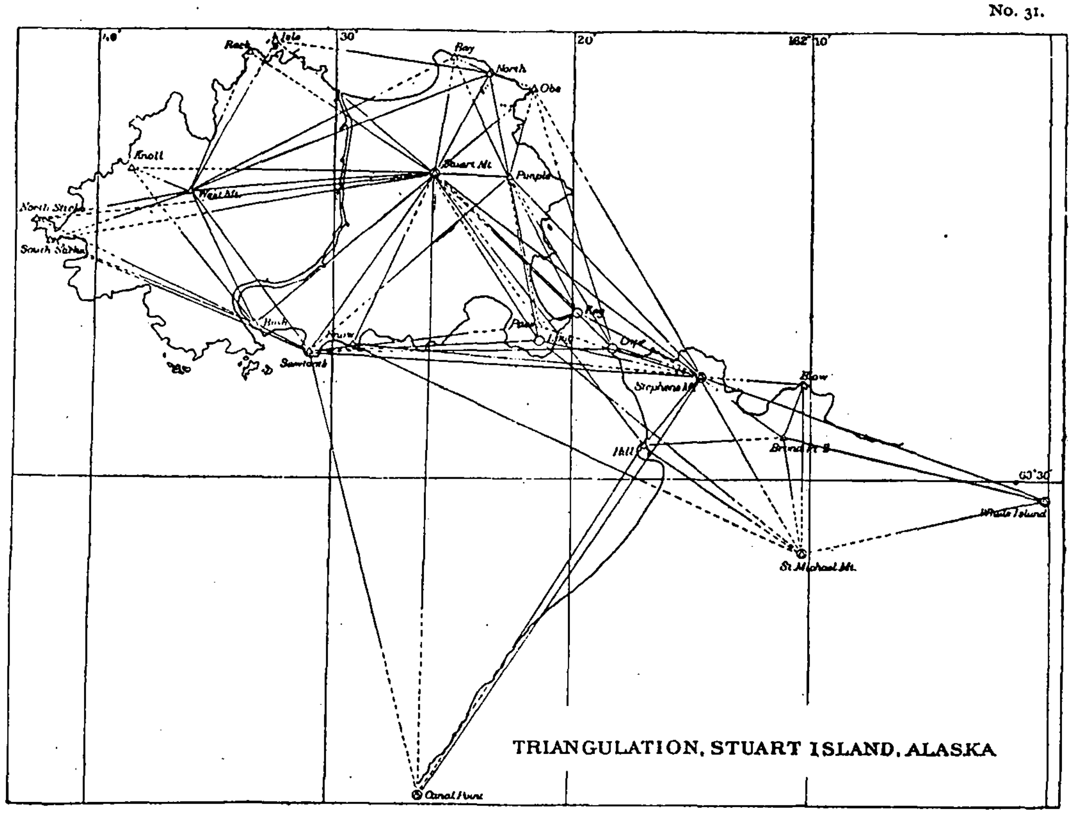

and hydrography of the passes, and developed the hydrography of the Kawanak for a distance of about 20 miles above the mouth to a point beyond the 3-fathom curve in the ocean.

The topography executed by Mr. Eaton north of St. Michael included about 16 miles of shoreline, to which must be added a part of the coast between Point Romanzof and Apoon Pass, which was done in the early part of the season. The total topographic work embraced 91 miles of coast line. The hydrography about Stuart and St. Michael islands, and that at the Yukon Delta, is embraced in 6 hydrographic sheets. Two magnetic stations were occupied during the season, at which the magnetic declination was observed.

The party left the Yukon Delta on September 15 and returned to St. Michael, where the vessel was laid up for the winter.

A better understanding of the features brought out by the work in the Yukon Delta may be had by reference to the sketch. It will be seen that the Kawanak Pass begins near the head of the Apoon Pass and flows nearly parallel to the Kwikpak, emptying into Norton Sound about a mile below the mouth of the latter.

The location of this channel was controlled by a system of triangulation extending 16 miles from the mouth of the pass, the last four stations of the scheme depending on sextant angles only for position.

The results of Assistant Faris's work in this region, important to navigation, are published in Coast and Geodetic Survey Bulletin No. 40, second edition, 1900.

The work in Alaska is so different from that executed in many parts of the United

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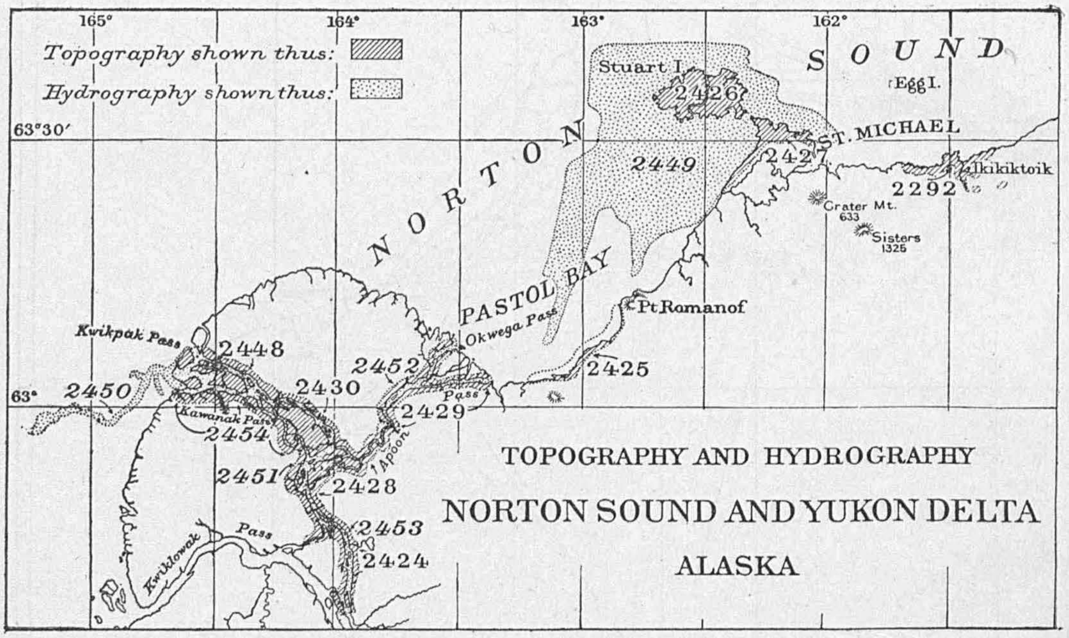

States that a brief outline of the conditions controlling the operations may not be without value. In the first place, the work is far removed from a base of supplies. There is much unfavorable weather, and transportation is expensive. The geographic features of the delta of the Yukon are continually changing, so that the most economical procedure was to make a fairly accurate map, without devoting much time to unnecessary refinement.

In conformity with these ideas it was decided to control the work by astronomic stations located conveniently to the main channels, to determine the longitudes by chronometer from St. Michael, and to observe the latitudes and azimuths. From the astronomic stations thus established a triangulation was developed, from which, when necessary, simple traverse lines were run, in order to establish minor details. It was considered more important to avoid large errors than to seek accurate refinement, and for this reason only such general checks as necessary were employed; that is to say, the measurement of all the angles of a triangle and the closing of the horizon, but no great effort was made to attain a high degree of precision, through the repetition of angular measurements.

Base lines were measured wherever necessary, and this made great precision in the angular measurements a question of secondary importance.

The triangulation of Stuart Island was completed about July 20, and covered an area of about 75 square miles. This work was performed, largely, by Mr. R. B. Derick-

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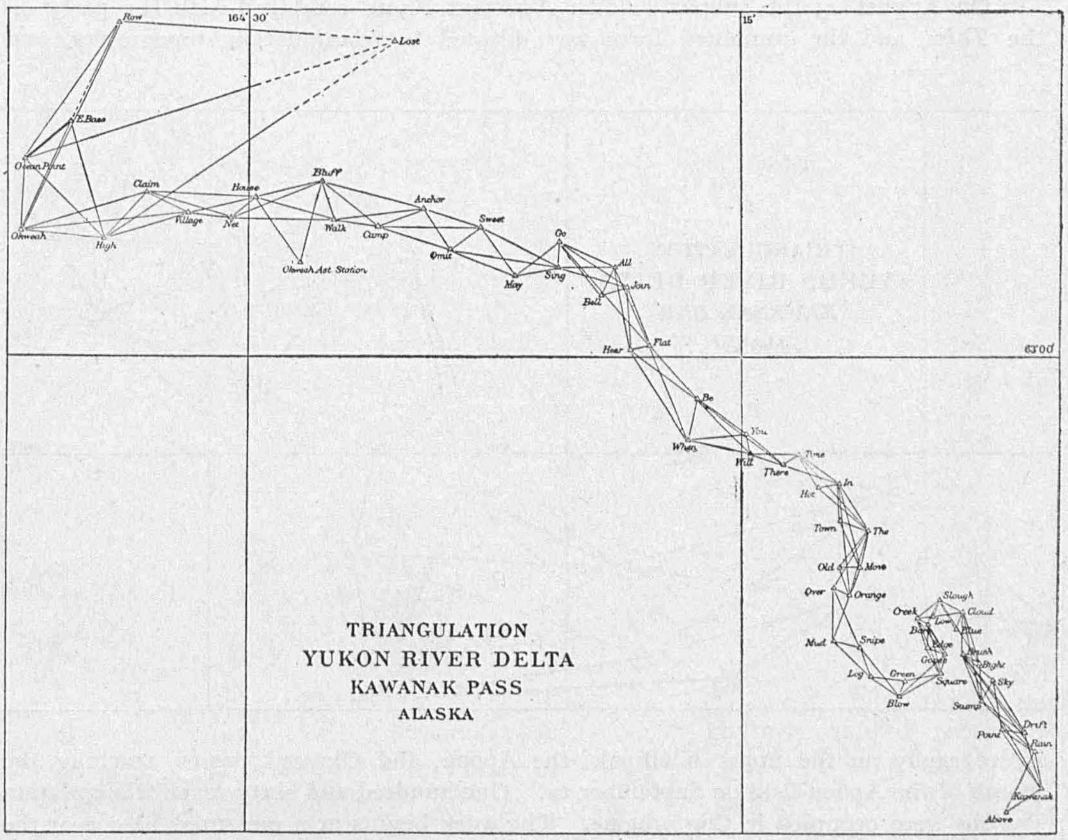

son, Aid. The field computations of this work were made, and the stations platted on the sheets for immediate use. It was necessary to occupy 72 stations in the triangulation of Kawanak Pass. This work was done by Assistant Flynn, and the signals were built by Aid G. S. Phelps.

Time, latitude, and azimuth observations were made by Assistant Flynn, near the mouth of the pass, and a base line was measured there. On August 2 the party under the personal direction of Assistant Faris, on the steamer *Taku*, proceeded to the mouth of the Kawanak Pass and took up the execution of a scheme of triangulation from its mouth running seaward to the 3-fathom curve. This work has already been described, and it is only necessary to add in this place that the scheme included 7 shore signals and 12 water signals, distributed along each side of the channel for a distance of 16 nautical miles from the mouth of the pass, and out of sight of the coast. Mention has already been made of the plan adopted in erecting water signals,* by means of gas pipe. The cost of these signals was about $3.50 apiece, including freight and all expenses from Seattle, which shows how much more economical it is to use signals of this kind than to depend upon the usual structures of wood. The water signals were, generally, located by angle measurements from shore stations, but the four outer ones depend upon sextant angles alone.

On August 23 the subparty under Assistant Flynn combined with the party on the *Taku*, and the combined force was devoted to triangulation, topography, and

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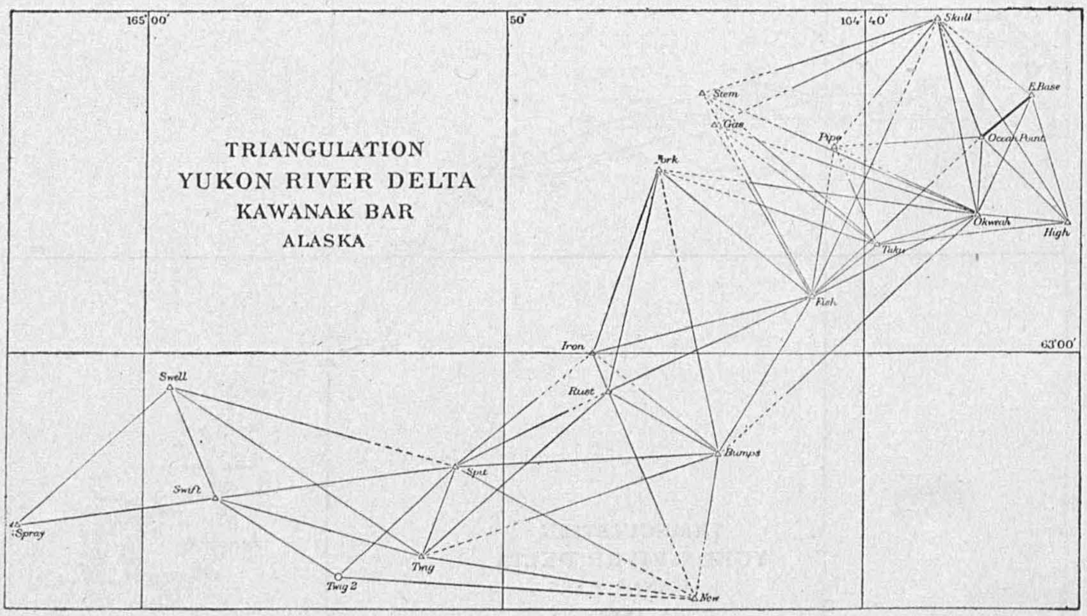

hydrography on the upper Kwikpak, the Apoon, and Okwega passes, reaching the mouth of the Apoon Pass on September 12. One hundred and sixty-seven triangulation stations were occupied in this scheme. The work begins at a measured base near the head of the Kwikpak and extends down that pass to another base at the head of the Apoon Pass, thence down the Apoon to its mouth, joining with the triangulation of 1898 from St. Michael. Another base was measured 6 miles above the mouth of the pass, at Kotlick. The narrowness and crookedness of the Apoon Pass rendered it very unfavorable for good triangulation. One hundred and four stations were required to cover its length of 35 miles.

BASE LINES.

No base line was measured for the Stuart Island triangulation, since it was connected with the adjusted scheme of 1898 along the coast. In connection with the

* Signals erected in the water. For illustrations see preceding report of Assistant Putnam.

other work, however, 4 bases were measured, at an average distance of 21 statute miles apart. The ends of the bases were marked by driving a large stub firmly in the ground and measuring between them with a 50-meter standardized steel tape, which lay on the ground and was stretched at a tension of 15 kilograms. The tape lengths were marked by pins stuck in the side of driven stakes which were aligned by the eye.

From the Kotlik base to the Apoon base there are 78 stations and a large number of the lines are only from 300 to 500 meters long.

TOPOGRAPHY.

The nature of the work in this part of Alaska is such that it is not always possible or desirable to use the plane table. Other methods were, therefore, employed, and the topography executed during the season was done by sketching, employing sextant angles for location of position, and by running traverse lines with a steam launch, compass, and log.

The work around St. Michael and Stuart islands was considered to be sufficiently important to employ the plane table, and this method was adopted in this part of the field. On the lower end of the Kawanak and Kwikpak passes positions were located by the use of a sextant, and in the passes themselves many lines were established by using a steam launch, compass, and log. When such traverse lines were run it was done so that the two ends of the traverse joined known positions, so that any errors could be readily adjusted. In some parts of the plane-table work celluloid sheets were used and proved very serviceable, in view of the continual moisture incident to this locality. The work was afterwards transferred from the celluloid sheets to projections on paper and filed with the

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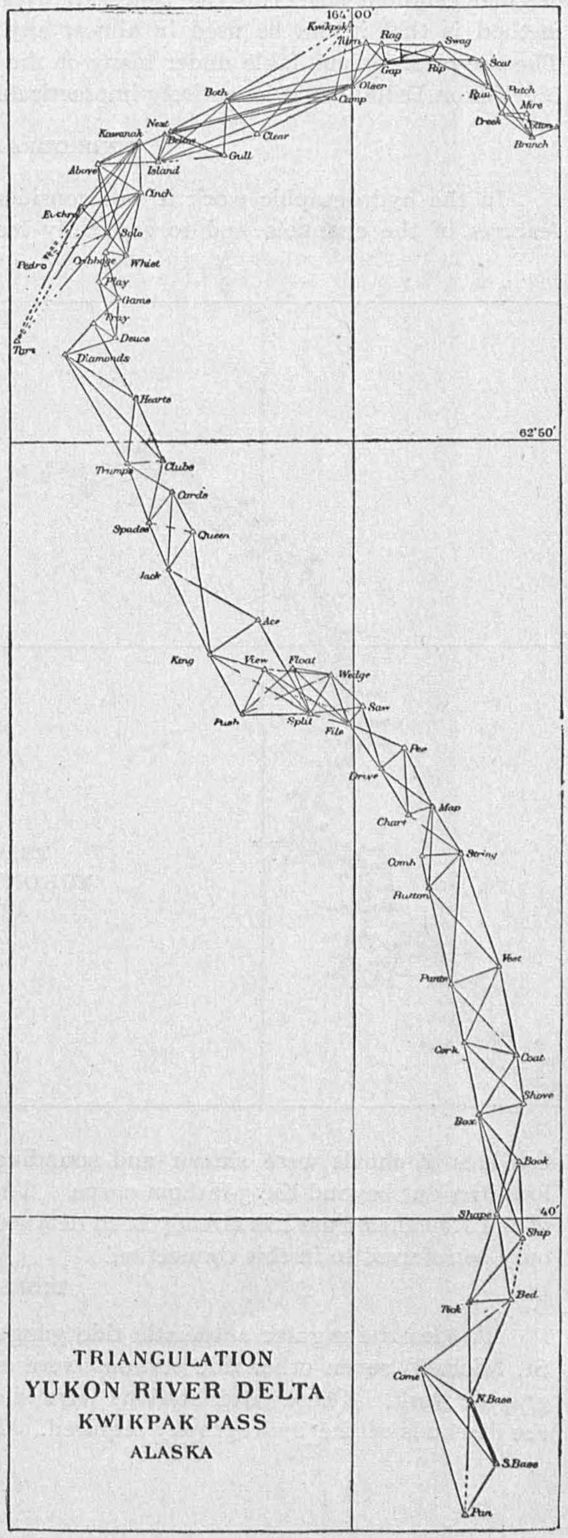

TRIANGULATION
YUKON RIVER DELTA
KWIKPAK PASS
ALASKA

original celluloid sheets in the Office archives. The great advantage of the sextant method is that it can be used in almost any weather, and admits of great rapidity. The use of the plane table under many of the conditions that exist along the coast of the Yukon Delta would be entirely impracticable, if not impossible.

HYDROGRAPHY.

In the hydrographic work it was considered most important to develop the main features of the channels and to especially locate minimum depths in critical places.

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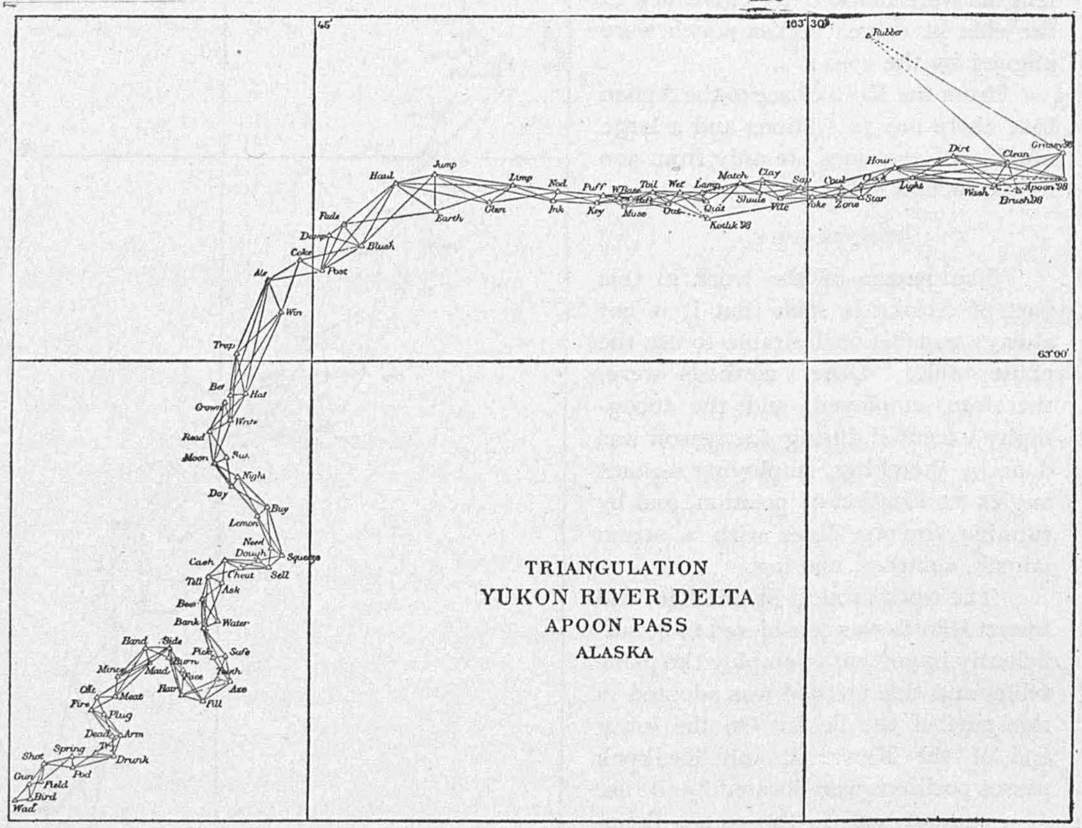

Outlines of shoals were shown and soundings were made from the shore in certain localities out beyond the 3-fathom curve. The location of the channel from the mouth of the Kawanak Pass has already been detailed in the first part of this report, and need only be referred to in this connection.

TIDES.

Besides the regular automatic tide gauge maintained during the entire season at St. Michael, seven other tide stations were established in connection with the hydrographic work. These latter stations were simply plain staffs, and were maintained as the demands of the hydrography required. There are two distinct types of tide in the delta of the Yukon, the Apoon and Okwega having one tide and all the other passes two tides a day.

Two magnetic stations, the one at Kotlik and the other at Okwega, were made, and declination was observed by means of a compass declinometer.

The barometer and thermometers were read at the Yukon Delta and at St. Michael during July, August, and September, the result of which showed the mean temperature for August and September to be 8°·2 C. and a mean pressure for the three months of 39·6 inches. The monthly means were made up from readings every two hours during the twenty-four of each day during the month.

On September 15 the party returned to St. Michael for the purpose of putting the vessels on the ways and properly caring for the outfit during the winter. On October 3 the Coast and Geodetic Survey steamer *Patterson*, under command of Assistant Pratt, sailed from St. Michael, bound for Seattle, with the party on board except Messrs. Flynn, Derickson, and Edmonds, who boarded the ship at Dutch Harbor.

The *Taku* was sent to Dutch Harbor, and was manned by Messrs. Flynn, Derickson, and Dr. Edmonds, these gentlemen having volunteered to make the passage with her.

The *Patterson* arrived at her destination on the 21st, and all temporary party employees were discharged and the party disbanded. In compliance with instructions from the Superintendent, Assistant Faris reported in person at Washington on the 4th of November. On the 13th, after six days' leave of absence, the computations and office work of the season's operations in Alaska were taken up and completed by April 27, 1900. From this date to May 13 Assistant Faris was on leave. From the 14th to the 26th he was attached to the Division of Terrestrial Magnetism, and on the latter date left Washington for Seattle to join the steamer *Patterson*, under the command of Assistant J. F. Pratt. He reported on the 1st of June, and was engaged in duty on that vessel until the close of the year.

H. P. RITTER: ALASKA, Copper River Delta.

TIDE.

TRIANGULATION.

TOPOGRAPHIC.

HYDROGRAPHIC.

E. B. LATHAM, *Assistant.*
H. C. DENSON, *Aid.*
R. E. CARSON, *Foreman.*

SUMMARY OF OPERATIONS.

450 square miles triangulation.
33 stations occupied.
45 geographic positions.
18 elevations determined trigonometrically.
210 square miles topography.
150 miles general coast line.
50 miles creek shore line.
1 topographic sheet.
125 square miles hydrography.
184 miles sounding lines.
761 angles measured.
2 tide stations established.
1 hydrographic sheet.
195 photographic views.
24 earthquake shocks recorded.

TRIANGULATION.

Instructions were issued on April 29 to Assistant H. P. Ritter to organize a party for the prosecution of work at the mouth of the Copper River, in Alaska. Assistant Ritter had carried on work in this locality during the past season, and his instructions were to take up the operations at the point left off and carry them on, in order to develop the region around Orca, Alaska.

The party left San Francisco on May 26 and arrived at Orca, Prince William Sound, on June 12, having called at Seattle on May 9 and Sitka on June 7. Immediately on arrival at the field of action operations were begun to build a camp. The outfit and boats, which had been stored at Orca during the winter, were overhauled, and all material was transported to the camp site situated near Cape Whitshed, about 12 miles distant.

From this point triangulation was carried on, starting from the base line "Whitshed to Egg Island," determined during the previous season, and carried around the cape, continuing in a northeasterly direction toward Orca and Cordova. Connection was made with the Orca astronomic station of 1898. From the base line just mentioned a scheme was also extended in a westwardly direction from Cape Whitshed to the vicinity of Point Johnson, Prince William Sound.

During the course of the work the positions and heights of the principal peaks of the different mountain ranges in the vicinity were determined. The triangulation stations were permanently marked. The triangulation party encountered many difficulties in their work, not the least of which was the great distance it was sometimes necessary to travel for the occupation of points. Camping sites were extremely difficult to find, and on many days it was necessary to travel as much as 15 miles to occupy a station.

HYDROGRAPHY.

Hydrographic operations began as soon as the other work permitted. Soundings were taken on nine days during the month of August. The hydrography of Orca Inlet, extending from the mouth to Spike Island, was executed with care. In addition

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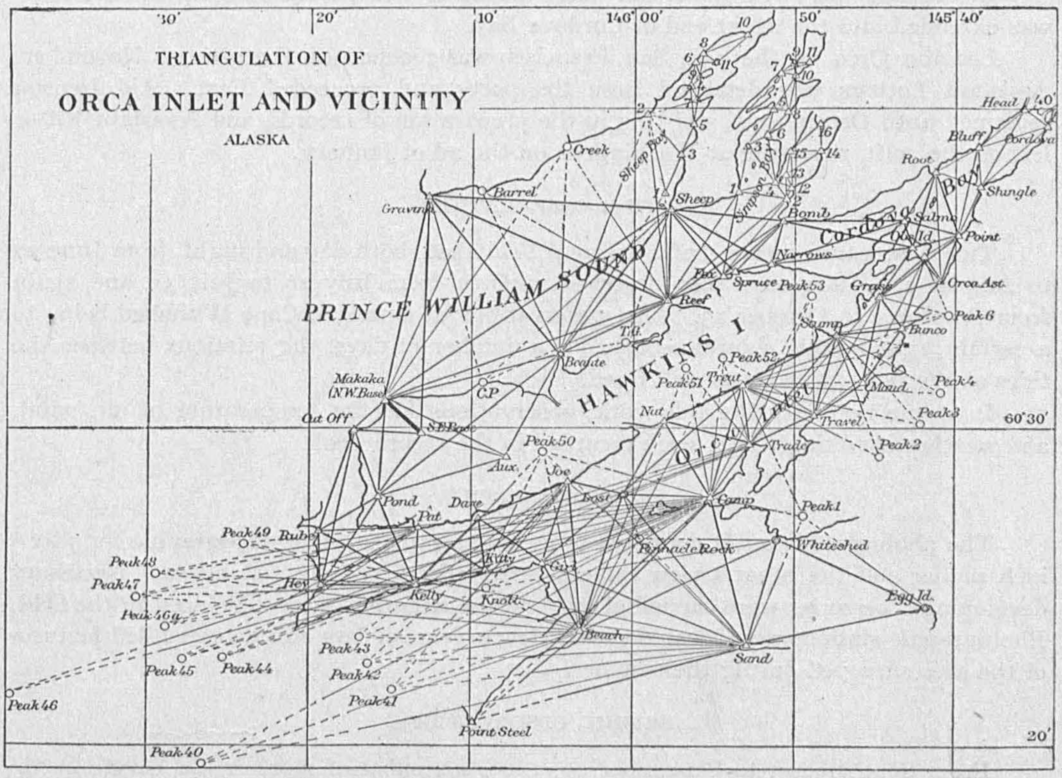

to the soundings, a number of flats, channels, shores, and rocks were located at extreme low water by means of the plane table. At Spike Island the hydrography joins that which was executed in 1897 by the United States Fish Commission steamer *Albatross*, Lieut. Commander J. F. Moser, commanding.

In order to show the general hydrographic conditions of the mud flats forming the western end of the Copper River Delta, a number of sounding lines were run extending from Cape Whitshed eastward as far as Glacier River.

TOPOGRAPHY.

The topographic work consisted mainly of delineating with the plane table the shore line and contiguous topography, and determining, in addition, mountain peaks and such other salient topographic features as time and weather permitted. The localities thus mapped during the season included the western end of the Copper River Delta from Egg Island to Cape Whitshed, Point Steel to the entrance of Orca Inlet, the eastern end of Hawkins Island Cut-off, and Orca Inlet from the entrance to the head of Cordova Bay.

Aid Denson was in charge of the triangulation work. Assistant Latham had charge of the photography, the location of tide gauges and bench marks, and the determination of time for tide observations. Assistant Ritter did the topography and exercised general supervision. The hydrography was done by the chief of party, Assistant Latham, and Aid Denson.

In the early part of October the party moved to Orca, from which point the work was extended into the upper end of Cordova Bay.

Leaving Orca on the 23d, San Francisco was reached on the 18th of November. Assistant Latham was detached from the party and proceeded East. Aid Denson remained until December 1, assisting in the preparation of records, and Assistant Ritter left on the 19th, reporting at Washington on the 2d of January.

TIDE OBSERVATIONS.

Tide observations were made at Camp Whitshed, both day and night, from June 27 to August 1. Tides were also observed at Orca from July 26 to July 31, and again from October 1 to October 23. The observations at Orca and Cape Whitshed being to a certain extent made simultaneously for a number of days, the relations between the tides at the two stations was well fixed.

In connection with the tide work, observations for the temperature of air, wind, and weather conditions, etc., were recorded in the record book.

PHOTOGRAPHY.

The photographic outfit consisted of 2 cameras; one a photo-topographic for 5 by 8 inch plates, and the other a view camera using plates 6½ by 8½ inches. Necessary developing accessories were carried along, and the negatives were developed in the field. Photographic stations were located with a view to furnish data and give detailed features of the area surveyed during the summer.

SEISMIC OBSERVATIONS.

From September 3 to September 29, 1899, a number of more or less severe earthquake shocks were felt in camp at Cape Whitshed. These were recorded by Assistant Ritter, and the list was submitted with his report. The work of sounding and running shore line during and after the disturbances gave an opportunity to judge of the effect of the earthquake shocks upon the topographic features. It was found that the changes were very slight, an overhanging outer or soft bank being sometimes precipitated into the water below.

The party arrived in San Francisco on the 18th of November, and the time from this date until the 19th of December was employed in closing up the field work, in obedience to the Superintendent's instructions of November 9. On December 19 Assistant Ritter left for Washington, where he arrived on the 1st of January, having had leave of absence on the way, at Cleveland, Ohio.

Steamer *Taku*, H. P. RITTER, Commanding: ALASKA, Copper River Delta.

TRIANGULATION.

TOPOGRAPHIC.

HYDROGRAPHIC.

TIDE.

H. C. DENSON, *Aid.*
H. MCINTYRE, *Sailing Master.*
GEO. W. CARLEY, *Engineer.*
CHAS. WALLACE, *Machinist.*
R. E. CARSON, *Foreman.*
GION FRANCESCHI, *Engineer.*

SUMMARY OF OPERATIONS.

250 square miles triangulation.
21 stations occupied.
18 miles coast-line topography.
125 square miles hydrography.
174 miles sounding lines.
473 angles measured.
2 tide stations occupied.

Assistant Ritter was engaged in the reduction of field work for the previous season until the 7th of March, when preparations were made to resume field work in Alaska. He left Washington on the 14th, bound for San Francisco, from which point he sailed for Orca, Alaska, via Seattle, on the 29th of March.

Arriving on the 17th, he was engaged in organizing his party and making preliminary observations until the 6th of May, when he left Orca for Unalaska, in order to bring over the steamer *Taku*, which was to be employed during the season in the neighborhood of Orca. Returning on the 26th of May with the *Taku*, surveying operations were continued without interruption and were still in progress on the 30th of June.

Steamer *Gedney*, E. F. DICKINS, Commanding: ALASKA, Chatham Strait, Rosario Strait.

TRIANGULATION.

TIDE.

F. W. EDMONDS, *Assistant.*
G. F. THOMAE, *First Watch Officer.*
A. H. DUTTON, *Second Watch Officer.*
W. G. APPLETON, *Third Watch Officer.*
F. G. CRIST, *Chief Yeoman.*
W. G. HAY, *Hospital Steward.*
E. H. FRANCIS, *Pilot.*
JAMES MITCHELL, *Chief Machinist.*

SUMMARY OF OPERATIONS.

750 square miles triangulation.
19 stations occupied.
19 geographic positions.
1 square mile hydrography.
9 miles sounding lines.
1 tide station established.
420 angles measured (trigonometric).
346 soundings.
416 angles (hydrographic).

On the 1st of July the steamer *Gedney* was in San Francisco Harbor, taking on stores preparatory for work in Alaska. Everything being in readiness, the vessel, under command of Assistant Dickins, sailed on the 4th of July and arrived at Seattle on the 9th. After a few repairs, the necessity of which had developed on the trip up the coast, the vessel left Seattle on Sunday morning, July 16, and arrived at Sitka on the 24th, having stopped on the way at Victoria Harbor and at Departure Bay, British Columbia.

After having taken on coal and made minor repairs to the *Cosmos*, which was found in rather bad condition, the party left Sitka for Killisnoo, where launch *No. 117* was taken in tow, and the working ground was reached on the 6th of August. Work was immediately begun on the triangulation, and signals were erected between the 7th and 21st. On the latter date observations began and were continued until September 22, at which date the complete connection between Chatham and Sumner straits had been made.

Owing to bad weather and other unfavorable circumstances, no base line or azimuth could be measured as a test. After closing work, the vessel proceeded to Killisnoo, where launch *No. 117* was left. Sitka was reached on the 27th. The *Cosmos* was housed for the winter, and left in charge of Col. M. C. Goodrell, United States Marine Corps, who kindly offered to have the boathouse inspected at least twice a month. Such parts of the machinery as required repairing were subsequently brought to Seattle, and a special report was made on the condition of the vessel.

Receiving instructions at this point to search for an uncharted rock in Wrangell Narrows, recently reported, the vessel left Sitka and proceeded to Killisnoo, where launch *No. 117* was hauled out and housed. Arriving at Wrangell Narrows on October 7, a search was made for the obstruction to navigation reported, but nothing was discovered except the Topeka Shoal, which is already charted, and on which it is believed the steamer *Cutch* struck.

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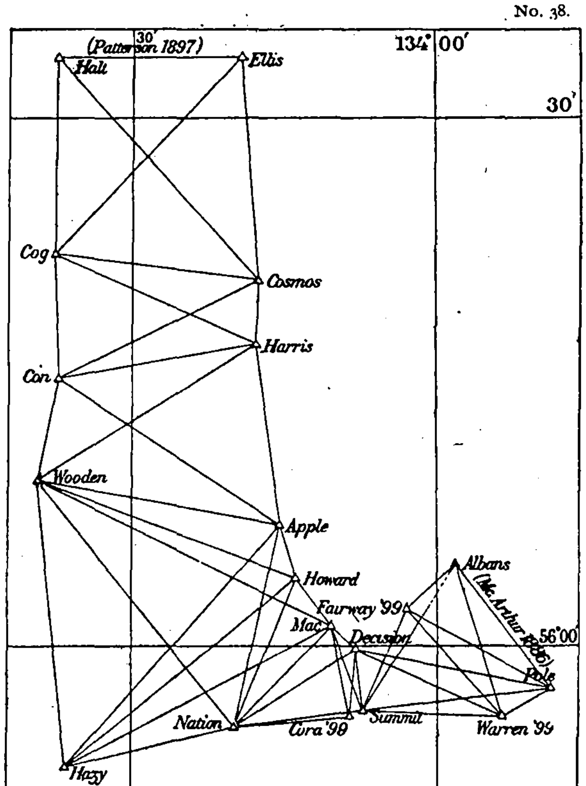

Triangulation between Chatham and Sumner Strait, Alaska

Passing through the strait on the voyage southward, it was noticed that the Point Lockwood rock buoy was missing. This was reported to the inspector of the Thirteenth lighthouse district. Arriving in Departure Bay, British Columbia, on the evening of October 11, the coal bunkers were filled the next day, and the ship got under way for Victoria, where she arrived about midnight. The *Gedney* sailed on the morning of the 14th for Seattle, and arrived in the afternoon.

Receiving orders at this place regarding the reported rock in Rosario Strait, the ship left on the morning of the 18th and arrived at New Whatcom in the evening. Two days were lost on account of bad weather, but on the 21st she proceeded to Rosario Strait, a tide gauge was established, and the necessary signals erected. On the 22d the Buckeye Shoal was located and developed, and on the 23d another shoal near the entrance to Obstruction Pass, which had been reported by the captain of the steamer *Lydia Thompson*, was located. The vessel then returned to Seattle and awaited further orders.

On the 28th Assistant Dickins received instructions to turn over the command of the *Gedney* to Mr. G. F. Thomae, first watch officer, and proceed to San Francisco for office duty. He arrived at the latter point on the 5th of November. Assistant Dickins's occupation for the remainder of the year is reported under the Western Division.

Steamer *Pathfinder*, J. J. GILBERT, Commanding: ALASKA, Golofnin Bay.

HYDROGRAPHY.

H. F. FLYNN, *Assistant.*
E. R. FRISBY, *Aid.*
A. H. DUTTON, *First Watch Officer.*
J. T. GOLDSBOROUGH, *Chief Engineer.*
C. W. FITZGERALD, *Second Watch Officer.*
W. M. ATKINSON, *Third Watch Officer.*
C. F. DEICHMAN, *Chief Yeoman.*
R. C. McGREGOR, *Recorder.*
J. J. MURPHY, *Hospital Steward.*
J. T. WATKINS, *Draftsman.*

On April 12 Assistant Gilbert received instructions to proceed as soon as practicable to Seattle, Wash., and take command of the steamer *Pathfinder*.

He left San Francisco on the 16th and reached Seattle on the 20th. On Sunday, the 22d, Assistant Gilbert was present at morning inspection and formally assumed command of the vessel.

The first duty was to attend to certain repairs. On May 18 the vessel was taken to Port Orchard, and early the next morning the *Pathfinder* and the *Patterson* were docked together. The vessel came out of dock on the 24th. She was delayed two days longer, getting some fittings from the foundry and machine shop, at the end of which time Assistant Gilbert returned with the vessel to Seattle. The last coal was taken on board on the morning of the 13th. Six officers and nine men of the United States Geological Survey were also taken on board, and the ship sailed at 12.30 the same day.

After a week's passage Tegalda Island, off Akutan Pass, was sighted. Approaching the island near enough to verify his position Assistant Gilbert shaped his course through the pass and entered Dutch Harbor at 10.30 that night. Coal was here taken aboard. Leaving Dutch Harbor Sunday morning, June 25, Nome was reached on the following Wednesday. A stay was made here only long enough to mail letters, and at 3 p. m. the vessel proceeded to Golofnin Bay, where anchor was cast at 9 p. m.

On Thursday, June 28, the Geological Survey party and outfit was landed in the morning, and in the afternoon six buoys were placed, marking the best channel through the bay. A line of soundings was run to the mouth of the bay. The buoys were made of oil barrels, and were anchored with concrete blocks of sand, gravel, and cement, weighing about :80 pounds each.

Immediately thereafter the party started for St. Michael, where the vessel came to anchor seven hours later. The next two days were occupied in putting down a shed over the *Yukon* and the launches, and on the 1st of July the only preliminary work remaining to be done was to launch the *Yukon* and set up the machinery.

E. OUTLYING TERRITORY.

S. FORNEY: PORTO RICO.

RECONNAISSANCE.

TRIANGULATION.

AZIMUTH.

WILLIAM BOWIE, *Assistant.*
J. S. BILBY, *Foreman.*

SUMMARY OF OPERATIONS.

1 177 square miles reconnaissance.
63 points selected.
1 170 square miles triangulation.
15 stations occupied.
55 geographic positions determined.
129 elevations determined trigonometrically.
1 azimuth determined.

Instructions were issued to Assistant Forney on the 15th of January, 1900, to take up triangulation in Porto Rico. He sailed on January 20, accompanied by Mr. J. S. Bilby, foreman, and arrived at Ponce on the 27th. From this point he proceeded to San Juan, arriving on the 3d of February. At this point an outfit of mules, saddle horses, and wagons were furnished through the courtesy of the department quartermaster, United States Army, and on February 2 the party left San Juan with the outfit for Ponce, arriving on the 4th.

On February 5 the equipage and instruments were moved from La Playa to Ponce, and the camp was pitched east of the city. The reconnaissance for the triangulation across the island from the line Cardona Light-Muertos Light to San Juan Light was immediately begun. After making an effort to observe from Cardona Light on a lozenge 5 feet square at Magota station, it was found that the results were unsatisfactory, and heliotropes were therefore stationed at Magota and Aibonito stations. This plan also proved unsatisfactory, owing to the clouds and fog which almost constantly hover over the mountain ranges during the day. At night, however, from 11 p. m. until 4 a. m., the mountain peaks were comparatively free from clouds. What are known as Economy gas lamps were then placed at these two stations, and the observation of horizontal and vertical angles carried on with little interruption, giving satisfactory results. Reconnaissance and triangulation was conducted simultaneously, and rapid and satisfactory progress was made; and the whole work was completed, together with the determination of an astronomic azimuth at San Juan, in three months from the time of beginning.

The island of Porto Rico was crossed by two quadrilaterals, and the main scheme of Assistant Forney's triangulation was connected with that of Assistant Hodgkins south of San Juan. In addition to the main scheme of triangulation across the island, prominent peaks lying to the eastward and westward, and prominent objects, such as chimneys and church towers along the southern slope and shore of the island, were determined by intersection. Complete series of vertical angles were measured on all points determined.

Assistant Forney states, as a result of his experience, that triangulation in the interior of Porto Rico can not be carried on advantageously without the use of lights

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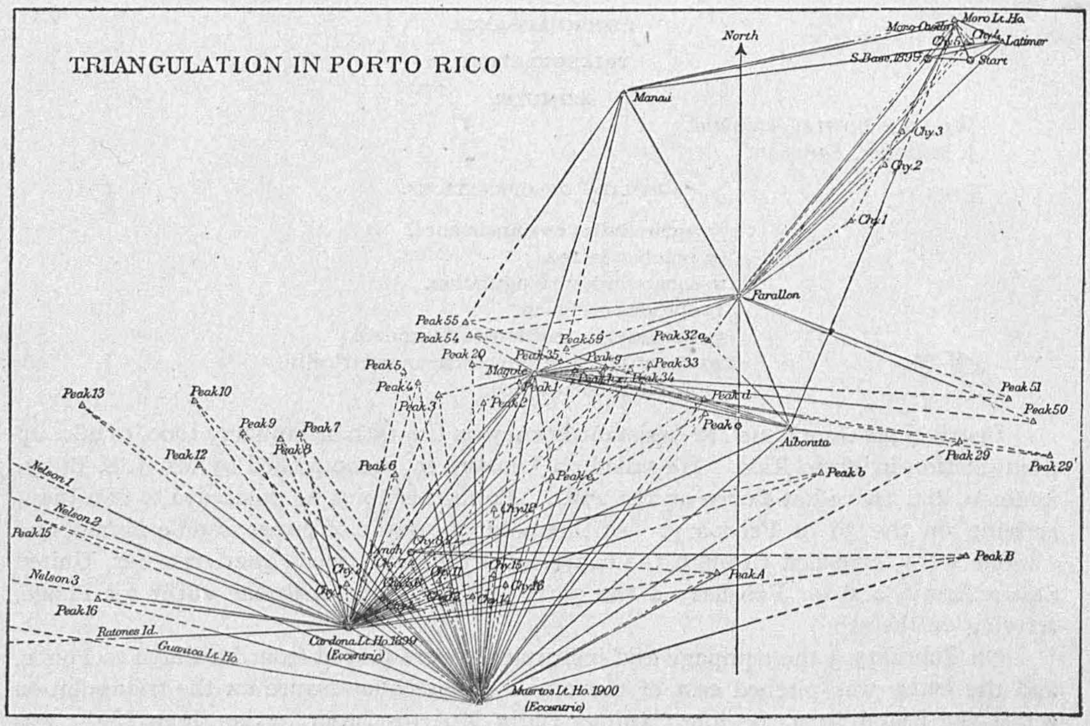
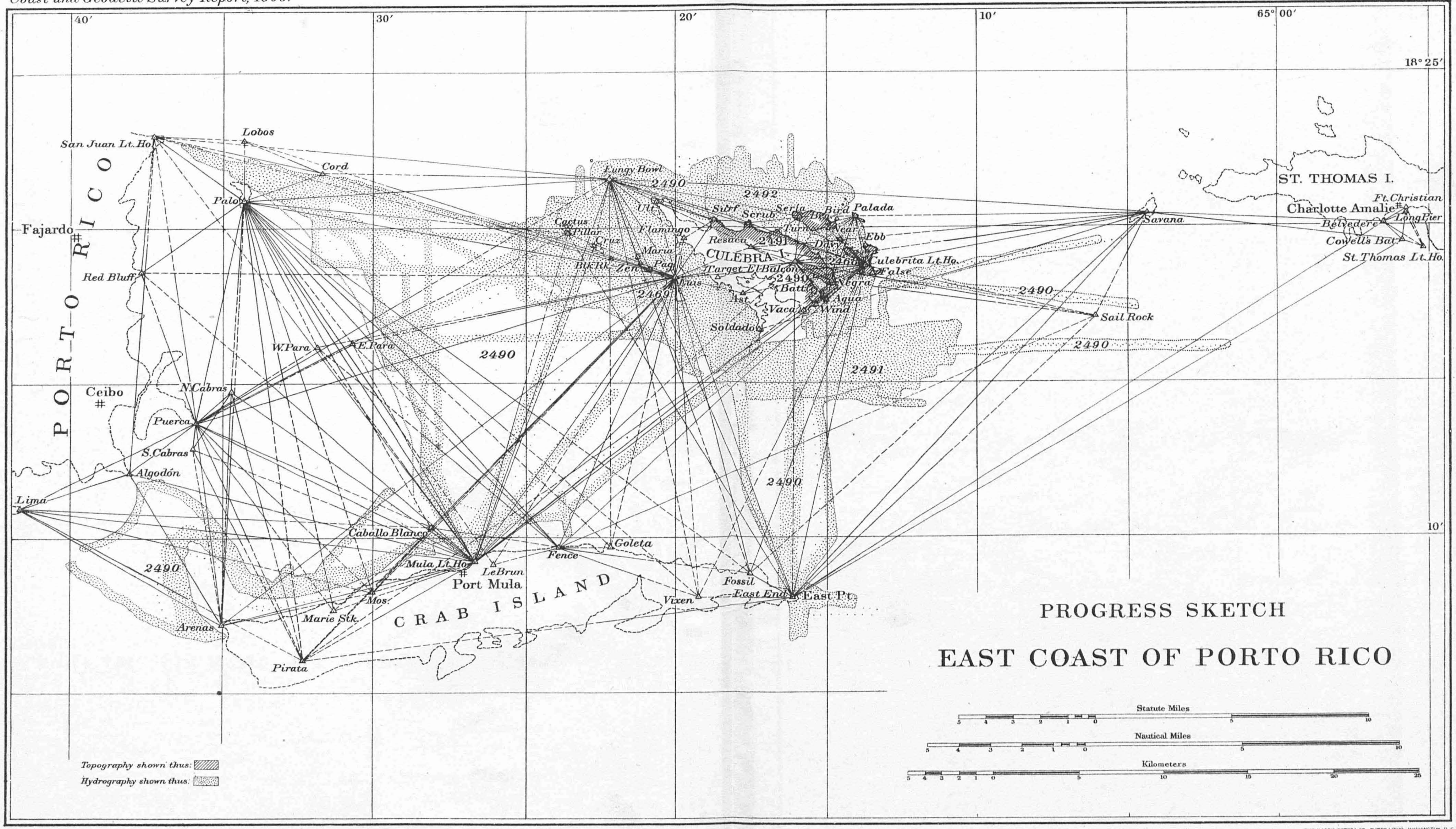


TRIANGULATION IN PORTO RICO

and night observations. He estimates that without this method the time consumed in the prosecution of the work would at least have been doubled.

Assistant Forney makes grateful acknowledgment to General Davis, commanding the Department of Porto Rico; to Major Glassford, the chief signal officer, and various other officers of the Army for aid given in the prosecution of the work and for courtesies extended.

On May 5, the triangulation having been completed as well as the azimuth observations at Latimer triangulation station, the camp equipage and instruments were packed and placed on board the U. S. transport *Crook* for transportation to New York. On May 10 the hands were discharged, and the same day Assistant Bowie, Mr. Bilby, and Assistant Forney sailed for New York, arriving on the 19th. Assistant Forney was employed in the Office until the close of the year.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Steamer *Blake*, W. C. Hodgkins, Commanding: Porto Rico, Culebra.

TRIANGULATION.

HYDROGRAPHIC.

TOPOGRAPHIC.

TIDE.

F. M. Little, *Assistant.*
H. C. Mitchell, *Aid.*
F. F. Weld, *Aid.*
W. F. Glover, *First Watch Officer.*
L. M. Hopkins, *Chief Machinist.*
C. A. Thompson, *Second Watch Officer.*
George E. Marchand, *Medical Officer.*
W. B. Proctor, *Third Watch Officer.*
J. A. McGregor, *Fourth Watch Officer.*
J. F. Pfau, *Draftsman.*
O. Straube, *Recorder.*
H. E. Putney, *Recorder.*

SUMMARY OF OPERATIONS.

595 square miles triangulation.
24 miles coast-line topography.
2 topographic sheets.
250 square miles hydrography.
950 miles sounding lines.
19 634 angles measured.
29 891 soundings.
1 tide station.
6 hydrographic sheets.

The work of repairing the *Blake*, at Baltimore, continued until the 10th of February. Assistant W. C. Hodgkins, commanding, received instructions in January to proceed to Porto Rico and Culebra Island and take up hydrographic and topographic work in that locality. The vessel got under way on February 10, but the weather being unfavorable, a short stop was made at Norfolk, Va. On the 14th she sailed for San Juan, which point was reached on the 20th of February. Culebra Harbor was reached before noon of the 24th. The Coast and Geodetic Survey schooner *Eagre* was found here at anchor, under command of Assistant J. B. Boutelle.

After consultation with Assistant Boutelle in regard to the condition of the work, the *Blake* proceeded to St. Thomas to make arrangements for using that point as a base of supplies. The work of the survey was taken up on the 27th of February, by making a reconnaissance of the islands and the building of the necessary signals.

A latitude station was selected on Battle Cay, a small island in Mangrove Harbor, on the east side of Culebra Island. A trigonometric connection was made between the triangulation of Culebra Island and the longitude station established some years ago at Fort Christian, St. Thomas. An intermediate station was established on Savana Island, about midway between Culebra Light and St. Thomas Harbor, which, in connection with the station on the eastern end of Vieques Island, enabled a fairly well-shaped scheme to be laid out. All of the triangulation of the season depends upon the base line near the head of Culebra Harbor, measured by Assistant Boutelle. A considerable number of triangulation points were established on the north coast of Vieques Island and on the east coast of Porto Rico, so that a topographic or hydrographic party would have no difficulty in beginning work anywhere north of Point Lima or east of Point Arenas.

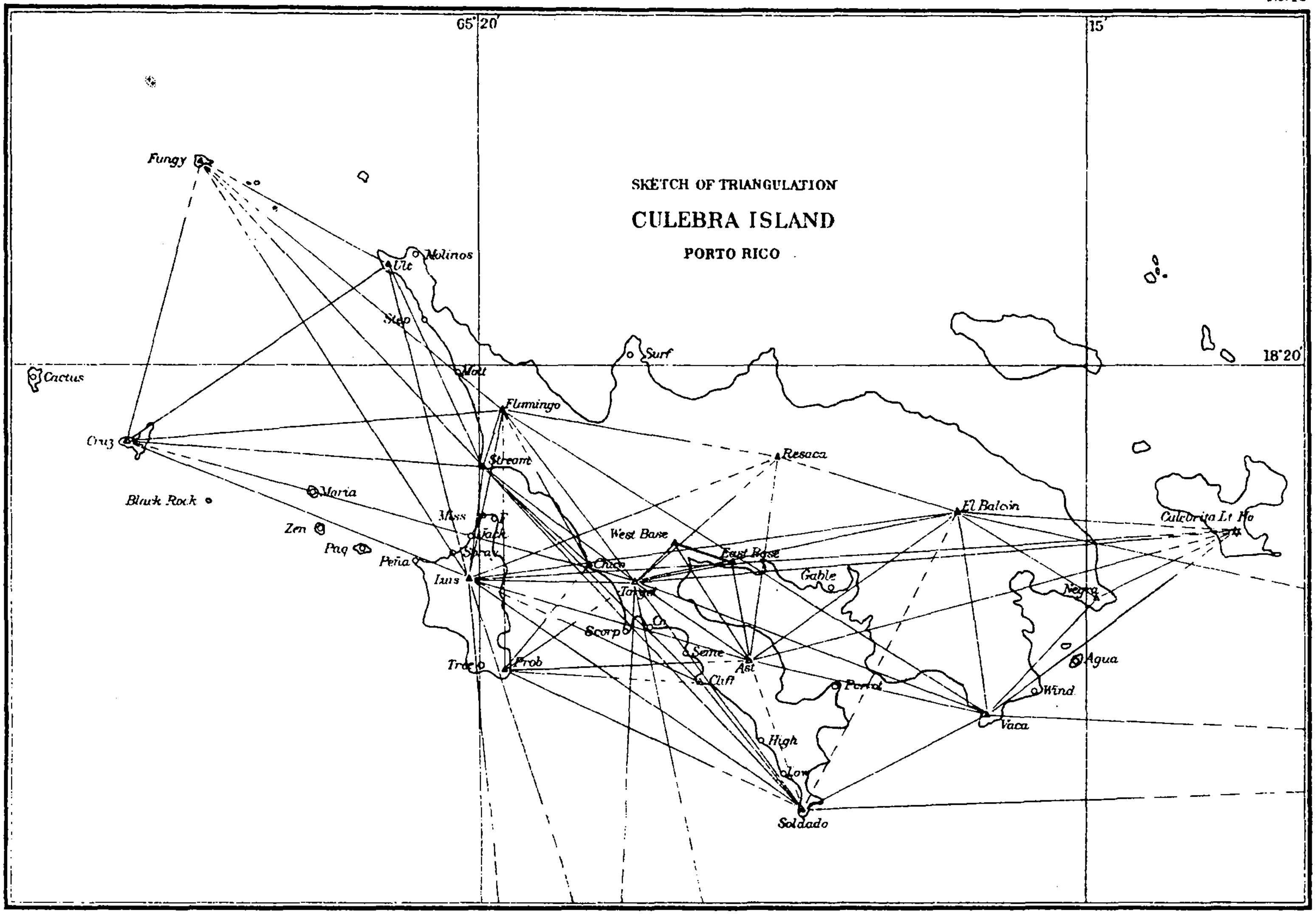
The topographic work of the season was limited to the survey of the shore line of Culebra and adjacent islands, the harbors being surveyed on a scale of 1:5 000 and the remainder of the shore on a scale of 1:10 000. The hydrography followed much the same rule. The party on the *Blake* had one sheet covering the so-called sound, east of Culebra, including Mangrove Harbor. Four sheets show the hydrography around the island, and one covers the extensive sheet of water between Culebra, Vieques, and Porto Rico. The eastern part of the sound, as far as examined, was found of sufficient and nearly uniform depth. West of this, and close to the shore of Porto Rico, there is a rather narrow and somewhat tortuous channel, with a depth of water sufficient for any ordinary vessel. To the south of a dangerous area there is also a good channel between these shoals and those lying toward the shores of the island of Vieques Island. Great caution should be exercised in this locality, as the indications of the shoal spots upon existing charts are thought to be unreliable, both as to their number and their positions.

Some distance to the eastward of the eastern rock a bank of considerable extent was discovered, with depths of 5 fathoms or less, while it deepened suddenly to 12 fathoms all around. There was no indication of this bank on the charts.

A number of lines were run through the passage between the north end of Palominos Island and a chain of islets and reefs, known as the Cordilleros, which extends nearly to Cactus Bay and forms a barrier between the Atlantic and Vieques Sound. This barrier is, however, more of a danger than a protection. The frequent gaps permit the ocean swell to pass with little hindrance in heavy weather, so that at Port Mula, on the northern coast of Vieques Island, the anchorage is very unsafe during a norther on account of the heavy swell which sets in.

The principal passages through the reef are those called Hermanos, and the Barriles. Both have been supposed to be deep and free from danger, but caution is necessary in navigating the Hermanos Passage until it is regularly surveyed, as rocks have been reported to exist nearly midway in the passage. The Barriles Passage has been quite carefully surveyed. The anchorages along the southeastern coast of Porto Rico are all poor, being upon roadsteads exposed to the prevailing winds of the sea.

On June 30 the *Blake* closed work at Culebra Island and proceeded to St. Thomas, to prepare for the trip to San Juan on her return to the United States.



THE NORRIS PETERS CO. PHOTO-LITHO. WASHINGTON, D.C.

Schooner *Eagre*, J. B. BOUTELLE, Commanding: PORTO RICO, Culebra.

RECONNAISSANCE.

BASE LINES.

TRIANGULATION.

TOPOGRAPHIC.

HYDROGRAPHIC.

ASTRONOMIC.

V. R. LYLE, *First Watch Officer.*
J. L. DUNN, *Second Watch Officer.*
F. F. WELD, *Aid.*
C. W. NOBLE, *Aid.*
C. O. BARRON, *Recorder.*
RUSSELL FOLEY, *Recorder.*
J. H. ULLRICH, *Medical Officer.*

SUMMARY OF OPERATIONS.

40 square miles reconnaissance.
55 points selected.
1 base line.
40 square miles triangulation.
21 stations occupied.
55 geographic positions determined.
1 azimuth station.
6 square miles topography.
67 miles coast-line topography.
2 miles pond shore line.
7 miles roads.
10 square miles hydrography.
378 miles sounding line.
9 439 angles measured.
23 721 soundings.
3 tide stations.

On January 6 Assistant Boutelle left Baltimore, bound for San Juan, P. R., where he arrived on the 21st of January. The party immediately began the survey of the harbor at San Juan, and signals were erected as a preliminary to the topographic and hydrographic work.

At this stage of the operations instructions were received by Assistant Boutelle to stop the work at San Juan and proceed with the vessel to Culebra Island, in order to make a survey of that locality. A base line and an azimuth were measured at Great Harbor, Culebra, and the triangulation was extended over the island and the outlying cays to the westward. The geographic positions were computed, using the published position of Culebra light-house as a base. The topographic and hydrographic work on the sheet covering Great Harbor was executed on a scale of 1:5 000.

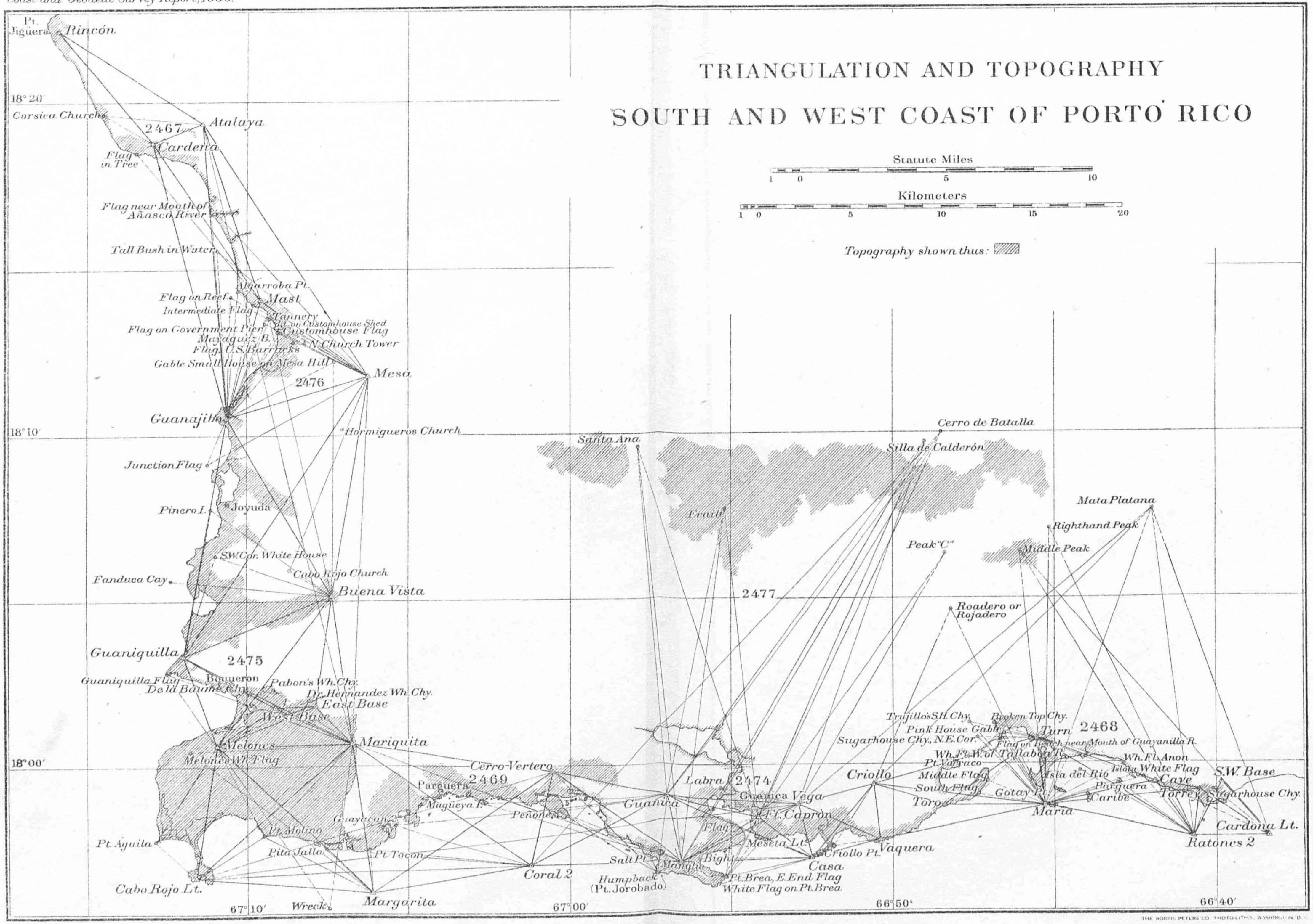
Assistant Boutelle reports the great difficulty experienced in executing the hydrographic work outside of the harbor, owing to the very heavy sea running at all times. During the three months at Culebra there were only three days when it was smooth enough for good work outside the harbor.

A topographic sheet was completed on the south side of the island, after which the inshore hydrography of the southwest shore of Culebra was executed.

On May 13 the *Eagre* proceeded to Fajardo and made a preliminary survey of that harbor. The triangulation was extended from the Culebra work already executed. The hydrography of the harbor was completed over an area covering the anchorage in front of the playa and extending to Cape San Juan, including the Laja Shoal, a dangerous obstruction to navigation in front of the harbor. The soundings were extended out to not less than 6 fathoms.

On May 31, in accordance with instructions from Washington, Assistant Boutelle proceeded with the vessel to San Juan, and after laying up the steam launch for inspection at that place he sailed for Baltimore on June 7, arriving there on the 17th.

Assistant Boutelle reports the inadequacy of sailing vessels for the execution of hydrography in Porto Rico and adjacent islands. A steamer that can stand a heavy sea is a necessity for all except harbor work. The question of water is a very serious one for any vessel without a distilling apparatus. The places where water can be obtained are St. Thomas, San Juan, Mayaguez, and Ponce, and it is necessary for a sailing vessel like the *Eagre* to employ at least one-third of her time in going for water.


TRIANGULATION AND TOPOGRAPHY
SOUTH AND WEST COAST OF PORTO RICO
Statute Miles
1 0 5 10
Kilometers
1 0 5 10 15 20
Topography shown thus:
Pt. Jigüera
Rincón
18° 20′
Corsica Church
2467
Atalaya
Cardena
Flag in Tree
Flag near Mouth of Añasco River
Tall Bush in Water
Algarroba Pt.
Flag on Reef
Mast
Intermediate Flag
Tannery
Flag on Customhouse Shed
Flag on Government Pier
Customhouse Flag
Mayaguez B.
Flag U.S. Barracks
N. Church Tower
Gable Small House on Mesa Hill
Mesa
2476
Guanajibo
18° 10′
Hormigueros Church
Junction Flag
Pinero I.
Joyuda
SW. Cor. White House
Cabo Rojo Church
Fanduca Cay
Buena Vista
Guaniquilla
2475
Guaniquilla Flag
Boqueron
De la Baume Chy.
Pabon's Wh. Chy.
Dr. Hernandez Wh. Chy.
East Base
West Base
Melones
Melones Wh. Flag
Mariquita
18° 00′
Cerro Vertero
2469
Parguera
Magüeya I.
Peñones
Guayacan
Pt. Molino
Pita Jalla
Pt. Tocon
Pt. Aguila
Cabo Rojo Lt.
67° 10′
Wreck
Margarita
Coral 2
67° 00′
Santa Ana
Fraile
Cerro de Batalla
Silla de Calderón
Peak "C"
2477
Roadero or Rojadero
Mata Platana
Righthand Peak
Middle Peak
Guanica
Labra
2474
Guanica Vega
Pt. Capron
Flag
Salt Pt.
Margila
Bight
Meseta Lt.
Criollo Pt.
Casa
Humpback (Pt. Jorobado)
Pt. Brea, E. End Flag
White Flag on Pt. Brea
Criollo
Vaquera
66° 50′
Trujillo's S.H. Chy.
Broken Top Chy.
Pink House Gable
Turn
2468
Sugarhouse Chy. N.E. Cor.
Flag on Beach near Mouth of Guayanilla R.
Wh. Flag W. of Tallaboa R.
Pt. Varraco
Middle Flag
South Flag
Toro
Gotay P.
Isla del Rio
Wh. Fl. Anon
Islota White Flag
Cave
Parguera
Caribe
S.W. Base
Torrey
Sugarhouse Chy.
Maria
Cardona Lt.
Ratones 2
66° 40′
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John Nelson: Porto Rico

RECONNAISSANCE.

TRIANGULATION.

TOPOGRAPHIC.

BASE LINE.

AZIMUTH.

J. E. McGrath, *Assistant.*
F. H. Brundage, *Aid.*

SUMMARY OF OPERATIONS.

300 square miles reconnaissance.
36 points selected.
1 base line.
300 square miles triangulation.
36 stations occupied.
101 geographic positions.
1 azimuth.
62 square miles topography.
151 miles coast-line topography.
104 miles rivers, creeks, and ponds.
55 miles roads and railroads.

At the expiration of a leave of absence, on November 16, Assistant Nelson reported at the Office and was engaged until the 22d in making preparations for field work in Porto Rico. He started on November 23 and arrived at Ponce on December 11, having been detained eleven days at San Juan while waiting for the arrival of the outfit and instruments and making arrangements for transportation with the quartermaster of the army.

The members of the party arrived in Ponce on December 12, and the party was immediately organized and field work begun. Reconnaissance was carried from the Ponce to Guayanilla Bay. Up to the close of the calendar year five triangulation points had been selected, six signals were built, and two stations were occupied. The party moved from Ponce to Tallaboa on December 22 and went into camp. Considerable delay was occasioned in the work while clearing out lines from the known triangulation points, as the entire country west of Ponce is covered with a dense growth of trees and brush. Three parties were in continual operation—triangulation, topographic, and signal building. By the 8th of January signals were up to within 4 miles of Guanica, and the topography was finished to Guayanilla Bay.

When the triangulation was started it was necessary to occupy the old station at Ratonas Island. The signal had been destroyed, and there was nothing to show that the spot had ever been marked, so that it was necessary to return to the Ponce base line for a starting point. A large lagoon near Point Cuchara was surveyed. This is a prominent feature and is shown on all published charts, but is very shoal.

The party was in camp at Guanica Bay from February 22 until March 2. On the 3d Assistant Nelson moved from Guanica to Parguera. The party remained here until the 17th, executing the triangulation and topography in the vicinity. On the 18th of March the party went into camp at Boqueron, near the bay of the same name. While at this station a base line and astronomic azimuth were measured in the Lajas and Boqueron Valley, near the bay. Observations for time were made at the camp, about half a mile west of the azimuth station at West Base. The party stayed at the Cabo Rojo light-house for a few days, while working around the southwest corner of the island, on account of the great difficulty in reaching this particular part of the coast.

On May 1 the party moved to Mayaguez, and from this point the triangulation and topography were carried to Rincon triangulation station, at Jiguera Point, where the season's work closed on May 29.

The party then proceeded on the U. S. transport *Crook* from San Juan to New York, arriving in Washington on the morning of the 7th of June.

Assistant Nelson speaks in high terms of the services rendered by Assistant J. E. McGrath and Aid F. H. Brundage; and he also acknowledges the kindness of the United States Army officers in furnishing transportation and other means for facilitating the work.

Schooner *Matchless*, W. I. VINAL, Commanding: PORTO RICO

TOPOGRAPHIC.

HYDROGRAPHIC.

TIDE.

WM. SANGER, *Chief Yeoman, U. S. N.*
SWEPSON EARLE, *Yeoman, First Class.*
JOHN W. CLIFT, *Chief Yeoman.*
GEORGE OLSEN, *Chief Yeoman.*
R. MCD. MOSER, *Recorder.*
F. H. AINSWORTH, *First Watch Officer.*

SUMMARY OF OPERATIONS.

4 square miles topography.
13 miles coast-line topography.
16 miles creek and marsh line.
30 miles roads and railroads.
5 square miles hydrography.
100 miles sounding line.
2 367 angles measured.
9 129 soundings.
2 tide stations.

The time between the 13th of November, 1899, and the 12th of February, 1900, was spent in Baltimore, the party being engaged in miscellaneous office work, and in repairing, renovating, and fitting out the vessel for duty in the south. Acting under instructions of February 5, the *Matchless* sailed for Porto Rico on the 12th, arriving at San Juan on the 2d of March. The voyage was a long and rough one, and it was necessary to spend a few days in repairing damages to the vessel and to allow the crew needed rest.

The hydrographic field work was begun in the harbor of San Juan, where the sounding was confined to the limits of shoal water on the south and west sides, thus completing the hydrographic survey begun in 1899 by Assistant Hodgkins. The shore line was rerun and topographic details mapped about one-half mile back from the shore. The contour curves shown by the Spanish survey of this vicinity were examined in a number of places and found to be correct in almost every instance.

Special attention was given to the development of shoals and the location of wrecks. The wreck of the *Cristobal Colon* lies in the middle of the entrance to the harbor, and was examined in company with a party from the United States Engineers office.

After completing the work in the vicinity of San Juan, the vessel sailed on June 2 for Charleston, S. C., in accordance with instructions dated May 21.

Steamer *Pathfinder*, F. W. PERKINS: HAWAII.

TRIANGULATION.

HYDROGRAPHIC.

TOPOGRAPHIC.

MAGNETIC.

AZIMUTH.

TIDE.

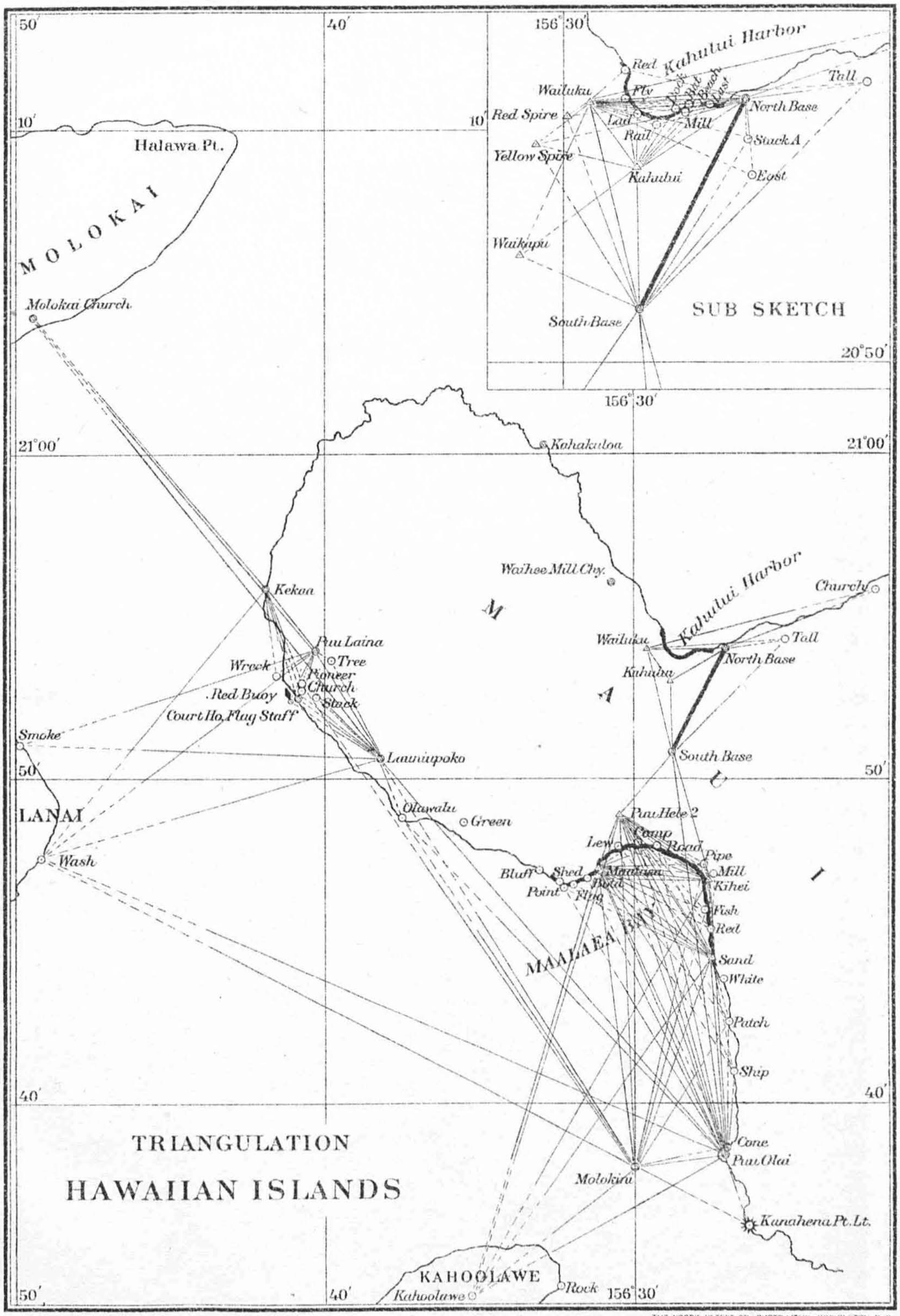
CURRENT.

H. F. FLYNN, *Assistant.*
E. R. FRISBY, *Aid.*
J. C. DOW, *First Watch Officer.*
C. W. FITZGERALD, *Second Watch Officer.*
W. M. ATKINSON, *Third Watch Officer.*
J. W. MCGRATH, *Fourth Watch Officer.*
GEO. S. LEWIS, *Fifth Watch Officer.*
J. E. SHEPHERD, *Surgeon.*
J. T. GOLDSBOROUGH, *Chief Engineer.*
EUGENE VIETH, *Acting Aid.*
C. F. DEICHMAN, *Acting Junior Aid.*
R. C. MCGREGOR, *Photographer and Recorder.*

SUMMARY OF OPERATIONS.

103 square miles triangulation.
16 triangulation stations recovered.
20 stations occupied.
74 points determined.
318 directions measured.
327 angles measured.
26 miles shore-line topography.
19 miles roads.
7 square miles topography.
421 square miles hydrography.
728 miles sounding lines.
9 403 angles measured.
23 284 soundings taken.
5 tide gauges established.
104 days tide observations.
3 old magnetic stations recovered.
5 magnetic stations occupied.
1 azimuth observed.

The U. S. S. *Pathfinder* arrived at Honolulu on the 2d of December, 1899, from San Francisco. Considerable liberty of action was given the commanding officer, Assistant F. W. Perkins, and he therefore investigated the field in order to know the



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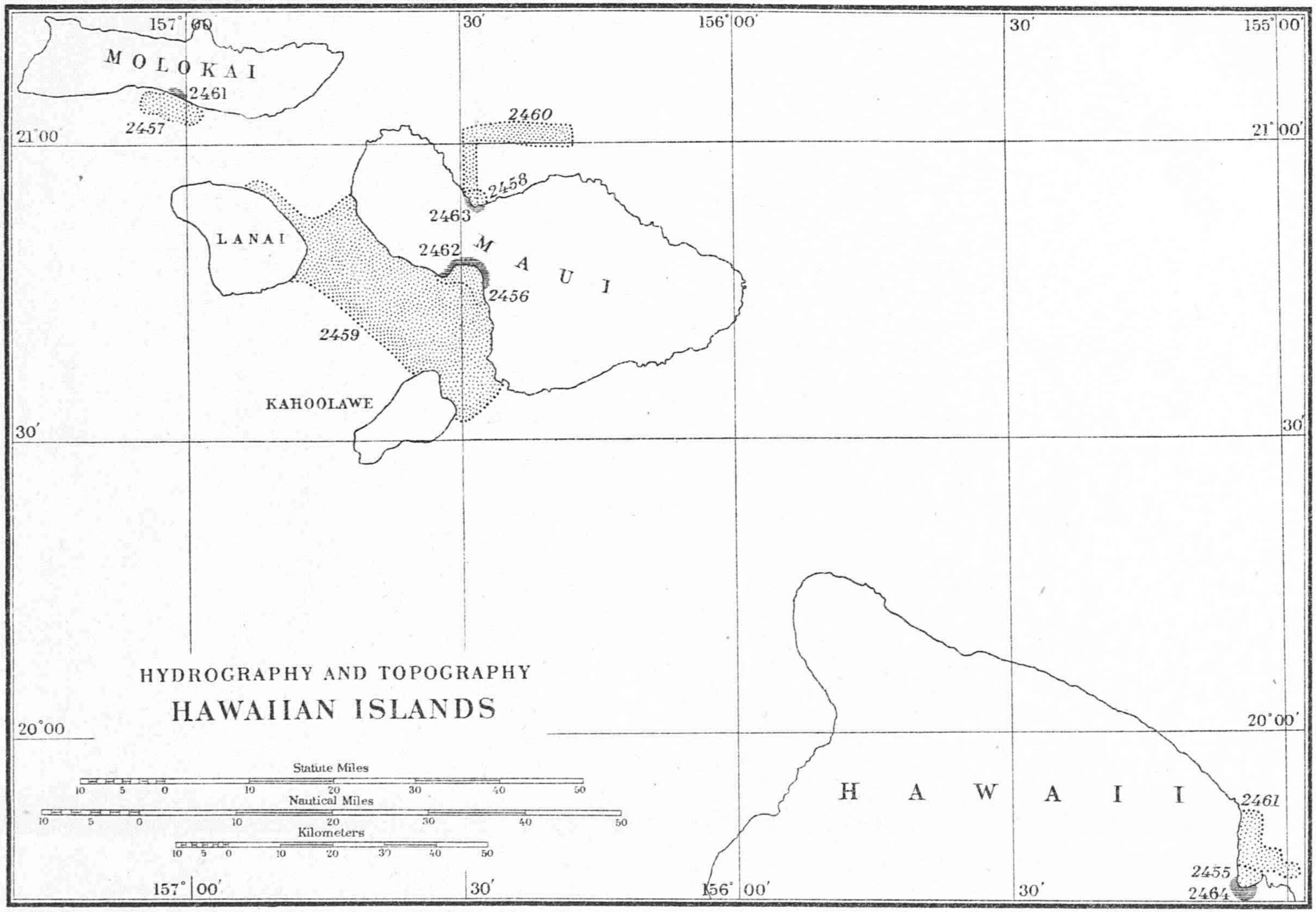

157° 00′
30′
156° 00′
30′
155° 00′
MOLOKAI
2461
2457
2460
21° 00′
2458
2463
LANAI
2462
MAUI
2456
2459
KAHOOLAWE
30′
HYDROGRAPHY AND TOPOGRAPHY
HAWAIIAN ISLANDS
20° 00′
Statute Miles
Nautical Miles
Kilometers
HAWAII
2461
2455
2464

most desirable points of work to be first taken up. At the request of President Dole, it was decided to investigate certain harbors at the island of Maui, where facilities for handling freight are quite insufficient at present, and the demand upon them is increasing.

A thorough hydrographic and topographic survey of the port of Kahului, on the north side of the isthmus connecting East and West Maui, was first made.

The harbor, which is a deep pocket at the western end of the coral reef that extends along the northern shore of East Maui, is extremely limited in area. The protection which the reef affords against the regular trade winds is sufficient to insure safety under the prevailing conditions, but the sea, which breaks heavily on the reefs at all times, is generally so severe in the harbor as to make handling cargo difficult, and when the winds haul to the northward it is extremely rough. Such conditions would make it very undesirable to bring a wooden vessel alongside of a wharf. The reef offers a good foundation for a breakwater, but a structure that would withstand the onset of the sea at that place would be very expensive, and could not be completed in time to meet the needs of the island.

The approaches were examined to the limit of the 100-fathom curve, and currents and wave conditions were also investigated.

The currents were observed by using bottles, each carrying a small flag and so weighted that only about an inch of the neck showed above water. These were set adrift outside of the mouth of the harbor and for a considerable distance along the outer edge of the reef, and observations made upon them to determine the velocity and direction of the current.

Upon the completion of the work on the north coast of Maui the party moved to Hilo, on Hawaii. At this point a detailed survey was made covering the harbor, the reef, and the approaches, and extending to the 100-fathom curve. Magnetic observations were also made.

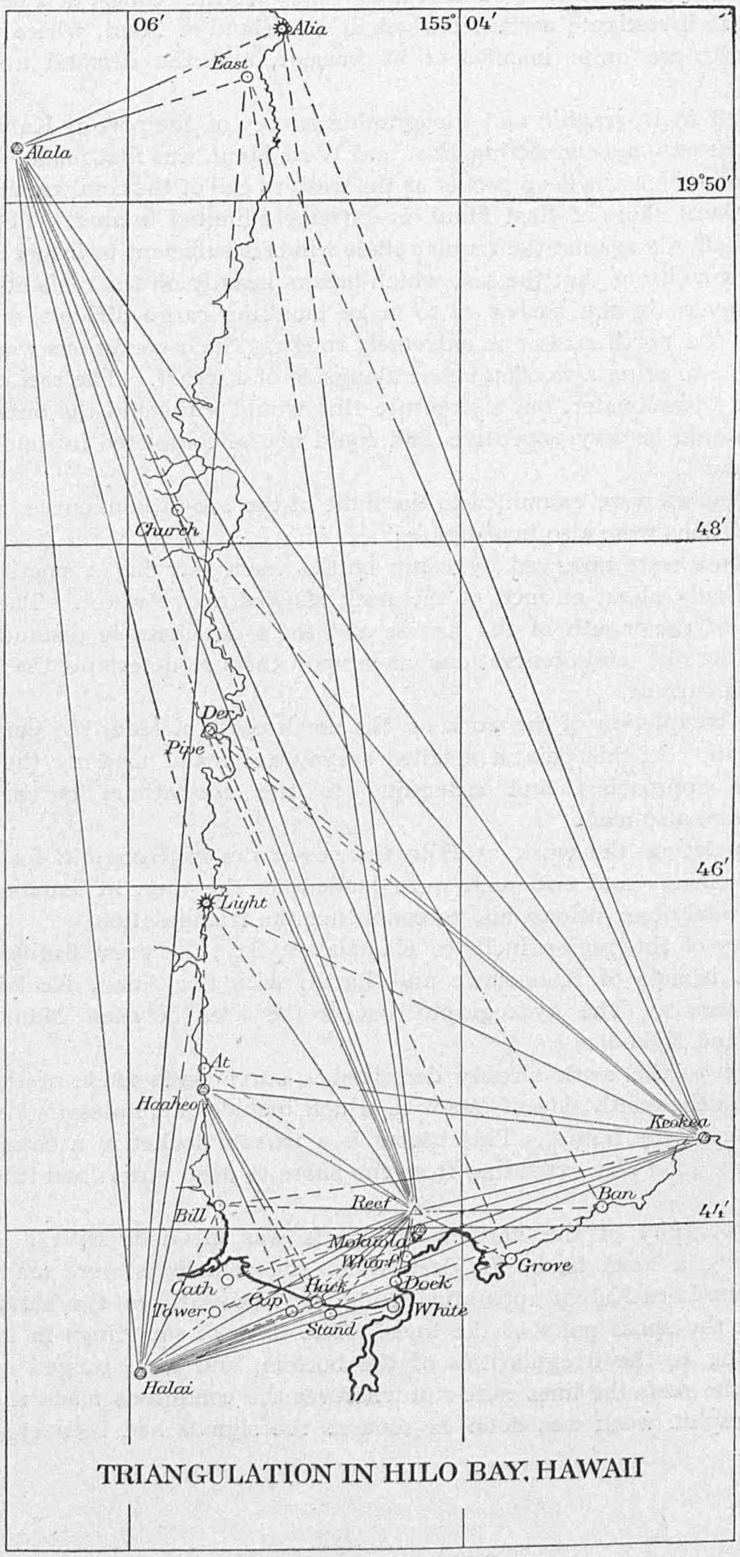
After completing the work at Hilo the vessel ran to Honolulu for coal, and a party of four officers and two men were landed on the way, at Lahaina, to make magnetic and tidal observations, and to commence the triangulation.

The survey of this region includes Kamalalaea Bay, the great flat lying between Maui and the islands of Kahoolawe and Lanai, with the Auau, Kealaikahihi, and Alalakeiki channels. The hydrography covers the area between Maui and a line joining Lanai and Kahoolawe.

In addition to the work already described, a survey was made of the harbor of Kaunakakai, on the south side of Molokai, which includes all necessary details. The entrance is marked by buoys. This harbor is a narrow pocket in a coral reef which gives access to a good pier extending from the shore to deep water, and it affords good shelter.

The hydrography of the harbors and reefs was all done with a launch and whaleboat, using a hand lead. In deep water the soundings were made from the steamer with the Lord Kelvin apparatus, using the Tanner tubes, the hand lead being substituted on the shoal parts of the lines. The lines of soundings in harbors were spaced according to the irregularities of the bottom, and were ranged in the usual manner. On the reefs the lines were run wherever the conditions made it practicable. Much hydrographic work was done as soon as the signals had been erected and in

No. 46.



TRIANGULATION IN HILO BAY, HAWAII

advance of the triangulation. For the steamer work outside of harbors the plan of running two or more lines parallel with the coast was finally adopted, the near inner one being as near shore as the nature of the bottom seemed to warrant, and to cover the remaining spaces out to the 100-fathom curve with lines sufficient to develop the general features of the bottom.

The triangulation was based on the Hawaiian Government survey work, and the method pursued was to accept the geographic position of a certain point, with the azimuth and distance to the farthest accessible station, and use this data as a base for the work.

The topography was confined to the shore line of the harbors and their immediate neighborhood, including the towns and villages. Outside these limits the shore line was used as determined by the Hawaiian Government surveys. Efforts were made to aid the topographic work by the use of the camera, but the conditions were unfavorable and the result was not very satisfactory. The haze in this region is persistent, and this necessitates considerable exposure in order to secure details. As the vessel always had a decided motion, it was necessary to choose between an under exposure and a blurred negative.

At Honolulu, Hilo, and Lahaina the magnetic stations previously occupied in 1892 by Assistant E. D. Preston were recovered and reoccupied. At Waikiki a telephone line made the selection of a new station necessary. At Kahului no previous observations had been made so far as known. Each of the determinations of declination consists of both elongations on a given day. At each of the stations except Waikiki the azimuth was determined from the adjacent triangulation. On account of the slight fluctuations of the needle and the irregularities in the time of elongation, the observations for declination were usually prolonged beyond the necessary time, and at Kahului and Hilo, on one day each, 10-minute observations were continued throughout the day without change of setting, while at Lahaina three such continuous sets were secured.

F. SPECIAL DUTY.

H. L. Marindin.

SPECIAL DUTY.

MISSISSIPPI RIVER COMMISSION.

Until the 23d of January Assistant Marindin was engaged in miscellaneous office work at Washington, D. C. On the date just mentioned a letter was received from the Honorable Secretary of War, transmitting a copy of a resolution of the United States Senate of the 22d, requesting a report on the amount of work done by the contractor, Mr. C. P. Goodyear, on the Brunswick Outer Bar, Ga. This report was completed on February 23 and was immediately forwarded to the War Department.

From this date until March 12 attention was given to various matters, among which was an inquiry as to the proposed hydrographic work in the harbor of San Pedro, Cal., and notes on the underrun of the salt water up the Hudson River, as well as to the possible effect of the proposed improvement of East Channel from Sandy Hook Bar in New York Bay.

On March 12 Assistant Marindin was called to attend the seventy-ninth session of the Mississippi River Commission, at St. Louis, Mo. This duty included a tour of inspection from St. Louis to New Orleans, at the conclusion of which Assistant Marindin returned to the office and reported on the 27th of March.

On the 29th a further request was received from the War Department for information as to the amount of material removed in the channel over the Brunswick Bar, Ga., by the explosion of dynamite. The computation of volumes was completed during the first part of April, and on the 26th the report was forwarded to the War Department. From the latter date to the end of the fiscal year he was engaged in miscellaneous duty in connection with the Mississippi River Commission and the Coast and Geodetic Survey.

L. A. FISCHER: BOSTON.

SPECIAL DUTY.

Graduation of bench standard.

During the month of May, Mr. L. A. Fischer, of the Office of Standard Weights and Measures, received instructions to proceed to Boston and graduate the 100-foot bench standard belonging to the street commissioners' office into feet and meters. This bench standard is adjacent to the west side of the old court-house building, and is suitably protected from the sun during a large part of the day.

The standard had large silver plugs inserted at 0 feet, 10 feet, 50 feet, and 100 feet, and at 1 meter and 30 meters—in all, six plugs. The surface of the bench standard was also polished at intervals of 10 feet and 3 meters, to carry temporary graduations. The graduating and comparing bar was 10 feet long, and was graduated at the following points: 1, 2, 3, 6, 9, and 10 feet, as well as at 1, 2, and 3 meters. The values of these graduations were carefully determined by comparison with the standards at the Coast and Geodetic Survey Office before the bar was shipped to Boston, and after its return to Washington additional comparisons were made to check the first.

S. W. Stratton: New York.

SPECIAL DUTY.

Marconi system of wireless telegraphy.

On the 28th of October telegraphic instructions were sent to Prof. S. W. Stratton, Inspector of Weights and Measures, to report to Admiral Farquhar, U. S. N., commanding the North Atlantic fleet, to witness the test by the Navy Department of the Marconi system of wireless telegraphy.

He proceeded to New York, arriving on the 30th of October, and reporting immediately to Admiral Farquhar on board the flagship *New York*. The tests were to be made by means of two ships, the *New York* and *Massachusetts*, and a shore station at Navesink, each being fitted with a set of Marconi apparatus. The ships mentioned proceeded to sea Monday morning. Communication was kept up between them and with the shore station throughout the day and early part of the night, at distances varying from 1 to 35 miles. The following day was stormy, with heavy rain and a gale. The vertical wire at Navesink was disabled by the storm, thus preventing communication with the shore station.

The tests were continued during November 1, and included the so-called interference experiments intended to demonstrate whether or not a third station could interfere with the sending of signals between two others.

The distances over which the messages may be sent depends largely upon the height of the vertical wire and the adjustment of the apparatus. A height of 150 feet was used in these experiments.

Professor Stratton concludes his report with acknowledgments, both to the officers of the United States Navy and to Mr. Marconi, for courtesies shown and opportunity given to witness the experiments.

E. L. Burchard:

SPECIAL DUTY.

Bibliography of the surveys of Mason and Dixon's line.

The importance of the boundary line between Pennsylvania and Maryland, and between Maryland and Delaware, has led to the preparation by this Office of a bibliography of the publications made on this subject. This work was intrusted to Mr. Edw. L. Burchard, chief of the Library and Archives Division, and the field work connected therewith was accomplished in July and August, 1899.

In order to have knowledge of all that had been done on this subject, as well as to prepare for more effective work in all the localities, Mr. Burchard undertook, by correspondence, to locate the material necessary for a report. To this end letters were sent to the editors of the principal newspapers and to the clerks of the county courts in each county along Mason and Dixon's line, as well as to large cities in the neighborhood. This procedure brought out considerable information and paved the way for an effectual search in the different localities mentioned.

Fourteen towns and cities were visited in Pennsylvania, Maryland, and Delaware; 24 libraries and city offices were examined, and 32 calls were made at newspaper offices and on historians.

G. Bradford.

INSPECTION OF CHART AGENCIES.

In obedience to instructions, Assistant G. Bradford started on June 1, 1899, to inspect the chart agencies on the Atlantic and Gulf coasts, as mentioned in the report for 1899. This duty was continued until July 8, when he reported in person at the Office.

On August 3 he again left the Office, under the same instructions, to inspect the agencies on the North Atlantic coast, and visited numerous agencies between Eastport, Me., and Newport News, Va. The inspection was carefully made, and much information collected from navigators and others interested in the improvement of charts.

Steamer *Endeavor*, C. C. YATES, Commanding: CHESAPEAKE BAY, Cape Charles City.

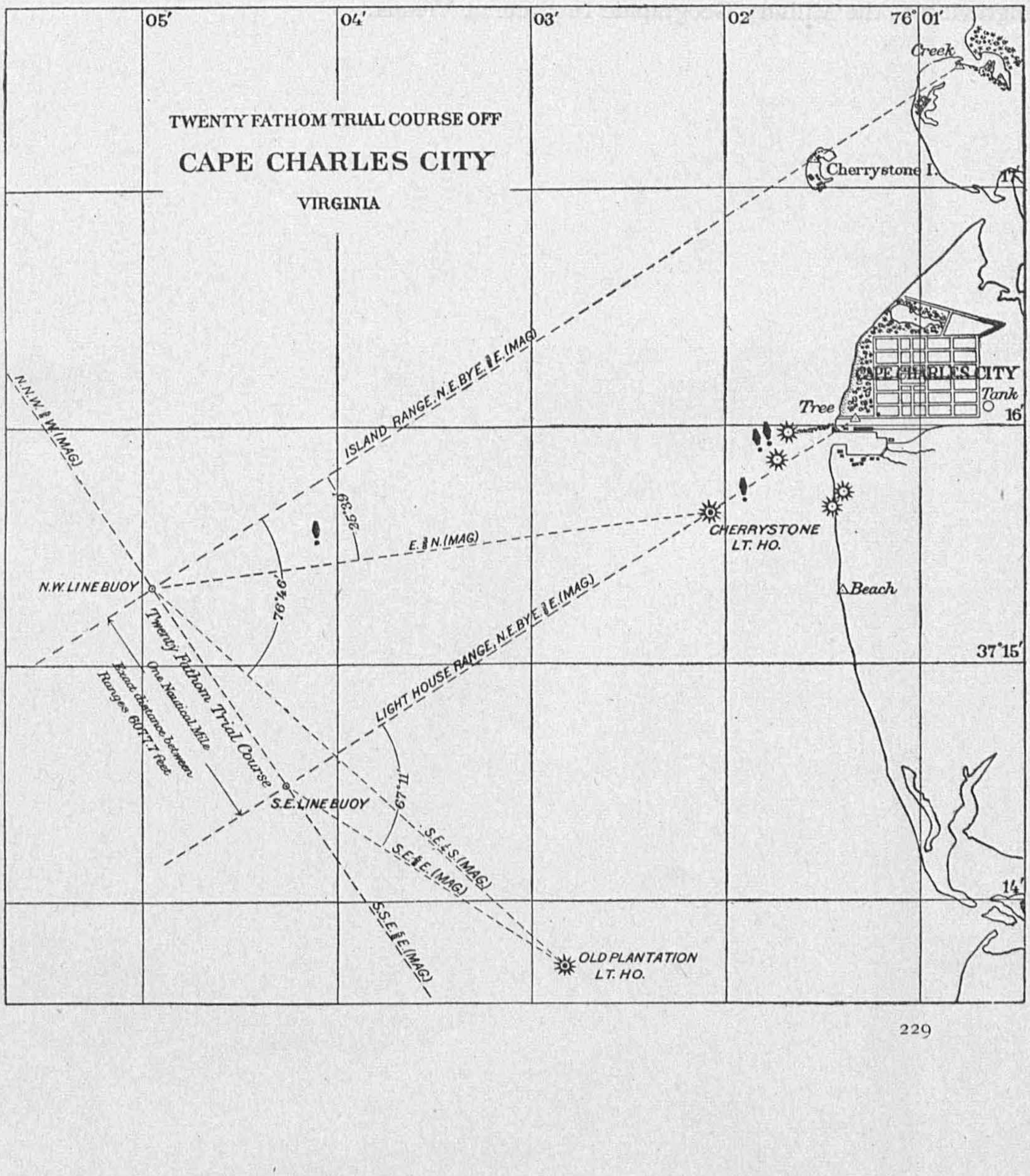
SPECIAL OPERATIONS.

Speed-trial course.

A. C. MITCHELL, *Aid.*
WM. BAUMAN, JR., *Chief Yeoman, U. S. N.*
OLE ANDERSON, *Carpenter's Mate, U. S. N.*
A. H. BLACKISTON, *Recorder.*

The *Endeavor* arrived at Cape Charles City on September 12, charged with the undertaking of laying out a speed-trial course for the ships of the Navy. This work

No. 47.



was undertaken pursuant to a request from the Navy Department, as it was desired to have a course exactly 1 nautical mile in length and in the deepest water obtainable at the location chosen.

Considerable difficulty was experienced in executing the necessary triangulation, on account of the heavily wooded shores. The range marks necessary for this work were also necessarily somewhat close, on account of the topographic features.

The party returned to Baltimore on the 28th of September and were engaged in office work in connection with the trial course until the 12th of October, at which date the completed records were sent to the Office, in Washington.

From March 14 until April 17 Assistant Yates was on leave of absence, and from the 18th to the close of the year he was on duty in Europe, engaged in studying the hydrographic methods and organizations of England, France, and Germany. He also established a number of foreign chart agencies and made a study of the processes of engraving at the Military Geographic Institute at Vienna.

F. A. YOUNG: VIRGINIA, Cape Charles City.

SPECIAL OPERATIONS.

Location of buoys on speed-trial course.

At the request of the Navy Department, an Assistant of the Coast and Geodetic Survey was detailed on March 26 to assist in the location of buoys at the ends of the trial course off Cape Charles City, Va. Assistant F. A. Young was charged with this work, and left Baltimore for Old Point Comfort on the evening of March 27.

Arriving on the following day, he joined the light-house tender *Maple*, which proceeded immediately to Portsmouth, where Capt. Joseph N. Hemphill, U. S. N., of the Board of Inspection and Survey, to whom Assistant Young reported, took charge. Two second-class can buoys, marked with horizontal white and black stripes, each furnished with 30 fathoms of chain and a block of granite weighing 3 000 pounds for an anchor, were taken on board. The tender next proceeded to Norfolk, where Lieut. Commander Richard Henderson, U. S. N., joined the party. As there was a stiff northerly breeze prevailing and a choppy sea running, it was impossible to locate the buoys from a small boat. Two trial buoys were prepared, each consisting of a small red keg, with 30 fathoms of line attached and anchored by a 15-pound weight. The southeast buoy was first located. The *Maple* was placed on range outside the outer position and steamed landward, the buoy being dropped when the required position was reached. The determination was made by means of sextant angles measured between objects on shore whose position was known.

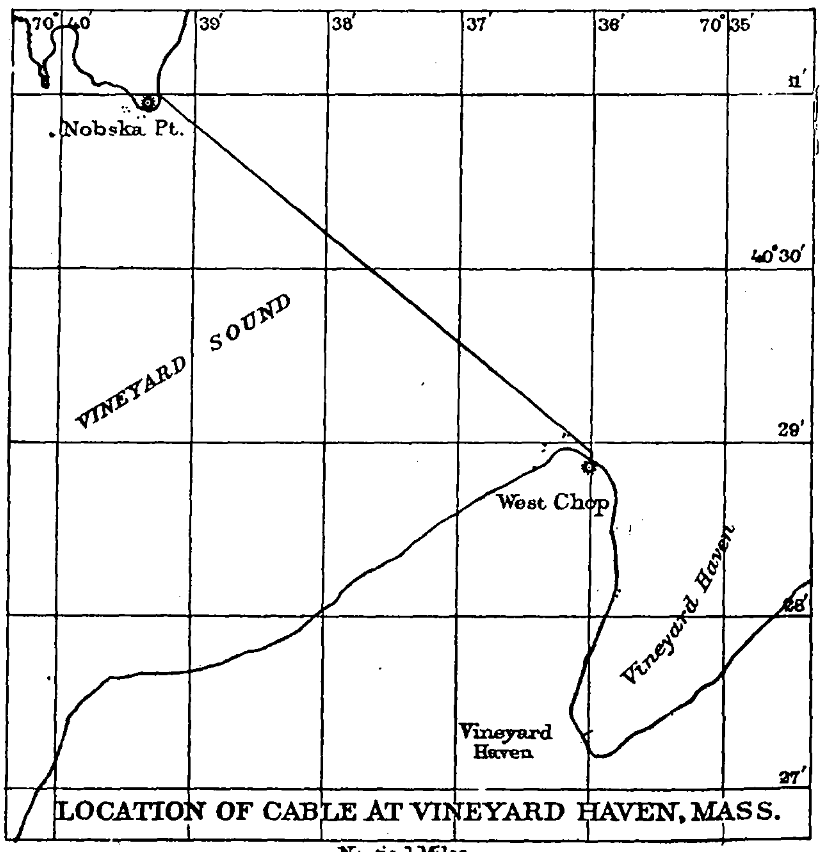
The northwest end was located in the same way, and the large buoys were then put in position. Each anchor is provided with 30 fathoms of chain, so that there is some play, and the differences in position due to ebb and flood tide would possibly amount to 50 feet. However, as the buoys are only to be used as marks, the distance being measured by ranges, this change of position has no material effect.

SPECIAL OPERATIONS.
LOCATION OF CABLE.

HARRY L. FORD, *Nautical Expert.*

Acting upon information that a submarine cable would be laid between West Chop light-house and Nobska light-house, Vineyard Haven, Mass., Assistant F. A. Young was detailed to determine its location at the time it was put down.

No. 48.



LOCATION OF CABLE AT VINEYARD HAVEN, MASS.

In obedience to instructions of February 21, he left Washington in company with Mr. Harry L. Ford on that day, and arrived at Woods Hole on the morning of the 22d. All preparations had been made to lay the cable on the 23d, but on account of delay in loading it in New York and a heavy southwest gale on the 25th and 26th nothing could be done until Tuesday, the 27th. On this date an attempt was made to start the line from Nobska Light Point, but in their endeavor to carry the end of the cable ashore it became jammed among the rocks, and so much delay was caused thereby that the laying was deferred until the following day.

On the morning of the 28th a second attempt was made, this time from the other end, namely, West Chop, and as the beach is there bold and free from rocks a favorable start was made. At 9.15 a. m. the line was begun, the pilot steering on a natural range and making straight across. At 10.30 the tug was anchored within 200 yards of the terminal at the other end. The entire work was completed by 2.15 p. m., and a message was sent over the line.

The first 2 miles were run in one hour, and during this time angles were taken every five minutes on the signals Falmouth Heights Observatory, Nobska Light, and Tarpaulin Cove Light. In the second half of the work the boat sometimes ran at a speed of 12 miles per hour, and the entire 2 miles were covered in about fifteen minutes. A projection was made before leaving the office, on a scale of 1:20 000, showing determined triangulation points, and the location of the cable was laid down from angles measured with the sextant.

Assistant Young acknowledges the valuable services of Mr. Harry L. Ford, and also speaks of the assistance rendered by Mr. McCoy, superintendent of construction for the telephone company, and Mr. Manson, who was present in the interest of the Akonite Company.

Edwin Smith: Maryland, Gaithersburg.

INTERNATIONAL LATITUDE.

STATION.

LONGITUDE.

MAGNETIC.

J. E. McGrath, *Assistant* (cooperating party).

SUMMARY OF OPERATIONS.

1 longitude station.
7 nights' longitude observations.
3 azimuth stations.
1 magnetic declination station.
2 stations for magnetic dip.
2 stations for magnetic intensity.

During the year Assistant Edwin Smith was in charge of the International Geodetic Association latitude station at Gaithersburg, Md. Considerable preliminary work was necessary in the establishment of this station, and Assistant Smith took formal charge of the operations on the 1st of July. The first work was to establish a station by erecting the necessary buildings, etc., for the latitude work.

By August 11 the observatory was sufficiently advanced to admit the placing of instruments. On this date Assistant J. E. McGrath reported to Assistant Smith for duty in this connection, and the work of determining the difference of longitude between the Coast and Geodetic Survey Office in Washington and the observatory at Gaithersburg was undertaken. Three exchanges of signals were had, on August 19, 22, and 25, Assistant Smith being at Gaithersburg and Assistant McGrath at Washington. The observers now exchanged places, and four more nights were obtained, namely, August 29 and 31 and September 1 and 4.

Work was then continued on the construction of the necessary buildings for the international latitude work, and on September 20, the date at which the instruments arrived from Germany, the observatories were so far completed that it was possible to put the instruments in place. On September 21 the zenith telescope was mounted in the observatory and the clock was set up in the office building.

The first observations were actually made on October 2, but owing to unforeseen difficulties with the electrical illumination no observations of permanent value were made until about two weeks later. The beginning of the international latitude observations dates from October 18, 1899.

As before stated, the expenses of this station are paid out of funds furnished by the International Geodetic Association.

The magnetic observatory was begun in September, but was not completed until the middle of October. The first observations were made on November 18, just one month after the beginning of the latitude observations. Since the latter date regular observations for declination, dip, and intensity have been made weekly.

The weekly magnetic observations were continued to April 4, after which date the observatory was turned over to the party of Assistant Bauer. The tent was then set up some distance northeast of the observatory, where magnetic observations were made on April 12 by Mr. Edmunds and Assistant Smith, and on April 16 by Assistant Smith alone. Magnetometer No. 3 was then returned to the Office. The dip observations were continued weekly until May 22.

Steamer *Endeavor*, JOHN ROSS: NEW YORK, Long Island Sound.

SPECIAL DUTY.

COAST PILOT PARTY.

HERBERT C. GRAVES, *Nautical Expert.*
HARRY L. FORD, *Nautical Expert.*
JAS. M. GRIFFIN, *Clerk.*

The Coast Pilot Party, under the direction of Mr. John Ross, was engaged in office work from the beginning of the year to the 22d of July. On this date, in obedience to instructions of July 17, Mr. Ross proceeded to Baltimore, Md., and assumed command of the *Endeavor*, relieving C. C. Yates, assistant, Coast and Geodetic Survey. The other members of the Coast Pilot Party reported on the same date, and in the afternoon the *Endeavor* proceeded to Bush River, Maryland, in order to land Assistant Yates and his party, who had been instructed to make a topographic survey in that vicinity.

On the 23d the *Endeavor* got under way for New London, Conn. The work in hand was the revision of the United States Coast Pilot, Atlantic Coast, Part IV, as far as is included in the limits of Long Island Sound. Stops were made on the way, at Hampton Roads July 24, Delaware Breakwater July 25, New York July 27, and the vessel reached its destination on the 28th. The collection of Coast Pilot information was immediately begun and continued for three days in the immediate vicinity of New London. From August 1 to August 7 the party visited Fishers Island Sound, Point Judith Breakwater Harbor, Great Salt Pond Harbor, Gardiners Bay, Greenport, Plum Gut, Niantic Bay, and Duck Island Breakwater Harbor. At all these places information was obtained and changes noted for use in the revision of the Coast Pilot.

As of special interest it may be noted that the life-saving station at Rock Point, near Greenport, was located, and an examination was made for a reported rock at Niantic Bay.

On August 8 the address of the *Endeavor* was changed to New Haven, Conn., and between this date and August 18 the following places were visited: Thimble Islands, Bridgeport Harbor, Port Jefferson, Sheffield Island Harbor, Northport Harbor, Oyster Bay, Captains Harbor, Hempstead Harbor, and Sand Point. At all these points information of value was obtained, more particularly in the line of reported rocks and dangers to navigation.

In order to investigate the reliability of certain information received regarding a rock off Larchmont Harbor, the *Endeavor* came to anchor on August 18 at City Island. While at this point the boilers were cleaned and preparations made for the return trip to Baltimore, Md. On August 22 the party proceeded to Hoboken, N. J., for coal, and on the 25th to Erie Basin, where the party, under orders from the Inspector of Hydrography and Topography, went on board a tug to assist in an examination of a reported danger in the harbor of New York.

The *Endeavor* left Sandy Hook on August 26 for Baltimore, Md. A stop was made at the Delaware Breakwater, and the party arrived at Baltimore at 10:45 p. m., August 28. On August 31 the party returned to Washington, the vessel in the meantime being turned over to Assistant C. C. Yates, by order of the Superintendent.

The localities mentioned above constituted the salient points of the trip. It should be mentioned in this connection, however, that besides visiting the places stated, both shores of Long Island Sound and its estuaries were carefully examined for such changes in hydrography, topography, and aids to navigation as affect the Coast Pilot volumes in these waters. A number of changes affecting the sailing directions in the second edition of the Coast Pilot, Part IV, were also noted.

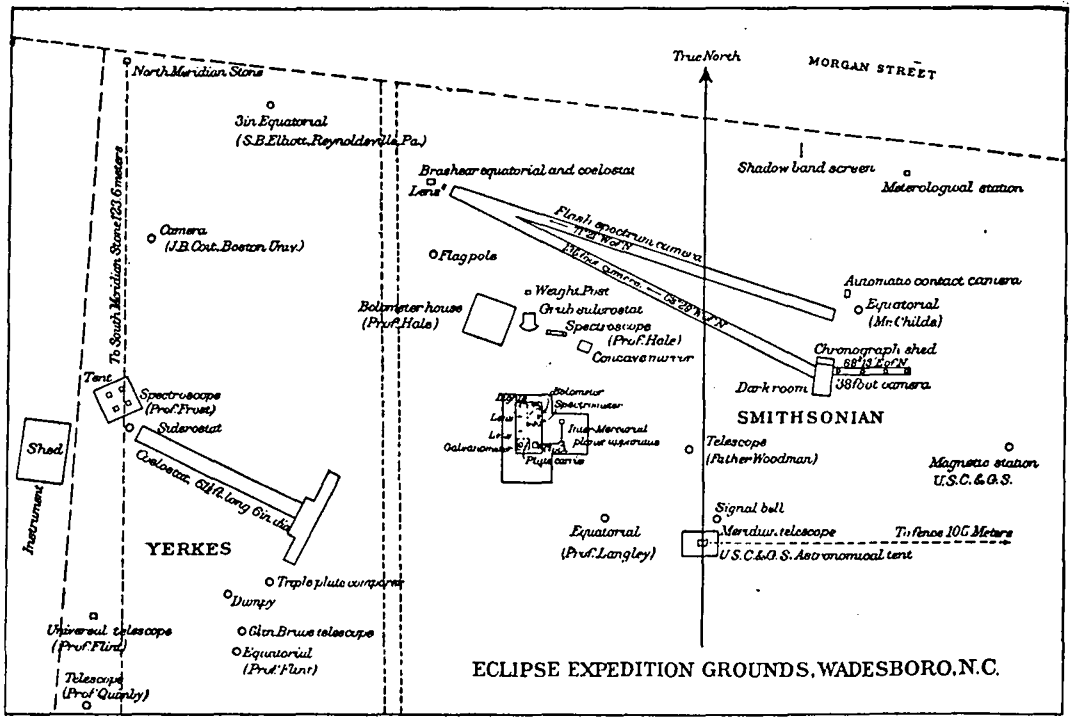
Mr. Ford was detached from the *Endeavor* on August 18 and ordered to Brunswick, Ga. Mr. Graves was detached on August 31, at Baltimore, and resumed his office duties in Washington. Mr. James M. Griffin resumed his duties at the Coast and Geodetic Survey Office in Washington on September 1. Mr. C. L. Green reported for duty on August 24 to assist in bringing the *Endeavor* to Baltimore. He was detached on August 30. From September 1 until December 31 the party was engaged in office work in Washington.

Mr. Ross remained with the party until March. On the 2d of this month instructions were issued directing him to make a report on the ports and waterways along the Atlantic coast, between Chesapeake Bay Entrance and St. Augustine, for the purpose of obtaining data for the revision of the Coast Pilot, Part VII. He left Washington on the evening of March 6, arriving at Norfolk on the morning of the 7th. From this point southward the trip was continued, and valuable information was acquired at many points along the route. Investigations were made between Chesapeake Bay and Albemarle Sound, in the inland passes between Georgetown and Charleston, S. C., the inland passage between Charleston and Beaufort, S. C., the traveled route between Beaufort and Savannah, Ga., and between the latter point and Brunswick. From Brunswick, Ga., to Fernandina, Fla., the necessary information was also acquired in order to revise the Coast Pilot in hand. South of Fernandina there is no inland waterway along the coast that is available for vessels of more than 3 feet draft, except Biscayne Bay and the Hawk Channel.

SPECIAL DUTY.

In connection with the observations of the total solar eclipse of May 28, Assistant Putnam was detailed for certain astronomic work for the Smithsonian Institution expedition. He made two trips to Wadesboro, N. C., the point of observations, the one extending from the 7th to the 12th of May and the other from the 26th to the 29th. The transportation was furnished by the Smithsonian Institution, which also defrayed

No. 49.



the actual expenses in connection with this work. The latitude and longitude of a central point in the grounds was determined to the nearest second of arc. The latitude depends on observations on nine pairs, observed on two nights by the Talcott method. The longitude depends on star-transit observations for local time made at Wadesboro on five nights, in comparison with the noon telegraph signals from the Naval Observatory at Washington on five days, using two chronometers. An azimuth was determined by sun observations in the morning and afternoon with the 7-inch theodolite, which was set up at the astronomic station. The reference mark was the tower of the Pee

Dee Institute. From this azimuth line various meridians in other directions were laid out with the theodolite, as needed in setting up and adjusting the various instruments.

With the assistance of Mr. Hoxie measurements were made with steel tape and theodolite to locate all buildings, apparatus, and instruments on the grounds, and from these the accompanying plan has been platted on a scale of 1:200.

The magnetic declination was determined at the magnetic station on May 27–28, using Coast and Geodetic Survey declinometer No. 733. The declination was found to be remarkably close to the agonic line. At the request of Professor Holmes, State Geologist of North Carolina, and by direction of the Superintendent of the Coast and Geodetic Survey, a meridian line was laid out for the use of surveyors and others. This meridian is marked by two marble blocks, 9 inches by 9 inches by 2 feet.

F. W. EDMONDS: CALIFORNIA.

SPECIAL DUTY.

From the beginning of the fiscal year to October 29, Assistant F. W. Edmonds was attached to the Coast Survey steamer *Gedney*, under the command of Assistant E. F. Dickins.

After having been detached from the steamer *Gedney*, and having taken a leave of absence, he reported to Assistant Rodgers on the 6th of November, and was engaged under his direction until the 30th of March.

In compliance with instructions of March 24, which were received on the 30th, Assistant Edmonds undertook the collection of data relative to the early surveys of the southeastern boundary of California. With this object in view he visited the offices of the United States surveyor-general at San Francisco, at Sacramento, Cal., and at Reno and Carson City, Nev. At the latter point tracings were made of two interesting maps of the surveys of 1863 and 1865. This work lasted until the 7th of May.

On the following day Assistant Edmonds reported to Assistant Rodgers for duty in the suboffice at San Francisco, and was assigned to general office work. On May 22 he reported to Assistant Fremont Morse for duty in office work under his direction. On the 29th of May Assistant Edmonds was directed to report to Assistant Dickins for duty on the steamer *Gedney*, and from this date until the close of the year his duties were aboard ship and in the suboffice at Seattle.

SPECIAL OPERATIONS.

SANITARY CONDITIONS.

PORTO RICO.

The following facts are taken from a report by Dr. Ullrich, who, as surgeon on the schooner *Eagre*, was stationed at San Juan, P. R., for a short time in February, 1900.

The city of San Juan is situated on a promontory, about 100 feet above sea level, sloping on both sides toward the water. The trade winds, which blow from the east nearly the entire year, temper the climate agreeably. In December, 1899, the extreme ranges of temperature were from 65° to 85° F., with an average of 76° for the month. The greatest daily range was 15°. The most rain falls in November, the least in March. The city is well drained, owing to the nature of the surface as well as to the sewers, which empty into the harbor near its entrance. The sanitary conditions during the old régime were woefully inadequate, but at present regular inspection is made, and property holders are obliged to comply within a reasonable time with modern sanitary requirements. The streets are now well paved, vitrified brick being used in the business portion of the city and small cobblestones in the remainder. They are kept clean by prisoners, and are swept several times daily.

The water supply comes from Stony River. A reservoir is established at Rio Piedras. From this point pipes carry the water a distance of about 8 miles to the city. The reservoir is new and has a capacity sufficient to supply about 700 000 gallons per day. Two large filters, which are as yet unfinished, will be used in connection with the reservoir. The water should not only be filtered, but boiled, before being used for drinking purposes. The vessels in the harbor are supplied with spring water brought off in lighters.

The population of San Juan, in 1897, according to Spanish records, was 33 955, of whom one-half can neither read nor write; 7 per cent of the remainder can read only. Public schools are crowded, but are well ventilated and lighted. The mortality records show that during the decade 1890–1900 the average number of deaths per year was 975. According to the last census the death rate was about 32 per 1 000, which is exceedingly high when compared with that of United States cities.

The vital statistics for August, 1899, show that the death causes are about equally distributed among 36 diseases, with the exception of one—pulmonary tuberculosis—which is several times as large as any of the others. The month of December, 1899, shows about an equal distribution, agreeing, however, with the month of August in that consumption is several times as large as the average.

From 1890 to 1899 a mortality table is furnished, classifying all deaths under nine heads, from which it appears that of the 4 000 deaths during this period nearly 2 000 were from tuberculosis. The next cause, in point of number, is malarial fever, with 731, and the last is diphtheria, with 52. No single case of smallpox now appears in the city, the disease having been stamped out by the vaccination on the island of 780 000 people during the months of April, May, and June. Leprosy and elephantiasis exist among the poorer classes. A small island west of the entrance of the harbor has been set aside by the board of health for the isolation of the leprosy patients. At present, however, they are confined in a small building in the rear of the city jail.

It is believed that the city is fairly healthy, notwithstanding the comparatively high death rate, which is believed to be due more to the character of the population and the unfavorable conditions than to the climate. Quarters of the poor are overcrowded, a condition which can not be remedied, owing to want of space. Americans residing here enjoy excellent health and speak well of the climate.

CULEBRA.

Culebra is a small island about 5 miles long and 2½ miles wide, lying 20 miles east of Porto Rico. Vieques, or Crab Island, is half as far away, and is four or five times the size of Culebra.

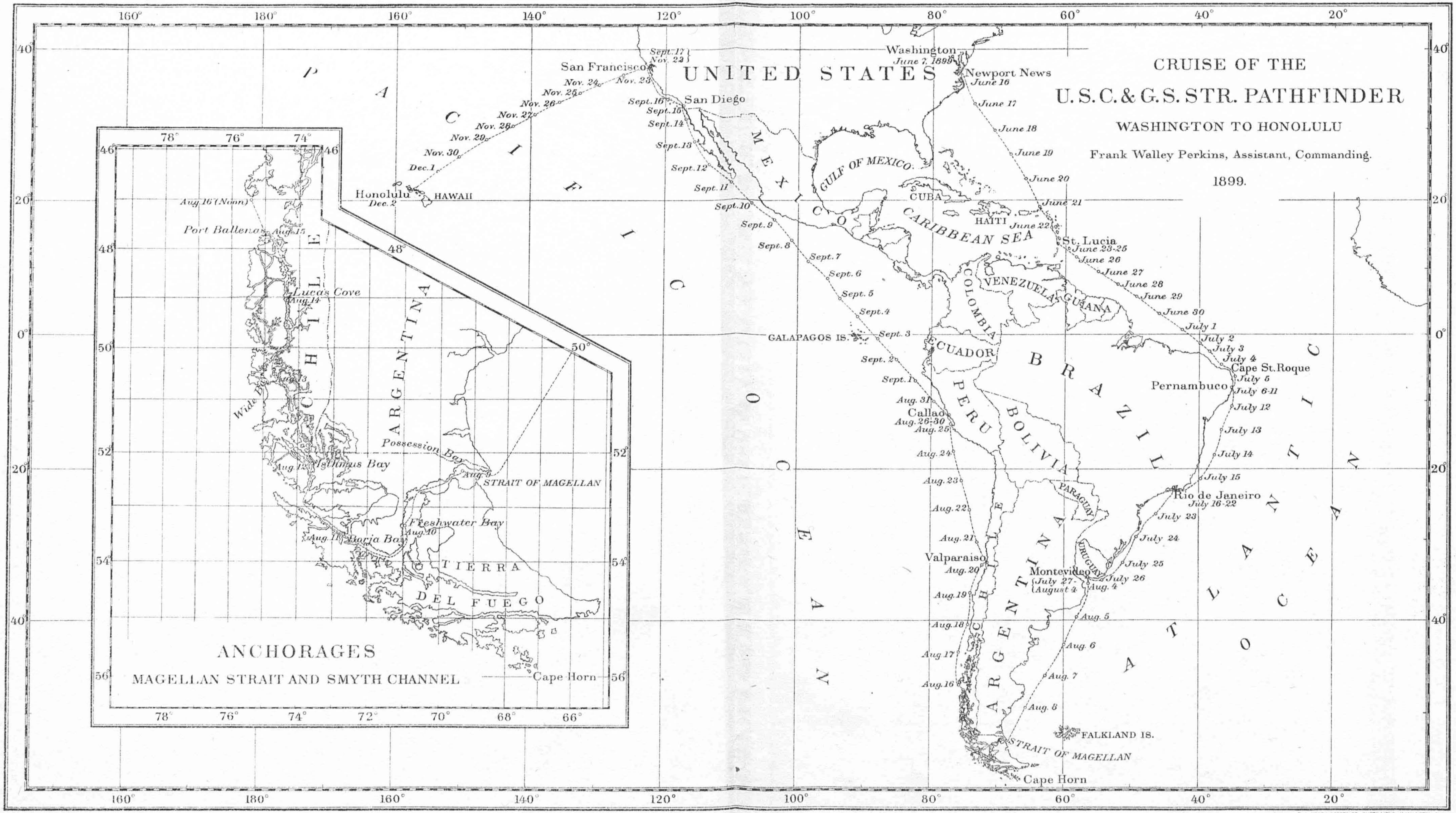
In connection with the last-named island, a report by Dr. Ullrich, a medical officer attached to the schooner *Eagre*, may be cited as giving some information of the sanitary condition of the place. The climate differs from Porto Rico by being somewhat cooler and less rainy. The general health of the people is good, but the most prevalent diseases, contrary to what one would expect, are consumption and rheumatism. Malaria also exists to a considerable extent where the soil favors its development.

In looking over the official records, Dr. Ullrich found no death from typhoid fever or smallpox. Notwithstanding this fact, the inhabitants were all vaccinated during the year.

There is absolutely no good drinking water except that caught during the rainy season in two large cisterns. This water is dealt out daily to the people, at the rate of 1 gallon per head for adults and one-half gallon for children. There are only two streams in the island that flow during the entire year. Water can be found by digging wells. In every case, however, it develops a peculiar odor after standing, and has a cloudy appearance and brackish taste.

The island has excellent grazing facilities, and at least 2 000 head of fine cattle were seen.

The most urgent recommendation made by Dr. Ullrich is that all drinking water should be either distilled or boiled. With this precaution he believes the climate as healthy in Culebra as in many favored places in the United States.



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

Cruise of the United States Coast and Geodetic Survey Steamer Pathfinder from Washington, D. C., to San Francisco, Cal., and to Honolulu, H. I.

A report by FRANK WALLEY PERKINS, Assistant, Coast and Geodetic Survey, Commanding.

The U. S. S. *Pathfinder* was designed especially for use in surveying the Aleutian Archipelago, where, owing to strong currents, distance from a base of supplies, etc., a vessel of considerable power and coal capacity was demanded.

Her field of operations was by no means to be confined to those northern waters, but a craft that was suitable for that region would be capable of keeping the open sea for long periods and in any kind of weather. Such a vessel would therefore be adapted for duty of any class.

She was built at the Crescent Shipyard, Elizabethport, N. J., and launched December 7, 1898. She is a three-deck steel vessel of extra strength, with 15 water-tight compartments, is 196 feet 3 inches over all, 33 feet 6 inches beam, 19 feet 8 inches depth of hold, and when equipped for sea draws 13 feet of water and has a displacement of about 1 000 tons. She is brigantine-rigged, carrying some 4 500 square feet of canvas; has a single screw 10 feet diameter and 13 feet pitch; triple-expansion engines developing 846 horsepower or 1 173 horsepower under forced draft, giving a speed of from 10·5 to 13 knots at sea. She is fitted with all the appliances and conveniences of a first-class steamer of her size.

I took command on June 1, 1899, and on the 7th ran down to Hampton Roads. The crew numbered 65, all enlisted men from the Navy. In the wardroom, with the exception of the doctor, draftsman, fourth and fifth watch officers, and captain's clerk, there were only Coast Survey officers, consisting of the first, second, and third watch officers, chief engineer, a recorder, and three cadet aids. The first watch officer served as executive officer. The recorder and cadet aids each stood watch with an officer of the deck.

It was not practicable to get the deep-sea sounding apparatus completed before sailing and no regular surveying work was contemplated, but it was hoped that more or less information could be collected without interfering with an early arrival at our destination, San Francisco, which was of primary importance.

On the morning of June 16 the vessel left Newport News and ran down to Old Point Comfort, where we lay to long enough to send off final telegrams and to pick up the mail orderly, who had been sent overland to meet us with the last mail. With a fresh northeast wind we then ran out of the capes of Virginia, and at 12·24 p. m. shaped our course for Anugada Pass, with St. Lucia, our first port, straight ahead.

In crossing the Gulf Stream that night the opposing wind and current gave us a rather nasty cross sea, but otherwise the run to Sombrero light was very comfortable. The vessel can roll and pitch, but she does it very easily, her heeling angle rarely reaching 15° from the normal, and solid water has rarely come on deck in the roughest weather, although the spray often made the bridge a very wet berth. It took two or three days for some of the party to overcome seasickness, but before we passed Sombrero light, on the 21st, all hands had reported at mess.

The engines and boilers worked admirably, causing us neither trouble nor delay on the whole voyage. The coal taken on at different ports varied greatly in quality, and although every precaution was taken it was not possible to determine with accuracy the amount received.

When under the lee of the island of Guadeloupe, on June 22, finding that we would make Port Castries in the night, we lay to and made some experiments with the Tanner sounding tubes, for use with the Lord Kelvin sounding machine. The results were highly satisfactory, and we have since made use of them in the regular work between 20 and 100 fathoms, where their results are sufficiently accurate and the method much more expeditious than with the hand lead.

At Port Castries, on the island of St. Lucia, which, by running at half speed all night, we reached at 6.30 a. m. on the morning of the 23d, we overhauled the machinery and blew down and filled the boilers with fresh water.

We lay alongside of the pier to coal the ship, and the coal was delivered by women, who carried it on their heads in flat baskets, of about 100 pounds capacity, a continuous line of them passing on at one gangway and off at the other, each woman receiving a tally check from the quartermaster stationed at the gangway as she came on board. At short intervals three or four women were stopped and their loads were weighed, from which a mean weight was deduced. By this method we took on 115 tons in about two and one-half hours. It is a very quick method when a regular chute is not available.

We sailed at noon on Sunday the 25th, and it had been the intention to go direct to Bahia, but yellow fever was raging there and I decided to run to Pernambuco. When leaving Port Castries the wind and sea were moderate from the east-southeast, but after passing the Barbados the sea was heavy enough to give us a motion of over 20°. The following day the wind and sea were dead ahead, and we had an opportunity to learn what a short ship could do at pitching.

The set of the current north of Cape St. Roque was strong from the west. We headed to the eastward to give the cape a good berth, and on the morning of the 5th squared away for Pernambuco, where we arrived on the morning of the 6th, after running at half speed all night. The captain of the port was very courteous, and obtained for me from the authorities at Rio permission to make magnetic observations. This I had applied for through our consul, and I had also brought up the subject when making an official call. The delay, however, was great, and this, together with almost constant rain, prevented our accomplishing all that was desirable.

Leaving Pernambuco on the evening of the 11th, we entered the magnificent harbor of Rio on the morning of the 16th (Sunday). There were a large number of war vessels at anchor, but none flying the American flag. While at Rio, where we remained until the 22d, we took advantage of the arrival of Mr. Buchanan, our representative at Argentina, to make a circuit of the bay with Minister Bryan and a party. Its navigation is quite easy, the charts good, and the scenery, like the harbor, is magnificent.

Leaving Rio on the 22d, we soon ran out of the rainy weather into the cooler climate and pamperos of Montevideo. This beautiful city was in gala dress to receive

General Roca, who arrived on August 3. All the ships were gay with bunting during the day, and with electric lights at night, leaving an agreeable picture of our last sight of civilization, as on the following morning we took our departure for the Straits of Magellan.

At 7.30 a. m. we got under way from the inner anchorage with a light head wind and smooth sea and stood over for Cape Antonio, whence we shaped our course for Cape Virgins, regulating our speed so as to enter the straits with a fair tide, which we did at 7 a. m. on the 9th. Passing south of Nassau Rock we ran in past the excellent light recently completed on Dungeness, and anchored at noon 5 miles west of Possession Point, in 10 fathoms of water.

At 6.40 a. m., on the 10th, the wind still from the north and east, with a mist obscuring the shores to the west and south, we steamed cautiously to the southwest. Cape Orange was sighted shortly after passing the Narrows Bank, and when abreast of Plumper Anchorage, Direction Hill was sighted. A wrecker was at work on a stranded steamer on Delgada Point, and as we passed through the First Narrows with a fair tide the wreck of one of the Grace Company's steamers was seen on the port hand. The mist clearing away, we sighted the buoy on Triton Bank, ran through the Second Narrows and Queen Channel, and entered Broad Reach before the turning tide had gained much force. The wind by this time was strong from the eastward, and as a landing at Point Arenas was impossible we kept on and anchored for the night in Freshwater Bay, 11 fathoms, hard bottom.

The region passed through during the day was decidedly uninteresting. As one enters the straits a single cattle ranch near Cape Virgins is seen, looking mean and desolate on the almost barren shingle. Possession Bay is a broad arm of the sea, the land being low and flat on the south, with bluff banks on the north and west, excepting the low point at Dungeness rising gradually inland, where at a few miles it culminates in rounded hills of moderate elevation. At Delgada Point there is a small bleak-looking settlement, and after passing the First Narrows an occasional isolated ranch house is seen on the treeless shores. As one approaches Point Arenas a scanty tree growth appears with occasional evidences of civilization. Point Arenas, or Sandy Point, is a straggling settlement of some size but scant attractions.

The 11th was typical straits weather, the wind still fresh from the eastward, bringing fog, rain, and snow, with clearer intervals. At 6 a. m. we got under way, rounded Cape Froward and ran up the English Channel, and at 2.28 p. m. anchored in Borja Bay, with 20 fathoms. Here were first found the boards posted on trees, giving names and dates when different vessels had used the harbor, and which were found at most of the anchorages from here on through the channels.

We were under way at 6.30 a. m. on the 12th, and steamed through Long and Sea Reaches, passing Tomar Island at noon. The weather was bright and cold, with a strong northerly wind and steady barometer when we headed up for Smyth Channel, and at 4.45 p. m. let go in 22 fathoms of water in Isthmus Bay.

On the 13th we ran to Wide Bay, and on the 14th anchored for the night in 13 fathoms of water outside of Lucas Cove. An examination was made of English Narrows, in order to know when the tide would serve, for the swift current that sweeps through this narrow and crooked channel is the greatest danger in these passages, aside from the rainy, foggy straits weather, of which we, however, had no personal experience. We passed through on the turn of the tide, at 7 a. m., taking the shorter and straighter course, east of Midchannel Island. A buoy on the point of the shoal making out from Cedar Point made this quite practicable. In place of the bright weather that we had since leaving Borja Bay, on this day it was overcast, fog hung about the mountains on either side and light rain or mist fell at times, but not enough to interfere with the navigation of the ship. Before noon we cleared the channels and anchored in Port Ballenas, in 26 fathoms of water.

The weather in the Straits of Magellen and in the Chilean passages is generally so unfavorable, the anchorages are so few and limited in extent, and the region so far removed from civilized centers, that it is most famous for its dangers and discomforts; yet, for grandeur and picturesqueness its scenery has probably few rivals. After rounding Froward the passage is through a succession of partially submerged mountain gorges; the depths are great, and the mountains, clothed at their lower levels with a thick growth of stunted trees and above ending in snow-capped peaks, rise for thousands of feet directly from the water's edge on either hand, while up lateral valleys can be seen the blue and wrinkled glaciers which fill them.

Great credit is due to the officers of different nations, who have under such adverse circumstances given us such excellent charts of this inhospitable region. Through the straits and in some portions of the channels they are all that could be desired; but in the latter most of the topographic work is entirely lacking in character. The shore line is for the most part fairly good, and the natural features are so bold that navigation is very easy when they are recognized. Unfortunately the draftsman has not done his work in a manner to display this. A better chart of the English Narrows and its approaches, especially at the north end, is very much needed. As the work could be done only at slack water and would have consumed several days, I did not feel authorized to stop to make it.

Of the natives we saw very little. A few columns of smoke here and there suggested their presence on shore, and one boat load of squalid men, women, and children waylaid us to beg for tobacco. The men wore remnants of shirts which covered parts of their arms and a short distance below the shoulders. A hag-like old woman had a square of matting secured about the neck by a string, leaving the whole of her parchment-covered skeleton exposed, save a small section of her back. One younger woman there was in the rudely constructed craft who was completely clothed, but the children who emerged from time to time from among the litter in the bottom of the boat, were entirely nude. When one remembers that this was in 50° south latitude, and that great cakes of ice were floating in the water, and, moreover, that these people were probably dressed more elaborately than usual, their indifference to cold is surprising.

There was little animal life. Occasionally the head of a hair-seal would appear above the water for a moment, and one or two were seen sunning themselves on the rocks. Near the head of the Chasm Reach we passed a flock of penguins. There were a few wild geese, among which the kelp goose alone was recognized. All are said to be unfit for table use. A few lonely looking ducks were also seen. Before entering the straits, and again near the Bay of Pines a few albatross came about the vessel, and a flock of cape pigeons bore us company from Isle Monte as far as Callao, when they left us, probably to escort some southbound vessel to lower latitudes.

The temperature ranged from 34° to 50° F., with a mean of say 40°. At midday on August 16 we passed Isle Monte and steered northward. There were evidences of recent heavy weather, but the sea went down the following day, and on the afternoon of the 20th we went into Valparaiso, where we stopped only long enough to get letters. The storm which we had just escaped had been very severe here, and the streets were all but impassable from the mud washed down from the hills, while the water front had suffered severely from the heavy sea.

The run to Callao, where we arrived on the 25th, was uneventful, but as the 4 000 miles steaming from Montevideo had nearly exhausted our coal supply, we remained here long enough to fill the bunkers. While this was being taken on board and the storerooms were being replenished, as many of the officers as could be spared from duty went into the interior, visiting Lima and taking a trip across the mountains. Unfortunately the railroad was not completed to the point where the revolution was active the day we went up, and we made so early a start the next morning on our return that we missed, by a few hours, a very one-sided engagement at the summit of the Pass, the troops on their way up passing us at our breakfast station as we came down.

Leaving Callao on August 30, we steamed north with light airs and a smooth sea. On crossing the line in the Atlantic, "Neptune," in the person of the largest and laziest sailor in the forecastle, accompanied by "Amphitrite," a comical little salt with a brogue as liquid as her husband's empire, with other familias, all grotesquely attired, and bearing emblems of their several offices, came on board and initiated his new subjects with all the ancient rites. In the neighborhood of the Galapagos, which gave warrant for the name, quantities of turtle were seen floating on the water, a score of which were added to our larder. The men went alongside of them in a small boat, seized them by the flipper, and turning them over, deftly hauled them inboard.

Throughout the voyage the machinery had worked perfectly, the weather had been propitious, violent storms had been reported by vessels just preceding or immediately following us, all of which we had escaped, and nothing happened to mar what was possibly one of the most satisfactory trips ever made over the same ground.

On the evening of September 13, however, when off the coast of southern California, the doctor reported that he suspected appendicitis in the case of Cadet Aid James J. Sylvester, who had been suffering more or less with abdominal pains since morning. The course was at once changed to San Diego, which the vessel reached the following evening. The next day he was sent ashore to the sanitarium at Coronado, and on the morning of the 16th an operation was performed, terminating fatally. The loss of this plucky little fellow, who was a universal favorite, cast a shadow over the whole ship's company and robbed our return to home waters of the pleasure that we had anticipated.

While at quarters on Sunday, the 17th, when abreast Point Pinos, an object was sighted through the mist a mile and a half inshore, the nature of which we could not at that time determine, but which it was later concluded must have been the great timber raft reported adrift somewhere near the entrance to San Francisco. The suspicion was reported upon our arrival, and led to the recovery and removal of that menace to navigation. We entered the Golden Gate that afternoon in a fog, and anchored off the city.

Certain improvements and alterations were suggested by our experience, and these, together with hauling out, cleaning bottom, and a few minor items of repair were authorized. Specifications were then prepared and bids asked for. The great amount of work on hand at all the shops and yards, occasioned by the great emergency calls on the part of the army transport service, and those employed in freight carrying more or less directly connected with or growing out of that service, made it hard to get bids. After much annoying delay, however, the work was taken in hand and on the 17th of November the vessel was ready for sea.

The Coast Survey expenses of the steamer from the time of leaving Washington until she reached San Francisco (exclusive of all pay except of cadets), and inclusive of putting her in as good condition as when she started was, in round numbers, $8 000, or, say, 55 cents per nautical mile. Of this 75 per cent was for coal.

The elapsed time was	102 days 9 hours 45 minutes.
Number of days at anchor	40 days 4 hours 56 minutes.
Number of days under way	62 days 4 hours 49 minutes.
Distance run	14 566 knots.
Average knots per day	234 knots.
The number of tons of coal expended was	842 tons.
Coal consumed at anchor	102 tons.
Coal consumed under way	740 tons.
Average distance per ton of coal	19·67 knots.

At Pernambuco, Montevideo, and Callao we coaled from lighters, the coal being passed aboard in baskets, occupying about two days at each place. As the coal bill is the largest item of expense, the inferior quality (mostly Welsh) and the scant weights add greatly to the expense of a voyage in these waters.

Recorder H. H. Pritchett made magnetic observations, and, assisted by the third and fourth watch officers (Atkinson and McGrath), obtained results for declination, dip, and intensity at Port Castries, Pernambuco, and Callao. These observations were made while the vessel was taking on coal—the time was always short and it was not always practicable to make full sets. It was a source of great disappointment that observations could not be made at other points. Tidal and current observations were also impracticable, but by the courtesy of Dr. Saboia, chefe da commissao de melhoramento do Porto de Pernambuco, I procured a tracing of one month's curve at that place, and information which I hope may lead to our obtaining data at a number of other ports in Brazil.

The establishment of agencies for the sale of our charts I did not find practicable. The number of local charts of the United States called for by vessels touching at South American ports is very small, and as the United States Hydrographic Office furnishes our charts to their agents the demand is amply supplied.

At midday on November 22, with full bunkers and storerooms, and a supply of instruments suitable for the anticipated work in the Hawaiian Islands, we started for Honolulu. A heavy sea was making on the bar through which we passed, and the vessel pitched heavily, but without taking on water. Outside the wind was contrary and the water rough, and for a week we steamed into a head sea with a gale in our teeth, but as the islands were approached we met the fine weather common to that region, and shortly after noon on the 2d of December entered the harbor of Honolulu and moored ship.

F. W. PERKINS: MANILA, P. I.

SPECIAL DUTY.

During the month of March, 1900, Assistant Perkins, who was in command of the *Pathfinder*, engaged in hydrographic and topographic work in the Hawaiian Islands, received instructions to proceed to Manila and report upon the conditions in that section bearing upon the work of the survey.

He sailed on the 30th of March from Honolulu, took a month's leave of absence without pay, which was spent in Japan and China, and reached Manila on the 4th of June. From this time until the 15th of July he was actively engaged, investigating the different conditions and collecting all available information as to the means of prosecuting work in the Philippine Islands similar to that carried on by the Coast and Geodetic Survey.

During his stay and on the way back, which was by way of Yokohama and San Francisco, numerous letters were written to the Superintendent of the Coast and Geodetic Survey, giving such information as had been obtained. From these letters and preliminary reports the following statements have been briefly summarized:

On account of the revival of business, which makes the interisland traffic very profitable, vessels of any kind are very difficult to secure, and even the Army and Navy are unable to obtain the small vessels that they require for light work in shoal water. Such vessels, however, could be bought or built at Hongkong, where the quality of the work and material is better, and the cost of material much less than at Manila.

The charge for docking vessels at Hongkong is about half what it is in San Francisco, and material is about the same price as on the western coast of the United States. On the whole, repairs can be made there as well as in the United States, and for somewhat less money. Coal can at present (August, 1900) be bought at Manila at about the following prices: Cardiff, $25 per ton; Australian, $20 per ton; Japanese, $16 per ton. The average supply of coal in private hands is stated to be about 16 000 tons.

The larger buildings in Manila are well adapted for use as offices, and for the needs of draftsmen, engravers, etc.

The observatory of the Jesuit Fathers has a very complete and well-selected instrumental outfit in both the seismic and meteorological departments. It has also a new equatorial and a good transit. The observations carried on there are continuous. Time signals are sent over the wires each day to all sections, and systematic observations of latitude are to be shortly begun. A small printing and lithographing plant is established in the observatory.

There exists also at Manila the lithographic establishment of Chofre & Co., which has been in operation for twenty years. The main building is about 80 by 100 feet.

They have roller presses, compositors' rooms, etc. The engines for running the plant are in duplicate and are run, alternating, a month each. Their steam planer is large enough for any size stone, and they have two good mills for grinding ink. The maximum size stones for which the presses are adapted is 65 by 95 centimeters, though there are only a few stones of that size. There is a large supply of stone on hand, but most of them are small. All the employees are Filipinos, with the exception of the manager or general foreman.

The telegraphic system extends all over the northern and western coasts of the island of Luzon and to many islands to the southward, and within a year it is estimated that all the islands will be connected with the capitol. The war has necessitated the construction of numerous telegraph lines, both land and cable, in addition to those operated by private firms.

Astronomic and hydrographic surveys of the east coast of Luzon and from Aponi east and south to San Bernardino are said to have been made by Capt. Juan de la Concha. They have not been published. Early tidal records extending back a number of years were found at the office of the captain of the port. These have been sent to the Hydrographic Office at Washington. A magnetic survey of the group and the adjacent coasts of China has been made by the Jesuits. The stations, however, were not marked nor described, so as to be available for future occupation, except at Manila, where systematic observations have been conducted for some ten years.

No records or instruments of value in the work of the survey appear to have been left by the Spaniards, though a few instruments evidently not considered worth sending away were found. The existing charts are very defective, the errors amounting in some cases to as much as 10 or 15 miles in relative positions. Such conditions, of course, make the navigation of these waters extremely dangerous, and emphasize the necessity of beginning as soon as possible an accurate and systematic survey of the group.

In view of the above, Assistant Perkins suggests the following plan for future work in the islands:

(1) *Longitudes.*—Advantage should be taken at once of the excellent telegraphic facilities, and as many astronomic parties as can be put in the field should be detailed with instructions to determine the position of as many points as possible.

(2) *Tides.*—As the astronomic work will practically be confined to coast points, tide observations could advantageously be made by these parties. Self-registering tide gauges should be maintained at Manila and at other important points.

(3) *Triangulation.*—More or less triangulation will be required, although the plane table should be used in making the preliminary surveys, except in the case of large bodies of water like Manila Bay.

(4) *Topography and hydrography.*—It will of necessity be some time before detailed topography can be done, but the plane table will be in constant requisition. The most satisfactory way of making a rapid preliminary survey of sufficient accuracy will be as follows: Upon reaching a harbor or region to be surveyed all available boats should be sent out to flag the coast. At the same time a tide gauge should be erected and observations commenced. A plane-table party should be organized and the shore line should be run and the flags and signals determined. One of the plane-table stations should be a previously established astronomic station, or should be occupied for an azimuth on

the sun, and time and latitude should be observed. If an officer is available for the purpose, magnetic observations should be commenced at the same time.

So soon as four or five signals or flags have been erected the hydrographic boats should commence work without boat sheets. The plane table can give from 4 to 6 or more miles of such shore line in a full day, so that the boat sheets for that section should be ready the second day. The hydrography of the previous day can be put on them and systematic work continued. Peaks and objects in the background of value to the navigator and outside the limits of the topographic sheet should be determined with the theodolite from bases furnished by the topography.

The best time for work is from November till May, but the other half of the year can be used for the surveys on the eastern coasts.

H. G. OGDEN: OCCUPATION DURING THE YEAR OF THE VESSELS OF THE COAST SURVEY.

CONDENSED STATEMENT.

The steamer *Pathfinder* sailed from Washington for San Francisco about the middle of June. She arrived on the 17th of September. After being docked and overhauled at the last-named place, she proceeded to the Hawaiian Islands on November 30, where she was engaged upon surveys and examinations until the end of March. At the end of this time she returned to Seattle, and after being docked for some minor repairs sailed for St. Michael early in June. She was engaged in work in Bering Sea at the end of the year.

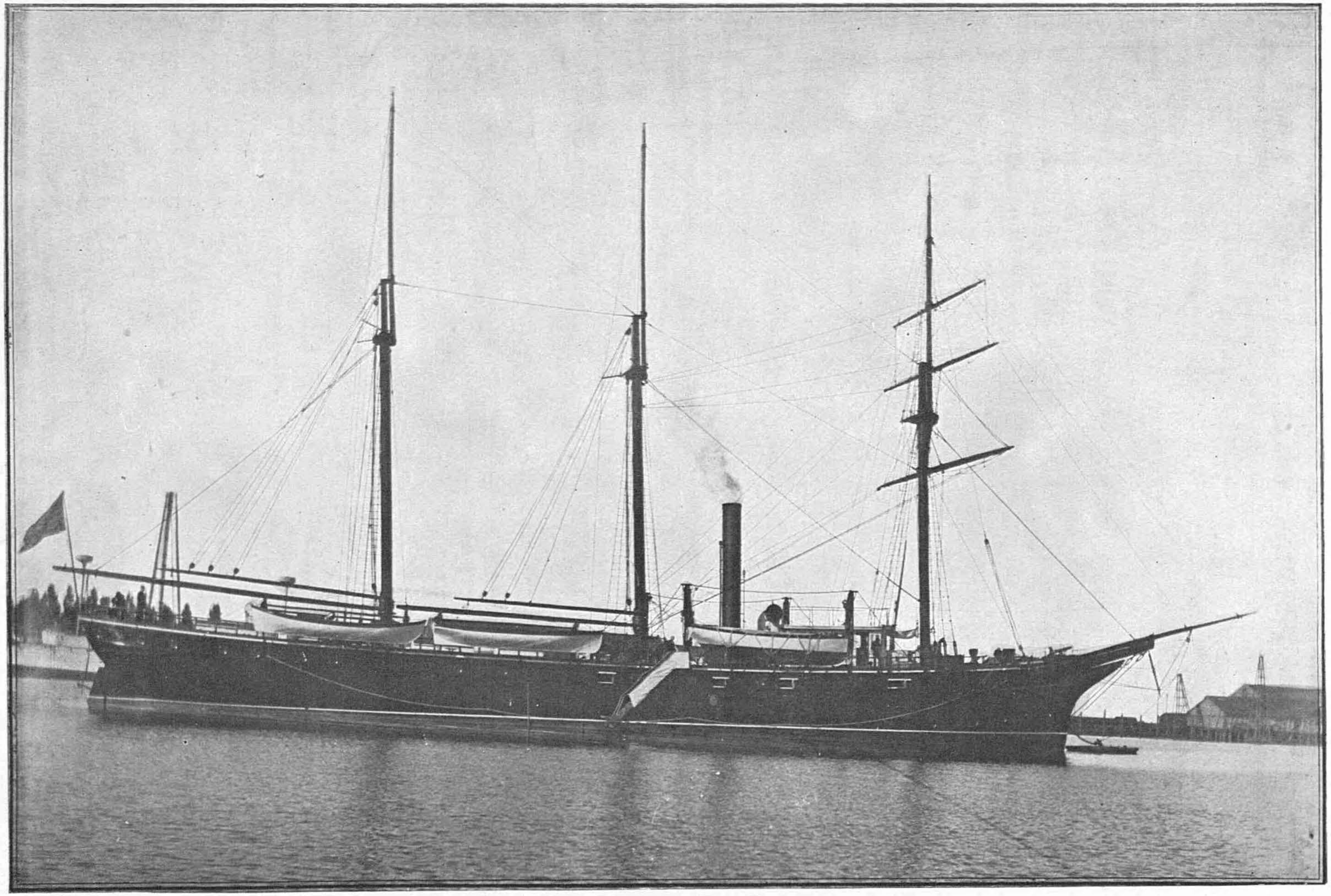
The steamer *Patterson* sailed during the month of June from San Francisco to engage in hydrography in Alaskan waters. During the season she developed the outer edge of the flats off the Yukon Delta, from Cape Romanzof to St. Michael, besides making a careful hydrographic examination of Golofnin Bay and some other points on the north shore of Norton Sound. She returned to Seattle in the fall, where, on account of a collision with the ferryboat *City of Seattle* while at anchor, she was practically under repairs during the whole winter. Late in June she sailed again for Bering Sea, her work being projected for this season to extend northward as far as Port Clarence.

The steamer *Blake* returned from Porto Rico in June, 1899. She sailed shortly afterwards for Boston, where a preliminary examination was made by the United States local inspectors to determine her condition and seaworthiness. The report of the inspectors indicated that considerable repairs would be required, but they were unable to make any positive recommendations until they should have an opportunity to open her out and find by actual sight the condition of her timbers. It was decided, however, that she should execute, immediately, on Nantucket Shoals, and especially on the Pollock Rip Slough, some work called for by the Light-House Establishment.

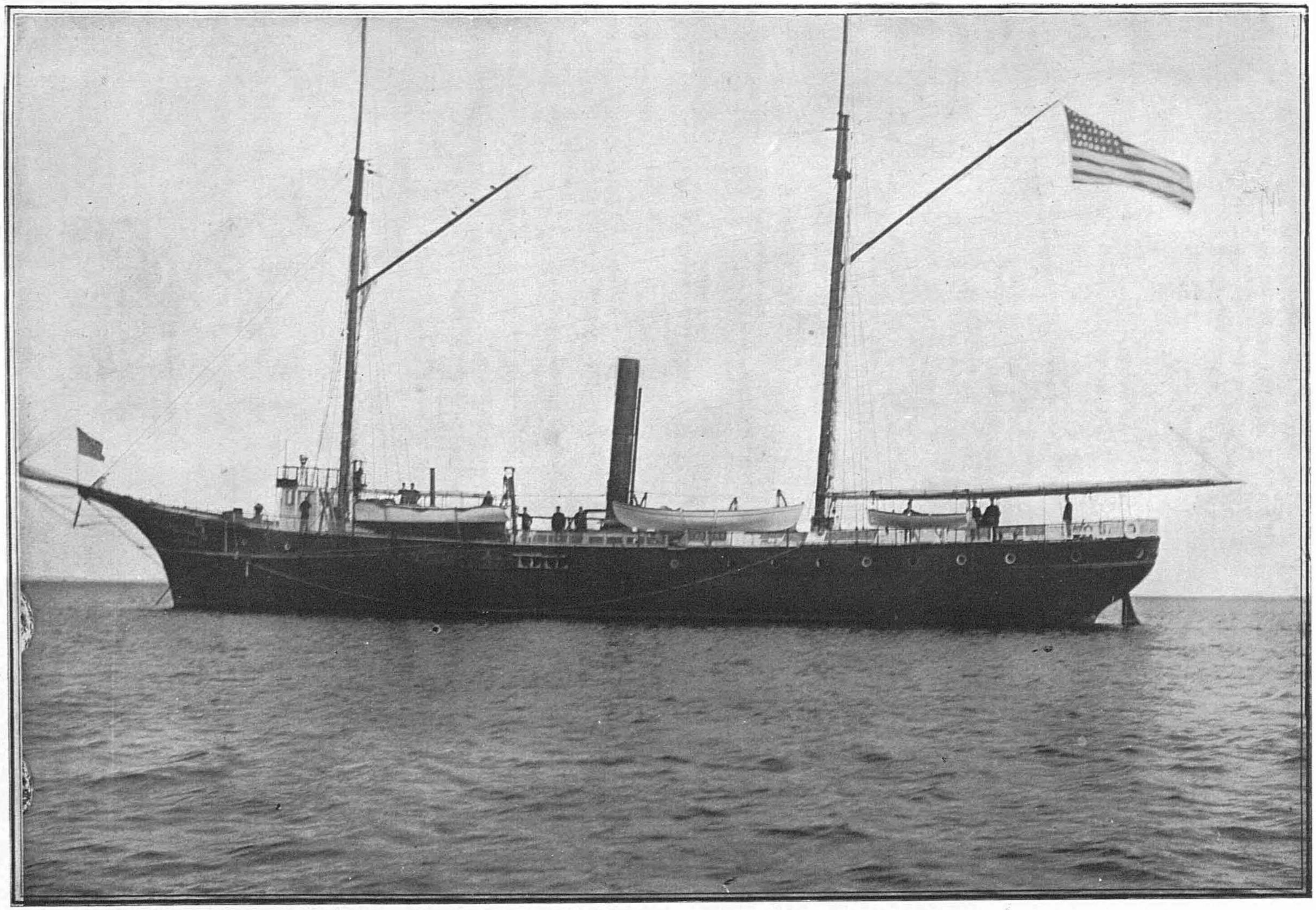
While making this examination the position of the Nantucket Shoal light ship was determined, with a view of verifying the location of some of the shoal soundings that had been obtained by the U. S. S. *New York*.

After completing this work she returned to Boston and made a thorough examination for some ledges which had been reported by the captain of a Cunard steamer. She was then put in dry dock, and, an examination being made, the frames and hull generally were found to be in good condition. The fashion timber and cant frames were badly decayed, and it was determined that they should be removed before the vessel should again proceed on an extensive voyage. She was subsequently ordered to Baltimore and put on the railway at Spedden's shipyard, where the necessary repairs were made. She sailed for Porto Rico in February and remained there until the close of the year.

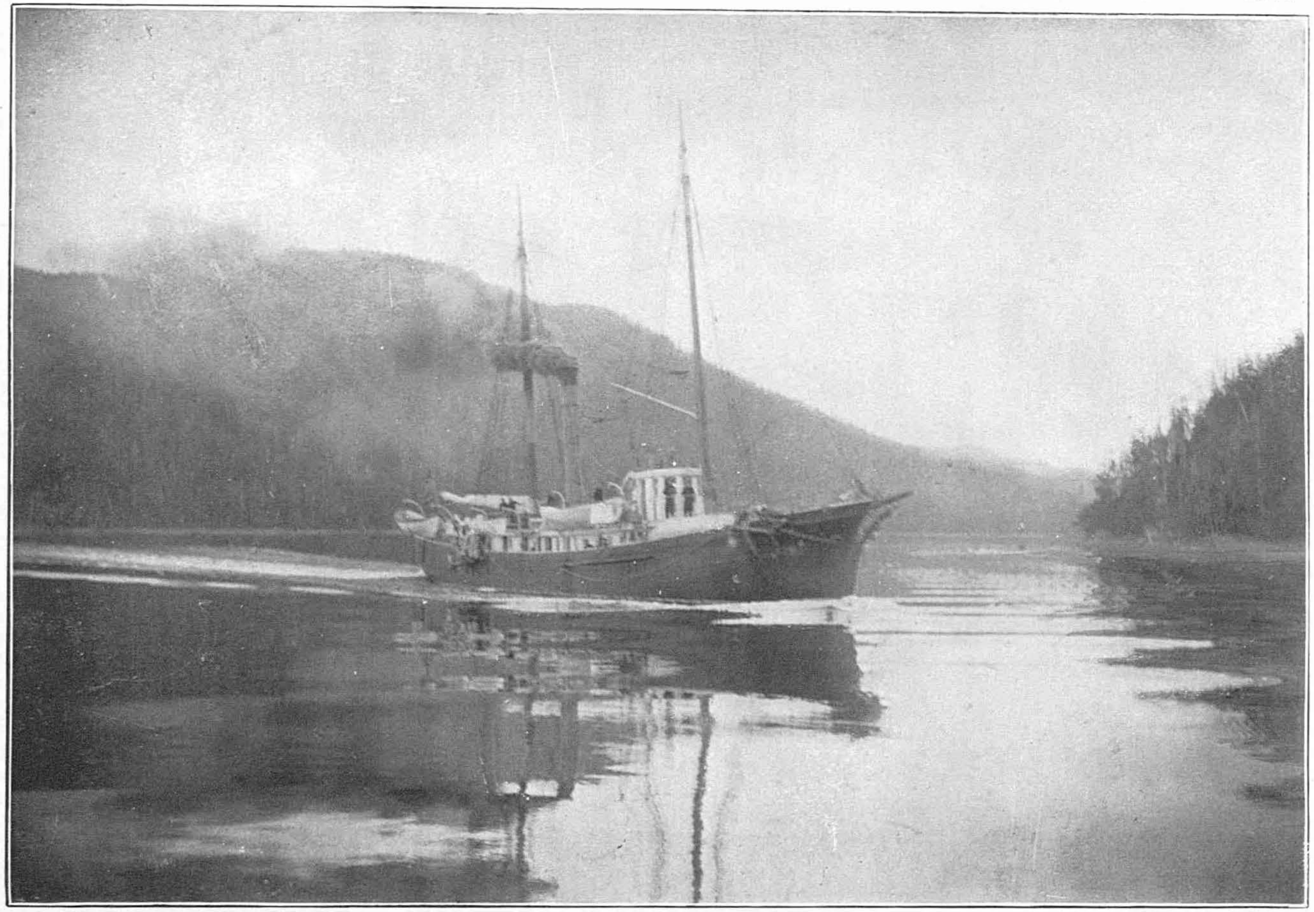
The steamer *Bache* was engaged during the summer months on the hydrography of Eastern Bay, Maryland, in connection with a shore party which was executing triangulation and topography in that locality. During the winter months she was laid up at



STEAMER PATTERSON.



STEAMER BACHE.



STEAMER GEDNEY.

Baltimore, and such slight repairs as were required to keep her in condition for work in Chesapeake Bay were made by the ship's complement. She left dock in May, and during the balance of the year was engaged in erecting signals in the lower bay for use in completing the triangulation necessary for a hydrographic survey in that locality.

The steamer *Gedney* sailed from San Francisco early in July, bound for Chatham Strait, Alaska. She touched at Seattle on the way. During the season, which was necessarily short, she connected the triangulation with that which had been previously executed in Sumner Strait. On the return of the vessel to Seattle a careful survey of Rich's Passage and the approaches to Puget Sound Naval Station was made. This was completed early in May. A careful inspection of the vessel was made at this time, and it was found that extensive repairs would have to be made before she was in a condition to again resume work in Alaska. These repairs were undertaken during the month of June, and were under way at the close of the year.

The steamer *McArthur* was in the hands of the Union Iron Works, at San Francisco, at the beginning of the year. The repairs were completed in July, and the ship was placed in ordinary in Oakland Creek. She resumed work in the vicinity of Brocks Island in October, and late in the season made a resurvey of San Francisco Bar.

The steamer *Endeavor* established a mile trial course for the Navy Department in the vicinity of Cape Charles City during the month of July. She was then assigned to the Coast Pilot party for the verification, in the field, of a new edition of the Coast Pilot embracing Long Island Sound, New York. Returning to Chesapeake Bay in September, she resumed the hydrographic survey of Sassafras River and other work in the vicinity of Pooles Island. During the winter months she was laid up in Baltimore, and in the spring was assigned to hydrographic work in the Delaware River to determine the best water for deep-draft vessels above Bombay Creek. She was engaged upon this work at the close of the year.

During the time from the 1st of July until the close of the season the *Yukon* was engaged at the mouth of the Yukon River. She remained at St. Michael during the winter, and in the following spring was assigned to the *Pathfinder* as a tender for her season's work in Bering Sea.

The steamer *Taku* was employed also in the Yukon Delta and was towed to Dutch Harbor by the *Patterson* on her return from the season's work in the fall of 1899. In the spring of the following year she was assigned to the party to operate in Prince William Sound. She was successfully towed there from Dutch Harbor under contract.

The schooner *Eagre* was ordered, in July, to New York, in order to make a survey at the request of the Navy Department in the vicinity of the Battery and Governors Island. On completing this work the *Eagre* was docked in the Erie Basin, and was opened out by removing a strake all around the vessel above the water line. As it was determined to send the schooner to Porto Rico during the following winter, extensive repairs were found necessary, and proposals were obtained for rearranging the quarters in the ship as well. The vessel was subsequently ordered to Baltimore and put in the hands of Woodall & Co., where the required repairs were made. She sailed for San Juan in January and returned to Baltimore during the month of June.

At the beginning of the year the schooner *Matchless* was engaged on a hydrographic survey of Chesapeake Bay, including the Susquehanna River and Northeast River. Upon the completion of this work she proceeded to Elk River and finished the survey of that stream and the Bohemian River. She was then overhauled and repaired in September for the cruise to Porto Rico. Very little work was found necessary. She left Baltimore for San Juan in February, and during the remainder of the season was engaged in completing the hydrographic and topographic survey of that harbor. Leaving there early in June she proceeded to Charleston, S. C., and made a survey of the old main channel, in compliance with a request from the Light-House Board. She was engaged upon this work when the year closed.

The schooners *Quick*, *Transit*, and *Spy* were not in commission during the year.

APPENDIX No. 3.

REPORT 1900.

THE OBLIQUE BOUNDARY LINE BETWEEN CALIFORNIA AND NEVADA.

By C. H. SINCLAIR, Assistant, Coast and Geodetic Survey.

INTRODUCTORY NOTE.

In 1893 Prof. George Davidson, Assistant, United States Coast and Geodetic Survey, undertook to collect information concerning the early surveys of the eastern boundary of California. His extensive acquaintance with men on the Pacific coast and with the events which have transpired since 1849, from many years residence in San Francisco, and numerous expeditions through the western coast region, gave him great facilities for obtaining accurate knowledge, and he corresponded with many of the surveyors who had been engaged upon the eastern boundary survey in order to ascertain facts in connection with it. This information, in the shape of letters, was kindly turned over to me by him.

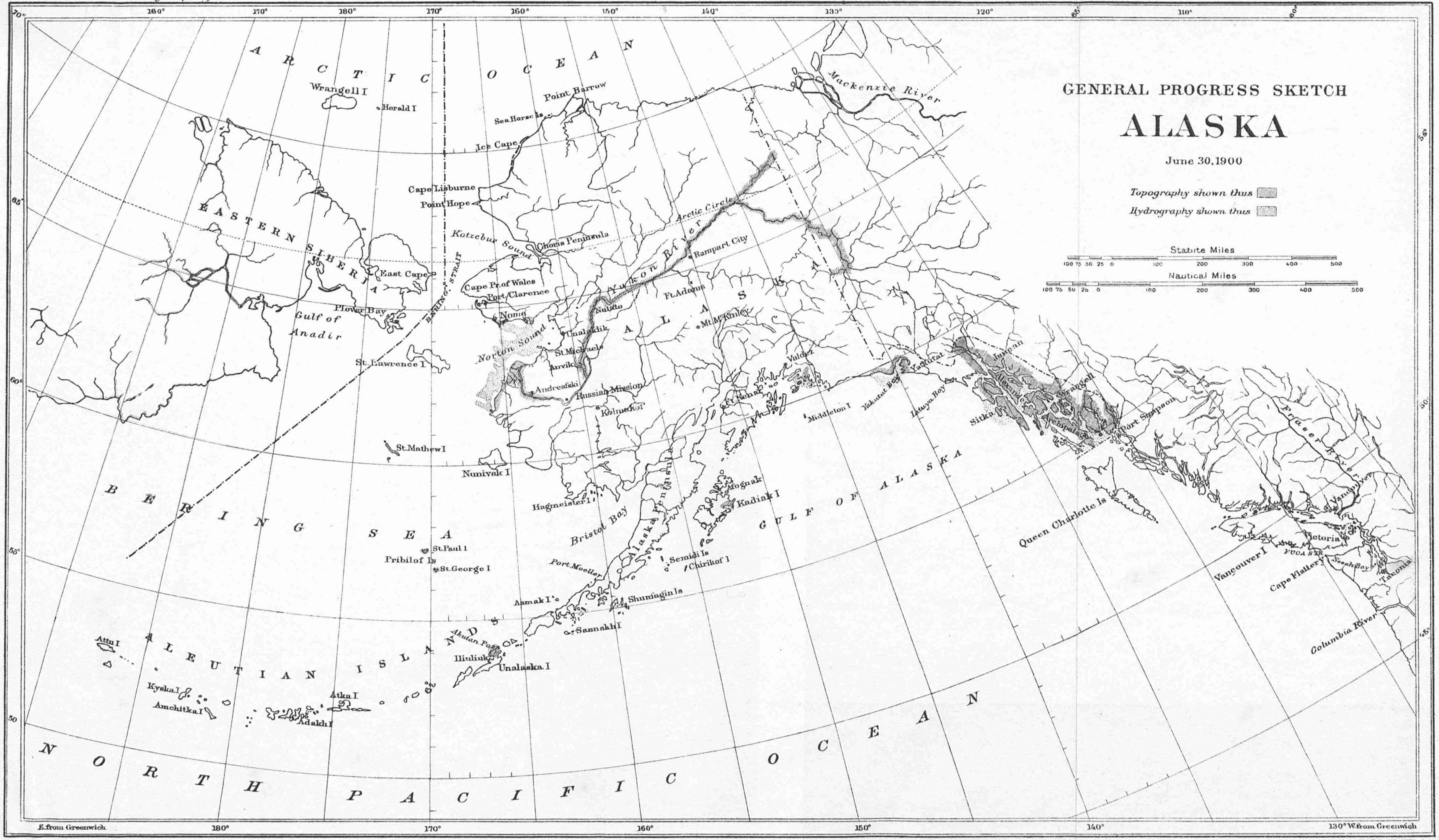
While the material concerning work executed less than fifty years ago is not so abundant as might be supposed and some of it is entirely without value, an effort has been made to give an outline of the principal surveys, and to bring together data that may be of future use. The matter here incorporated is limited, principally, to extracts from reports, and to a reproduction on a small scale of such early maps and sketches as could be found. Although it has not been practicable to investigate thoroughly all of the possible sources of information, it is believed that most of the important documents have been examined.

In April, 1900, Assistant Frank W. Edmonds, Coast and Geodetic Survey, examined the records in the offices of the United States surveyors-general at San Francisco, Cal., and Reno, Nev., as well as the offices of the State surveyors-general at Sacramento, Cal., and Carson City, Nev., for material bearing upon the early surveys of this boundary. No trace of the Goddard map could be found, but copies of the map of Houghton & Ives of 1863, and of the extension of that survey by Lawson & McBride in 1865 were found, and a tracing was made of each.

Mr. Edmonds was also able to settle conclusively the fact that a telegraph line ran from San Francisco to Sacramento and Placerville, and thence, via Lake Valley and Genoa, to Carson City, so it is presumed that Lieutenant Ives, who made observations for latitude and longitude in Lake Valley at the south end of Lake Tahoe in 1861, utilized this wire for longitude, as there was a telegraph office at the Lake House, which was very close to his astronomic station near the lake shore.

Nothing could be found relating to the work executed by Lieutenant Ives in 1861 except the allusion to it by Mr. Houghton, surveyor-general, California (Rep. for 1863, pp. 36–37), in which he states that the "field notes and topographic maps" of Lieutenant Ives were delivered to him for examination; that both initial points were determined by Lieutenant Ives, and that the Colorado terminus was marked in three places as 114° 36′. The sketch which shows the river as it was in 1861, is believed to have been copied from the map of Lieutenant Ives.

The Coast and Geodetic Survey Office was drawn upon for computation of the geodetic line, geographic positions, etc. Assistant W. B. Fairfield prepared nearly all of the tabulation, description of stations, and computation of heights. Assistants Baldwin, Nelson, Flynn, Edmonds, and McGrath rendered valuable aid in the computations.



THE NORRIS PETERS CO. PHOTO LITHO., WASHINGTON, D. C.

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APPENDIX NO. 3. 1900.

THE OBLIQUE BOUNDARY LINE BETWEEN CALIFORNIA AND NEVADA.

I. FORMATION OF CALIFORNIA AND NEVADA.

After the Mexican war a large territory was ceded to the United States by the treaty of Guadalupe-Hidalgo, February 2, 1848. A portion of this territory was formed into the State of California September 9, 1850. Its limits, in part, as defined by the State constitution, are as follows:

> Commencing at the point of intersection of the forty-second degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich and running south on the line of said one hundred and twentieth degree of west longitude until it intersects the thirty-ninth degree of north latitude; thence running in a straight line in a southeasterly direction to the river Colorado, at a point where it intersects the thirty-fifth degree of north latitude; * * *

The above defines the eastern boundary of the State, but this report only treats of the oblique portion of the eastern boundary—namely, that which is included between the intersection of the thirty-ninth degree of latitude with the one hundred and twentieth meridian and the thirty-fifth degree of latitude with the center of the Colorado River.

Utah was organized as a territory, also, on September 9, 1850, from a portion of the Mexican cession. Its western boundary was made to conform to the eastern boundary of California.

Nevada Territory was formed from Utah Territory on March 2, 1861. It became a State October 31, 1864. Several additions were made to its area before it reached its present dimensions. Its western boundary was made to conform to the eastern boundary of California. Only the oblique portion of this boundary was retraced by the United States Coast and Geodetic Survey.

II. EARLY SURVEYS BEARING ON THE EASTERN BOUNDARY OF CALIFORNIA.

A. SITGREAVES, 1852.

In 1852 Capt. Lorenzo Sitgreaves, United States Topographical Engineer, reached the Colorado River of the West. His sketch of the river and his report are published in Executive Document No. 59, Thirty-second Congress, second session. His nearest camp to the present Camp Mohave was No. 33. One day's march north of this, at

No. 32, observations were made for latitude and longitude. The latitude is given as 35° 08′ 55″.4, longitude 114° 39′ 27″. From the sketch it will be seen that the longitude of Camp No. 33 is nearly the same as that of No. 32, on the east bank of the river.

The California oblique boundary is shown on the sketch, but it is not prolonged to the river; its prolongation would intersect the thirty-fifth parallel of latitude in longitude 114° 40′, very nearly. This topographic sketch is on a scale of 10 miles to the inch and the topography is too general to be of value here, but it has an historic interest because Mr. G. H. Goddard used Sitgreaves's longitude (114° 40′) of the Colorado terminus to compute the oblique line from Lake Tahoe (Bigler) to the Colorado River.

B. GODDARD, 1855.

1. INSTRUCTIONS OF SURVEYOR-GENERAL MARLETTE.

The following extracts are made from the "Report of a survey of a portion of the eastern boundary of California and of a reconnaissance of the old Carson and Johnson immigrant roads over the Sierra Nevada, by George H. Goddard, civil engineer."

SURVEYOR-GENERAL'S OFFICE,
Sacramento, August 3, 1855.

SIR: As you are now provided with the necessary men, animals, and instruments, you will proceed without delay to Placerville, en route for Carson Valley. * * *

At or near Carson Valley you will determine, astronomically, with some precision, the position of the *eastern boundary of the State;* and I would suggest that such portion of the *State line* as shall fall *in Carson Valley*, or so much of it as you may deem necessary, be measured and defined with tolerable accuracy. * * *

Very respectfully, your obedient servant,

S. H. MARLETTE, *Surveyor-General.*

GEO. H. GODDARD, Esq., *Civil Engineer, etc.*

INSTRUMENTS.

(1) An altitude and azimuth instrument, by Parkinson & Frodsham, of London; 12-inch horizontal circle, divided to 10′ and reading to 10″; 16-inch vertical circle, divided to 5′ and reading to 5″; telescope, 4-foot focal length, 3-inch objective, 2 eyepieces, 120 and 180 diameters. The instrument was supported on a central pillar, and the telescope revolved at one extremity of its axis, by which it was more adapted to astronomic than to geodetic purposes.

(2) A very fine 6½-inch theodolite, of English make and usual construction.

(3) One large chronometer, by Dent, London, No. 1946.

(4) One small chronometer, by Parkinson & Frodsham, London, No. 1628.

Also, a cistern barometer and an aneroid barometer; a sextant and two artificial horizons.

2. LAKE BIGLER (TAHOE) ASTRONOMIC STATION.

"Bigler Lake is a noble sheet of water from 15 to 20 miles in length by 6 to 7 in width. We arrived at its shore at dusk and camped at the point of timber which forms the eastern boundary of the swamps on the southern end of the lake.

"*September 15.*—I went along the beach of the lake to the mouth of the Truckee River. This beach is a strip of firm, solid ground inclosing the swampy flats. I selected a favorable site for our astronomical station. * * *. It was near the mouth of the river and sufficiently far from the timber to prevent its interrupting our view. I had a block cut and prepared for the instrument. * * *.

"*September 16.*—Had a raft made, and floated the block half a mile along the lake shore to the place chosen yesterday. * * *.

"*September 18.*—* * * In the afternoon crossed the Truckee on our raft and went to the point of timber on the western side of the flats, from which I took bearings on our tent and the flag on the granite block. * * *—(Goddard's report, p. 112.)"

"*September 21.*—* * * The continued bad weather had prevented my getting the observations I most desired at this camp; still, considering the means I had at my disposal, the result of the survey had been satisfactory, and its main object attained. The position now of the boundary line between Eldorado County and Carson Valley was determined with a very small amount of error, and it only remained to carry that line over the mountains to see exactly where it would fall in the valley.

"Previous to doing this, however, the observations had to be recomputed with the corrected result already obtained, and on that being done a monument should be erected at the point where the boundary leaves the lake, and a station fixed in line therewith on the summit of the ridge above Carson Valley. As this, however, could not be done before the office work required in the first instance was completed, I concluded that it would answer all present purposes to connect Carson Valley with the survey and locate the several settlements there, so that when the map of the entire work was completed the boundary line could be drawn thereon with accuracy, leaving the tracing it off on the ground to a future occasion. (Same, p. 115.)"

3. LONGITUDE, LATITUDE, AND AZIMUTH OF THE OBLIQUE BOUNDARY.

The latitude and longitude of this camp, by a mean of our best observations, is latitude 38° 57′ 01″; longitude 119° 58′ 02″, and its altitude above the sea 5,850 feet. The initial point formed by the intersection of the thirty-ninth parallel with the one hundred and twentieth meridian is therefore 4 miles distant from the camp, on an azimuth of 30° 30′ west of true north. Assuming the longitude given by Capt. L. Sitgreaves, United States topographical engineer, of the point where the Colorado River crosses the thirty-fifth parallel as 114° 40′, the boundary line will form part of a great circle uniting these two points, and at the thirty-ninth parallel and one hundred and twentieth meridian the line will make a spherical angle with the meridian of S. 48° 25′ 55″ E., and at the junction of the 114° 40′ meridian and thirty-fifth parallel of N. 45° 13′ 05″ W.

It may prove of interest to insert the results of observations at this station:

	Date.	Latitude and longitude. °	′	″	Remarks.
	Sept. 16	38	57	06·1	Mean of transit observations.
	18		57	13·2	Mean of transit observations.
	20		57	01·1	Mean of 10 transit observations.
	21		56	20·6	Mean of sextant observations.
Adopted latitude	....	38	57	01·1	
	Sept. 18	119	58	15	By rate.
	18		56	30	First satellite of Jupiter.
	19		58	00	Third satellite of Jupiter.
	20		58	48	Lunar transit, imperfect.
Adopted longitude	....	119	58	08·2	

Accompanying the report the following maps were mentioned:

(1) A topographic map of the country embraced in the survey, showing the boundary line between the State of California and the Territory of Utah from the

intersection of the one hundred and twentieth meridian and thirty-ninth parallel, as far as surveyed, on a scale of 2 miles to the inch.

(2) Map of the lines of the triangulation.

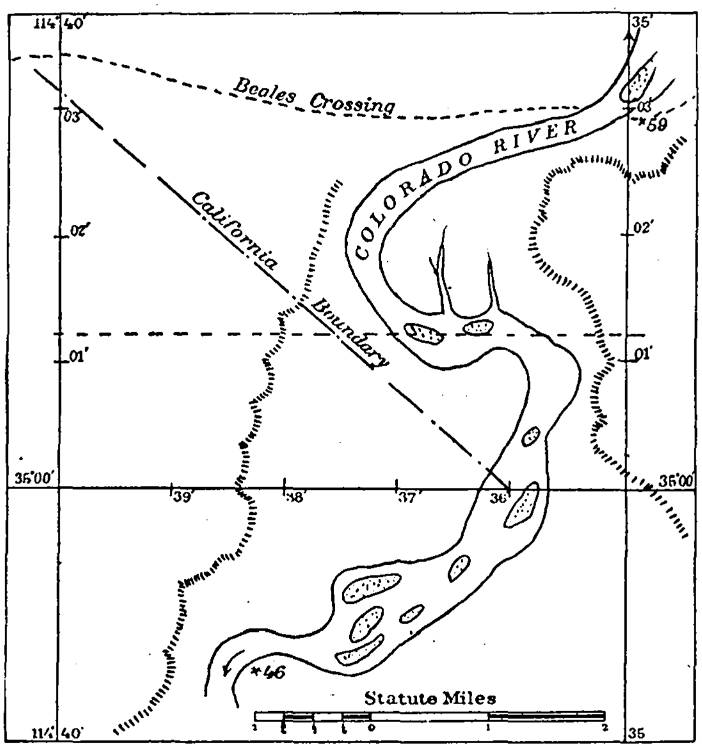
(3) Section showing the profiles of the old Carson and Johnson roads, etc. None of these maps could be found.

C. LIEUT. JOSEPH C. IVES, 1858 AND 1861.

1. COLORADO RIVER EXPLORATION, 1858.

In 1858 Lieut. Joseph C. Ives, United States topographical engineer, made a reconnaissance of the Colorado River, and a map of the expedition was published on a scale of 6 miles to the inch. That portion of the map near the thirty-fifth parallel was enlarged and is inserted to show the approximate shape and direction of the river at that time. A report of the expedition is found in House Executive Document No. 90, Thirty-sixth Congress, first session, Washington, 1861.

No. 1.



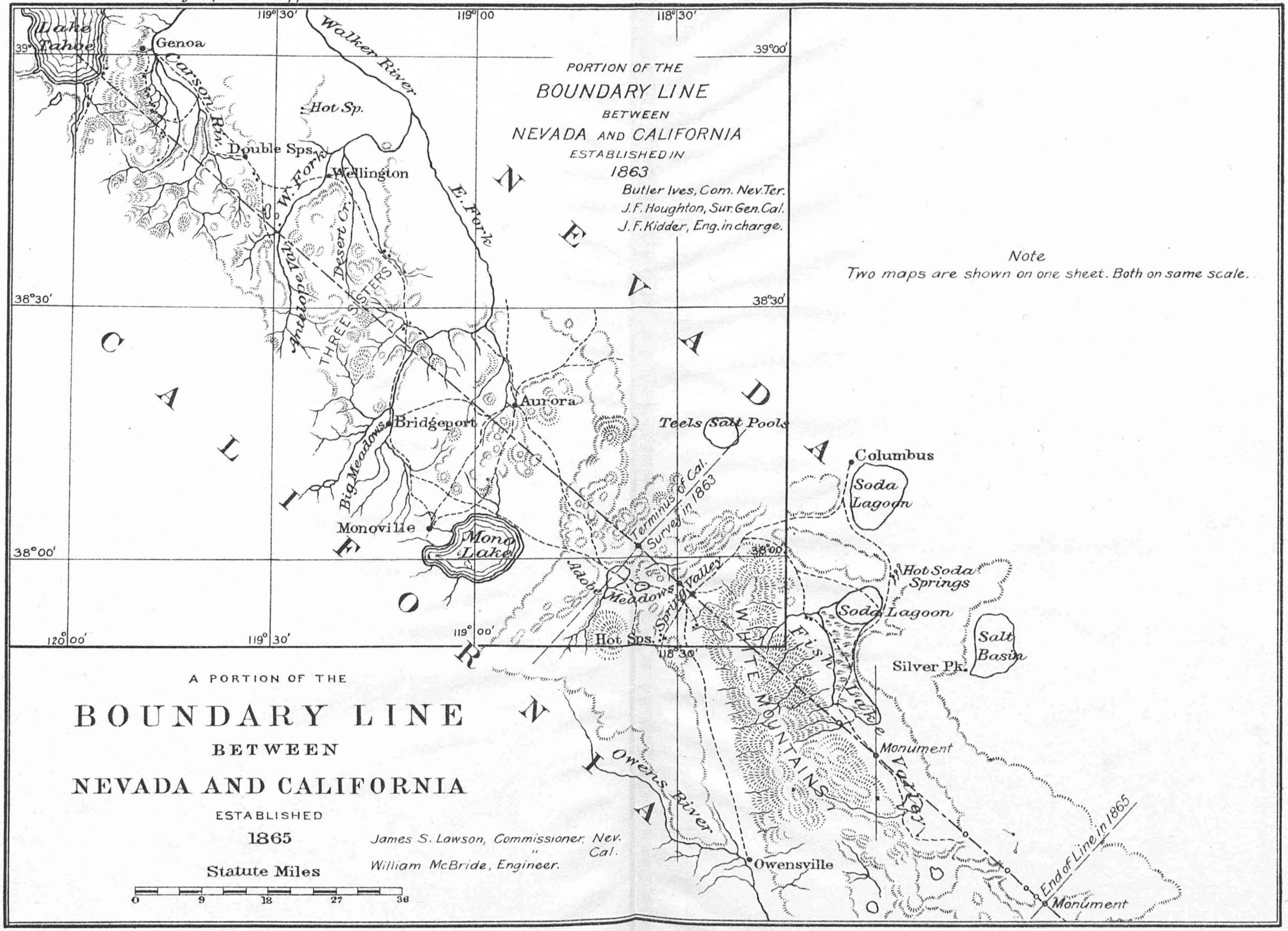
From Explorations of Lieut. Ives, 1858

Another sketch, headed "From Lieut. Ives's Topographical Notes, 1863?" (1861 probably), shows Ives's observatory, and the Colorado River, at latitude 35°, with longitude 114° 36′ drawn at the channel crossing. Very little could be learned about his Colorado River work in 1861. This sketch is on a scale of 1 inch to the mile.

Lieut. J. C. Ives did no work on the Colorado in 1863 because it was during the civil war, but he is sometimes confounded with Butler Ives, commissioner from Nevada in 1863, for tracing the boundary southeast from Lake Tahoe in connection with Surveyor-General J. F. Houghton, of California.

2. LONGITUDE AND LATITUDE, SOUTH END OF LAKE TAHOE.

In 1861, Lieut. Joseph C. Ives, under direction of the Department of the Interior, made observations for latitude and longitude at the south end of Lake Tahoe to locate the northwest terminus of the oblique boundary of California. These observations were completed and he reported to the Secretary of the Interior under date of August 30,



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

1861, that the field astronomic duty was completed, and it only remained after the computations were made to run the line, which any surveyor could accomplish. Finally, on the 11th September, 1861, Lieutenant Ives, pursuant to instructions from the Department, turned over to the United States surveyor-general's office (California) the field notes, maps, reports, and computations of the astronomic observations which had been taken. (See Annual Report General Land Office, 1865, pp. 13, 14.) These field notes, maps, etc., were in the office of the surveyor-general of California (E. F. Beale) in 1863, and were examined by Mr. J. F. Houghton.

I have no evidence as to when the work on the Colorado River at latitude 35° was executed, but presumably in 1861, from reference to it by Mr. Houghton. No one knows what became of these maps, etc., of Lieutenant Ives; letters were written to Mr. Houghton, who examined them personally, to the United States surveyors-general of California and of Nevada; to the surveyors-general of the same States, and to the General Land Office, Washington, D. C., and finally Assitant F. W. Edmonds searched the offices of the surveyors-general in California and Nevada in vain.

Although the legislature of Nevada authorized the governor to have the boundary between California and Nevada established from Lake Bigler (Tahoe) as far southeast as Esmeralda, by act approved November 29, 1861, the following letter from the surveyor-general of Nevada shows that nothing was done until 1863:

CARSON CITY, NEV., *June 21, 1900.*

Mr. C. H. SINCLAIR,

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

DEAR SIR: In reply to your inquiry of the 16th instant, I beg to state that the Territorial legislature of Nevada, by act approved November 29, 1861, authorized the governor "to have the boundary line between the State of California and the Territory of Nevada surveyed and established from Lake Bigler to below or south of Esmeralda, at as early a day as practicable." One thousand dollars were appropriated for the purpose, but the act provided "that if the State of California shall establish the boundary line before the 1st day of March, 1862, then this act shall be null and void."

The records do not show that any action was taken by the Territory of Nevada or State of California until 1863, when the line was surveyed from Lake Bigler to Mount Diablo base line in Esmeralda County, Nev.; Butler Ives, commissioner for Nevada; J. F. Houghton, surveyor-general of California; J. F. Kidder, engineer in charge. This is the first survey of the boundary line south of Lake Bigler or Tahoe of which I can find any record.

* * * No field work was done under the act of 1861 in 1861, nor, so far as I can ascertain, before 1863.

Respectfully, yours,

E. D. KELLEY,

Surveyor-General and State Land Register.

D. J. F. HOUGHTON AND BUTLER IVES, 1863.

1. LONGITUDE AND LATITUDE, SOUTH END OF LAKE TAHOE.

The Report Surveyor-General California, 1863, contains the following statement:

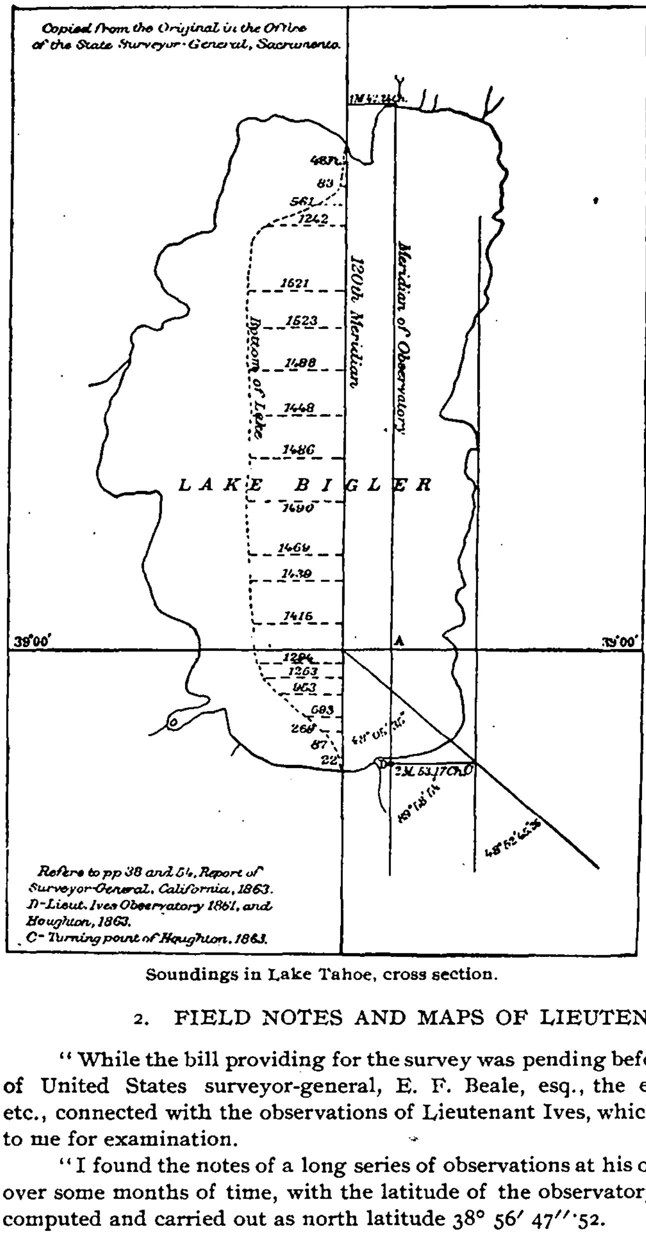
"By an act of the legislature approved April 27, 1863,* it was made the duty of the surveyor-general of the State to define and establish the entire eastern boundary line of the State by running, measuring, and marking a transit line between the point of intersection of the thirty-ninth parallel of north latitude with the one hundred and twentieth degree of longitude west from Greenwich, near Lake Tahoe and the point where the thirty-fifth degree crosses the Colorado River, as the said points were established by Lieutenant Ives, chief astronomer of the United States Boundary Commission, appointed for that purpose." * * *

Butler Ives, esq., a United States surveyor of experience, was appointed by the acting governor of Nevada, Orion Clemens, as commissioner. Twenty-five thousand dollars were appropriated for running, not only the oblique boundary line to the Colorado, but also that portion northward along the one hundred and twentieth meridian from the thirty-ninth parallel to the Oregon boundary, latitude 42°. Mr. John F. Kidder, an engineer and surveyor of large experience, was engaged as engineer in chief, and Mr. James S. Lawson as compassman and topographer.

The report further states:

"Immediately upon the passage of the act above referred to, appreciating the importance of having the position of the initial point at Lake Tahoe definitely determined as a starting point and anxious to avoid the delay and expense of establishing an observatory to determine longitude, I took the latitude and longitude of Lieutenant Ives's observatory at the south end of Lake Tahoe as determined by himself, making, myself, test observations for latitude, which agreed to seconds with those made by him. As no report has been published of his field work and computations, and as some doubt has been expressed as to whether Lieutenant Ives ever reduced his observations so as to determine the initial points at the lake and on the Colorado, I will here furnish the evidence I have been able to obtain, that they were so determined by himself. (Report Surveyor-General California, 1863, p.36.)"

No. 3.



Soundings in Lake Tahoe, cross section.

2. FIELD NOTES AND MAPS OF LIEUTENANT IVES EXAMINED.

"While the bill providing for the survey was pending before the legislature, through the courtesy of United States surveyor-general, E. F. Beale, esq., the entire field notes, topographical maps, etc., connected with the observations of Lieutenant Ives, which were in his possession, were delivered to me for examination.

"I found the notes of a long series of observations at his observatory near Lake Tahoe, extending over some months of time, with the latitude of the observatory, taken by sextant and sidereal clock, computed and carried out as north latitude 38° 56′ 47″·52.

"Observations were made by myself, and the latitude computed, which differed only in seconds from that of Lieutenant Ives, and his results were used in the survey as correct.

"A careful search for his reduction of his observations for longitude resulted * * * in a failure to find them among his notes. (Same, p. 36.)"

In 1861 the Territorial legislature of Nevada authorized the governor to have the boundary line run from Lake Tahoe as far southeast as Esmeralda to determine the position of Aurora with reference to the boundary line.

3. LONGITUDE RESULTS OF LIEUTENANT IVES AT LAKE TAHOE AND THE COLORADO RIVER.

"In order to establish the initial point at Lake Tahoe, which was necessary before the work could proceed, Mr. Kidder placed himself in communication with Lieutenant Ives, then at work at his observatory in Lake Valley, who in his answer, dated August 28, 1861, says: "I trust our observations this week will give us our longitude with reference to San Francisco." And fourteen days later he telegraphed from San Francisco, September 11, 1861, to Mr. Kidder as follows: "Approximate longitude of station is seven hours fifty-nine minutes and fifty-three seconds west of Greenwich," all of which correspondence and telegrams are in my possession, on file in this office.

* * * * * * *

"The initial point on the Colorado River is by act of Congress admitting the State of California into the Union where the thirty-fifth parallel crosses the Colorado, which is marked in *three different places upon the topographical field books and maps accompanying Lieutenant Ives's survey as 114° 36′* west from Greenwich, at which place a monument was placed, distant about 2 miles from Fort Mojave. (Report Surveyor-General California, 1863, p. 36.)"

The azimuth of the line was computed at the Office of the United States Coast Survey.

The oblique line was run 102 miles and 46 chains southeast from Lake Tahoe beyond Aurora nearly to the White Mountains, where Indians and the approach of winter put a stop to the field work. No work was executed at the Colorado River end of the line, as it was evidently the intention to trace the line through from Lake Tahoe to the terminus located by Lieutenant Ives on the Colorado, and correct back.

A copy of the map showing this survey on a scale of 6 miles to the inch is in the office of the surveyor-general of Nevada, at Carson City. A tracing was made for the United States Coast and Geodetic Survey, where it is on file. This map is shown here, on a reduced scale, on the same sheet with the map of the continuation of the boundary survey, for a distance of 73 miles 11·92 chains, in 1865, by William McBride, engineer, and James S. Lawson, commissioner, of Nevada.

INSTRUMENTS.

For astronomic work an alt-azimuth by Parkinson and Frodsham, of London, with a 12-inch horizontal circle reading to ten seconds and 16-inch vertical circle reading to five seconds, telescope 4 feet focal length, was used. This is probably the instrument used by Goddard in 1855. For ranging out the line a straight-line transit by Temple, of Boston, a model of superior workmanship, was secured.

4. SOUNDINGS IN LAKE TAHOE ALONG THE ONE HUNDRED AND TWENTIETH MERIDIAN.

The average depth of 21 soundings taken on the one hundred and twentieth meridian is 934·24 feet; that of 12 soundings extending over a distance of 12 consecutive miles, exclusive of 3 on the north and 6 on the south shore, is 1 424·6 feet. The greatest depth reached was 1 523 feet. The deep soundings invariably show the bottom to be composed of fine, impalpable mud, except one made some 3 miles from the north shore, where the lead was bruised upon a rocky bottom at a depth of 1 242 feet. The shoal soundings gave a bottom of sand, or sand, gravel, and bowlders. Its waters are transparent, and abound in the finest quality of lake trout. Its outlet is the Truckee River, which at the point where it debouches from the lake has a capacity equal to a current 4 feet deep by 60 in width moving at the rate of 3 miles per hour. It is fed by numerous streams from the surrounding mountains, many of whose highest peaks are covered with perpetual snow. Its shores for the greater part are bold and rocky, alternating with sand and shingle beaches in the more sheltered places. (Report Surveyor-General California, 1863, p. 54.)

E. JAMES S. LAWSON. 1865.

This line was a prolongation of the line run by Houghton and Ives in 1863. James S. Lawson was appointed commissioner by the governor of Nevada under the act of February 7, 1865, amended March 10, 1865, these being the dates of approval by the legislature. The commissioner was directed to survey and establish the western boundary line of the State of Nevada for a distance of 70 miles from the point where the same had been suspended by the joint commission from the State of California and the Territory of Nevada in 1863. He says:

"I engaged the services of William McBride, a thorough and competent surveyor and engineer, at the maximum rate allowed, to wit, $45 per mile. * * * On the 1st of May we reached the terminus of the California survey, which was readily found, as I had been one of the party comprising that expedition in 1863, and had been upon the ground again in 1864 to aid in further securing the points of the line at this place.

"The monuments and marks were undisturbed, and no difficulty was found in determining the course of the line from the center points established beneath the mounds, as well as from the original stakes, which were still standing, and which were found to coincide with the holes drilled in the rocks.

"From these center points the line was continued with a new and carefully adjusted instrument of superior make by reversals at each setting upon fore and back sights. * * *

"No new observations were necessary in extending the line from the end of the California survey, as those above referred to are believed to be correct, and the fullest assurance is felt of the accuracy of that work in the field; hence it was deemed advisable to extend the boundary from the points already established. * * *

"On the 1st of June we had reached the end of the seventieth mile, the limit of the work by the provision of the act authorizing the survey. This point being difficult of access as well as description, I deemed it advisable to continue the line to a more favorable point, which was found upon an isolated ridge of rocks at the head of a valley extending south and eastward at a distance of 3 miles 11·92 chains in advance, and which, being marked by hole in rock and mound of stone, may readily be found from the map and field notes accompanying the report.

"Substantial monuments and marks were made at the most conspicuous points, sufficient to define the course of the line and perpetuate it for a long time and until cut-stone or other monuments shall be required."

A reproduction of this map, reduced from a tracing, will be found among the illustrations of this report. This map is on the same sheet with the Houghton and Ives survey of 1863, being a prolongation of that survey to the southeast. The original, which is in the surveyor-general's office, was on a scale of 6 miles to the inch. Three thousand four hundred and fifty dollars were appropriated to meet the expenses of this survey.

F. EXAMINATION OF ARCHIVES IN CALIFORNIA AND NEVADA BY ASSISTANT F. W. EDMONDS, FOR MATERIAL BEARING ON EARLY SURVEYS.

SAN FRANCISCO, CAL., *May 3, 1900.*

Dr. HENRY S. PRITCHETT,

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

SIR: I have the honor to submit the following report upon the work assigned to me by your instructions dated March 24, 1900, to gather data bearing upon the early surveys of the eastern boundary of California, from Lake Tahoe to the Colorado River:

1. SEARCH FOR NOTES AND MAPS OF LIEUTENANT IVES IN SAN FRANCISCO.

On Monday, April 2, I called upon the United States surveyor-general at San Francisco, who immediately ordered a search made through the files of his office for maps and field notes, etc. Nothing was found there but the records of the Von Schmidt survey of 1872–73. While this search was going on I examined the letter books of United States Surveyor-General E. F. Beale, who held office in 1863, and found the following letter addressed to Surveyor-General Houghton, dated March 23, 1863:

"Yours of the 20th instant duly at hand. I have made careful examination of books and sketches left in my charge by Lieutenant Ives, late of the boundary commission. I find upon his topographical sketches that the initial point is set down as 114° 36′ west of Greenwich."

"I can find no data referring to Lake Bigler, of the intersection of the thirty-ninth parallel north latitude and the one hundred and twentieth parallel west longitude from Greenwich."

The foregoing letter is doubtless the basis of the following statement, quoted from Surveyor General Houghton's Report for 1863, p. 36:

"A careful search for his observations for longitude resulted * * * in a failure to find them among his notes."

a. Telegraph line from San Francisco to Placerville, Lake Valley, Genoa, and Carson, in 1859 or 1860.

I have taken considerable pains to settle, if possible, the question of Lieutenant Ives's longitude observations in Lake Valley, and have corresponded with a number of persons and interviewed others. I here submit the result of my inquiries.

In regard to the existence of a telegraph line at that time there is no doubt. I quote the following extracts from letters written to me by Mr. James Gamble, who had charge of the lines of the old California State Telegraph Company:

"I can not give you the exact date of the completion of the first line connecting San Francisco with Carson City without referring to my scrapbook, which is in my desk at San Francisco, but will do so the first time I am in San Francisco if desired. It was about 1859 or 1860. I think that a company known as the Humboldt Telegraph Company completed a line between Placerville and Carson City, Virginia, and Gold Hill. At Placerville this line connected with the California State Telegraph Company of which I was the general manager. The Humboldt and other lines in California were consolidated with the California State Company in 1860, and all placed under my management, when the Overland Telegraph Company was organized to build the line from Virginia City to Salt Lake, there to connect with the Western Union, which was then building west. This line was built under my direction in 1861 and completed on the 24th day of October of that year, giving California direct communication with the eastern States. * * *

"The telegraph station in 1861 was at Yank's, on the old stage road, and from there the wire *followed the road to Genoa.* I am under the impression that Ives had a telegraph connection with his camp, but cannot locate it. * * *

"Yank, or Clements, his proper name, had his station on the old stage road some distance south of the lake. He afterwards rented or purchased Tallac, where he kept a place for tourists. * * * Mr. Clements is not living."

The following is extracted from two letters of Mr. Frank Bell, one of Mr. Gamble's old assistants, who had personal charge of the mountain wires:

"I took charge of the lines in 1862. Yank's station was about 6 miles from lake, the shortest route, and about 7 miles from the Lake House. The Lake House was situated directly on the lake, our wire passing it. *We had an office at Lake House.* Goddard's station was 1½ miles east of Lake House or 1 mile west of Friday's station, but at the time the first survey was made Captain Lapham kept this station; Goddard did not keep it for some years afterward. It is only a few hundred yards from the lake. Lake House was nearest point the wire ran to the lake." * * *

b. Telegraphic longitude by Lieutenant Ives, 1861.

"At time you refer to (August and September, 1861) I was in Los Angeles. My recollection is that this matter was talked over after my return. I have an impression that an attempt was made to use the telegraph which had been completed shortly previous, but not being very well equipped with repeaters, was not very successful."

Mr. George Senf was stationed at Sacramento at the time of the Ives survey, and he tells me that he *remembers* Lieutenant Ives and the fact of *his using the telegraph line for his longitude work in Lake Valley*, but he does not recall whether the results were successful. He is now employed in the Western Union Telegraph office at San Francisco.

On September 11, 1861, Lieutenant Ives telegraphed Mr. Kidder the "approximate longitude" of his station, and as he had made use of the wire for three weeks from San Francisco it would seem to indicate that some difficulty was experienced in successfully obtaining the exchange with San Francisco; probably, as Mr. Bell says, due to the lack of a sufficient number of repeaters along the line.

2. SEARCH FOR NOTES AND MAPS IN SACRAMENTO.

At Sacramento I made a very careful search in the surveyor-general's office for the maps and field notes of Lieutenant Ives, personally opening and examining all the rolls of old maps in the office. I was given free access to the files, but could find nothing bearing upon his work. Professor Davidson in writing to me said:

"The Ives story I long since consigned to the unattainable. His notes were not in the public office, nor were they in the private papers of General Houghton, because he had them all looked over. I was well acquainted with the keeper of the archives in San Francisco and they were not findable."

a. Goddard map (of 1855) lost.

Neither the Goddard nor the Houghton and Kidder maps could be found in the Sacramento office. Upon returning to San Francisco I called on Mr. Goddard at his office, and he told me that his map was not turned over by him, owing to the fact that he was not paid to complete it, but that later it was purchased by Lieutenant Wheeler for the sum of $100; it finally fell into the hands of the State university, where it was lost track of, and when Mr. Goddard himself sought to recover it the map could not be found.

b. Goddard monuments on oblique boundary.

It (the Goddard map) was on a scale of 2 miles to the inch, and showed the position of *his astronomic station at the lake*, the *monument* marking the line there, and the *two monuments* which he set at the terminus of the line near the crossing of the road, about

15 miles southeast of the lake. One of these monuments was placed close to the road and the other on the summit of a hill about 200 feet above the surrounding valley. No intermediate marks were established.

Mr. Goddard spoke of some of the hardships he encountered while making his survey, one of the most serious of which was the hostile Indians, who killed some of his animals.

In his longitude work at the lake he used two chronometers, which he says varied considerably in their rates, due to transportation over the mountains. His longitude depended on the mean of several observations made of the eclipses of the satellites of Jupiter. About this time some of his party left him, and he remained with one man for some time to obtain a "lunar." The weather was cloudy, however, and he had to leave, destroying much of his equipment to prevent it from falling into the hands of the Indians.

When his survey was made the Territory of Utah wanted to establish a court at the Mormon town of Genoa, and it was made a part of his duty to determine on which side of the line the town was situated.

In the surveyor-general's office at Sacramento I discovered three maps rolled together, marked on the outside in pencil "Higley's East Boundary Survey." One of these I traced and refer to as Exhibit A.* It shows topography along the shore of the lake, while the one adjoining this on the north extends a distance of 35 miles to Sierra Valley and shows the topography on either side of the one hundred and twentieth meridian for a width of 4 or 5 miles. The third sheet extends to the westward of Sierra Valley about 25 miles to Jackson, on the Yuba River. No one in the office knew anything about these maps, and they bear no title except the pencil inscription on the back. Higley was surveyor-general of California from 1858 to 1861, to near the end of the year. He did not personally go into the field. The shore line on the west side of the lake is in pencil, as well as a portion of the oblique line, and I have copied the ink and pencil portions just as they were on the original.

Later, in Carson City, I came across the following, which I believe refers to this map:

"LAWS OF THE TERRITORY OF NEVADA, PASSED AT THE FIRST REGULAR SESSION OF THE LEGISLATIVE ASSEMBLY, WHICH WAS HELD AT CARSON CITY, OCTOBER AND NOVEMBER, 1861.

CHAP. XLIII.—*An Act to audit the claim of John F. Kidder for surveying the boundary line between California and the Territory of Nevada. (Approved November 28, 1861.)*

Be it enacted, by the Governor and Legislative assembly of the Territory of Nevada, as follows:

SECTION 1. That the account and claim of John F. Kidder, deputy United States surveyor, for making survey of the boundary line between California and the Territory of Nevada, from the initial point at Lake Bigler to Honey Lake, be, and the same is, hereby audited and allowed as indebtedness against the Territory.

SECTION 2. It shall be the duty of the Territorial auditor, as soon as said officer shall have been elected or appointed, to issue a warrant, payable out of the revenue, to said John F. Kidder, for the amount of five hundred and fifty dollars ($550) of his claim. The said warrant shall draw interest from the time of its issuance until paid, at the rate of ten per centum per annum.

SECTION 3. It shall be the duty of the Territorial treasurer to pay said warrant out of any moneys not otherwise appropriated, collected into the treasury of the Territory".

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*This tracing is at the United States Coast and Geodetic Survey Office, Washington, D. C. It is not of special interest and is not shown here.

About this time Mr. Kidder was chief clerk in the United States surveyor-general's office for Nevada Territory, and an act of the Territorial legislature approved November, 1861, provided for the running of the line to below Esmeralda, provided the same was not run by the State of California before the 1st day of March, 1862.

I feel confident that this map is the work of Mr. Kidder, the more especially as I am informed there was no other work to the north of the lake as early as 1861.

Mr. Kidder is now in too critical a condition to be communicated with.

* * * * * * *

3. SEARCH FOR NOTES AND MAPS IN RENO AND CARSON CITY.

On April 12 I arrived at Reno, Nev., where I called upon the United States surveyor-general, but found nothing pertaining to the boundary except the map and field notes of the Von Schmidt survey.

a. Maps of 1863 and 1865.

The following morning I went to Carson City, and there called upon the surveyor-general of the State. I was much pleased to find the maps of Houghton and Kidder of 1863, showing the entire survey from the lake northward to the Oregon line, and from the lake southeastward to the White Mountains, where the survey terminated. * * *

In addition to the above I found a map of the same scale (6 miles to the inch) by James S. Lawson, in 1865, commissioner for the State of Nevada to survey and establish the western boundary of the State for a distance of 70 miles from the terminus of the survey of 1863.

* * * * * * *

Very respectfully submitted.

FRANK W. EDMONDS,
Assistant, United States Coast and Geodetic Survey.

G. DANIEL G. MAJOR, 1868.—ONE HUNDRED AND TWENTIETH MERIDIAN.

The following extracts from the field notes of Daniel G. Major, on the California and Oregon boundary, were obtained from the United States Land Office, Washington, D. C.:

Latitude of observatory established near Camp Bidwell	41° 51′ 34″·4
Thence north to forty-second parallel	8′ 25″·6
8′ 25″·6=9 miles 55 chains.	
Longitude of observatory established near Camp Bidwell	120° 05′ 47″·55
Thence east to California-Nevada boundary	5′ 47″·55
5′ 47″·55=5 miles 35 yards.	

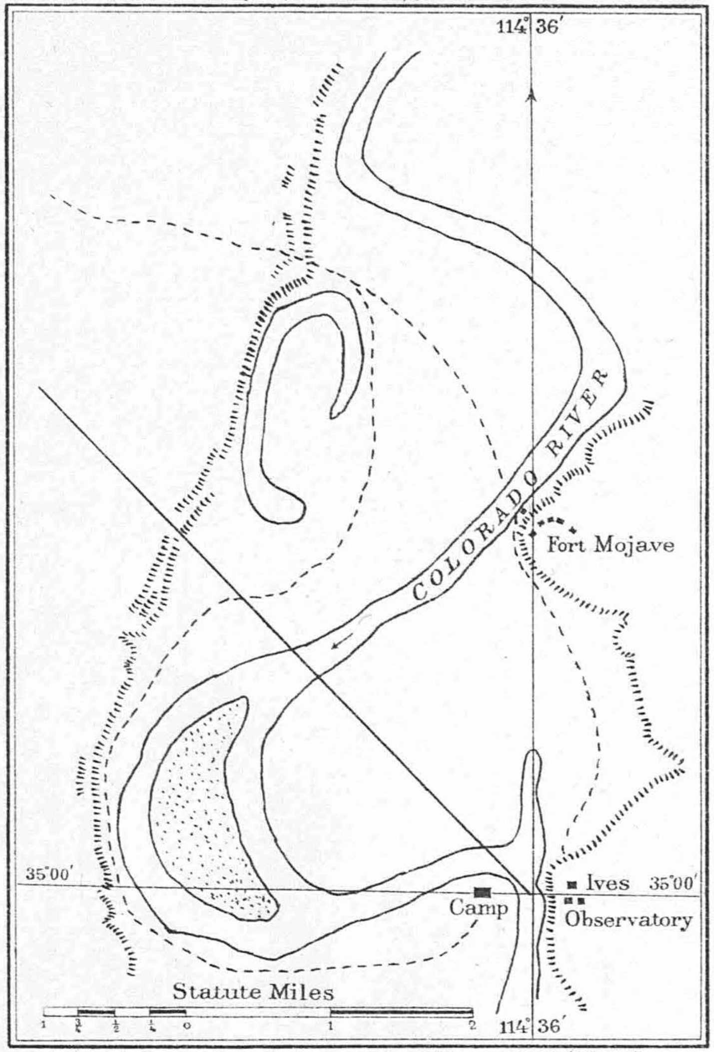
* * * * * * *

Thence measured east 38·38 chs. and reached the intersection of the 120° meridian of west longitude with 42nd parallel of north latitude the corner of the boundary of California and Nevada on the southern boundary line of the State of Oregon.

Established, therefore, at a point 4 m. 78·38 chs. E. and 9 m. 56 chs. north of the observatory at Camp Bidwell, the initial point and monument at the intersection of the 120th meridian with the 42nd parallel on southern boundary of Oregon, situated on the north side of a long rocky hill 13 chs. north of a station known as "12 Mile Creek" (from Bidwell), also 10 chs. north of a new military road from Camp Bidwell and Surprise Valley to Fort Warner.

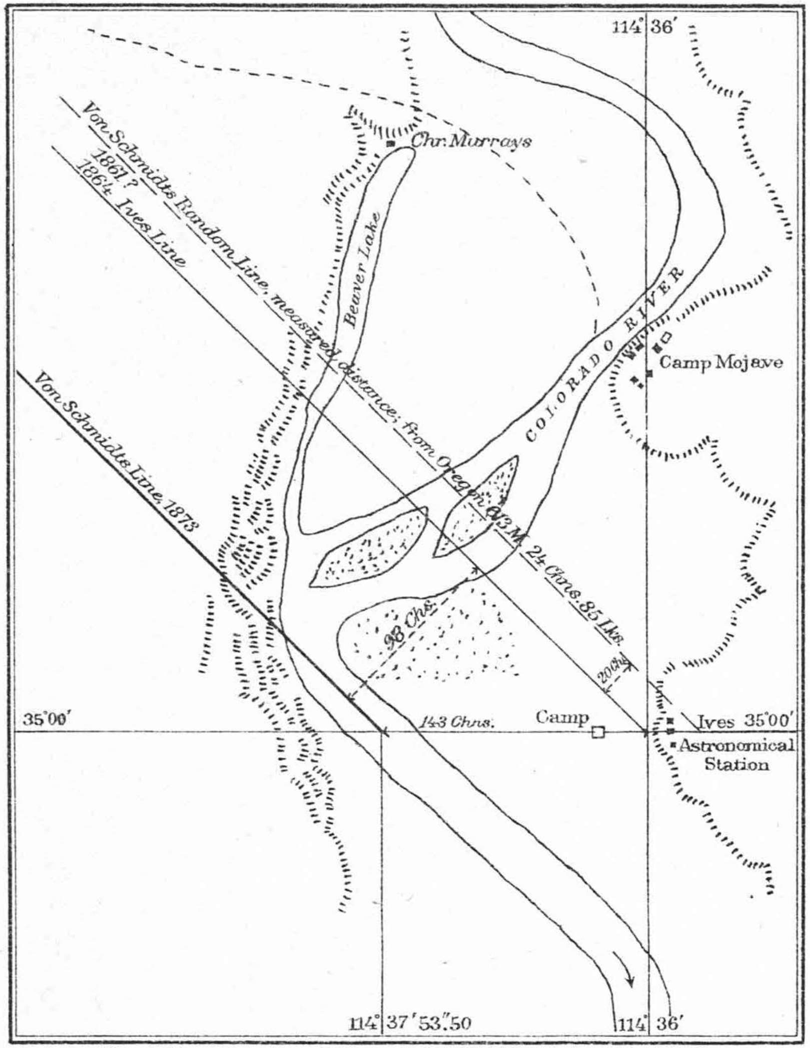
On night of Sept. 11th, having transit instrument over the initial point of boundary, observed Polaris at greatest eastern elongation and found that the mean of several determinations marked off

No. 4



From Lieut. Ives Topographical Notes, 1863 (1861?)

No. 5



From Topographical Notes of A.W Von Schmidt, 1873

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

on the earth's surface agreed substantially with line as run by observations at observatory, Camp Bidwell. * * *

Made deep excavation near rocky ledge; deposited three large black bottles (glass), also charred cottonwood stake 30 inches long and 6 inches circumference; built about it a monument of large stones, well shapen, circular, 9 ft. diameter, 7 ft. high, 4 ft. diameter at top, surmounted by a dressed sandstone 20″ x 20″ x 10″, marked as follows in deeply cut characters, viz: On north face, "Oregon;" on south face, "Long: 120°," "Lat: 42°;" on east face, "Nevada;" on west, "California;" on top, "D. G. Major, U. S. Astr., 1868."

Distance to large rock 4 ft. x 4 ft. 30 links, direction S. W. to large rock 3 ft. x 3 ft., dist. 22 links, direction N. Planted a juniper post 6 ft. long, 8 inches square at top, marked on S. E. "N," on S. W. "C," on N. W. face "O," on N. E. face "1868, 120° L, 42° L." Blazed and marked many trees in creek bottom."

This extract from the field notes does not describe the method of determining the latitude and the longitude, nor the instruments used, except a mention of transit. It may be assumed that the longitude was not telegraphic, because in 1872 Von Schmidt found, by prolonging the one hundred and twentieth meridian from Verdi northward to the forty-second latitude, that the northeast angle or corner of D. G. Major was 3 miles too far west. The Verdi longitude was determined by telegraph, from San Francisco.

The notes of D. G. Major state that at the observatory established at Camp Bidwell—

"A lengthy series of astronomical, magnetic, and barometric observations were made, extending into three lunations, for the purpose of ascertaining the intersection of the one hundred and twentieth meridian with the forty-second parallel, a geographical position of much importance, it being the initial point of the California-Nevada line on the Oregon boundary.

Over three thousand observations were made at this observatory, and the results deduced after a rigorous discussion were reduced to Camp Bidwell, and are perpetuated on a stone monument. * * *

On the cap stone surmounting the monument I engraved the latitude, longitude, magnetic variation, and altitude above mean sea level; also the hour lines for a sun dial."

Col. Robert S. Williamson, United States Engineer Corps, about 1868 set a monument near Verdi, supposed to mark the one hundred and twentieth meridian.

H. THE ALEXEY W. VON SCHMIDT LINE, 1872–1873.

On July 20, 1872, Willis Drummond, Commissioner of the General Land Office, entered into contract with Allexey W. von Schmidt to run the eastern boundary of California, as defined by article 12 of the constitution of said State and confirmed by act of Congress entitled "An act for the admission of the State of California into the Union," approved September 9, 1850 (Stat. L., Vol. IX, p. 452). The consideration was $41 200, and bond was given for $82 400. He was required to make all of the determinations of latitude, longitude, and azimuth in his own proper person. For determining longitude on the line of the Central Pacific Railroad he was permitted to use the telegraph either with Salt Lake City or San Francisco. The northeast corner of California, as established by D. G. Major, was made by the Department the initial point of the survey, and the numbering of the successive miles was to begin from the Oregon boundary, or forty-second parallel of latitude.

In his field notes Von Schmidt states that he established a point at Crystal Peak, near Verdi, Nev., by telegraph, as the one hundred and twentieth degree of longitude west from Greenwich, and traced that meridian north to the forty-second degree of latitude, the south boundary of Oregon, and established the northeast corner of

California more than 3 miles to the east of the point located as such northeast corner by Daniel G. Major in 1868. He states:

From Major's corner I therefore ran east * * * 258·73 chs., at which point I established a large stone monument for the northeast corner of the State of California * * * . The monument consists of a post 8 ft. long and 8 inches square, marked on the north side "O Lat. 42 deg.;" east side, "Nevada;" south side, "1872, Long. 120 deg.;" west side, "California." This post is solidly built into a stone mound 6½ ft. high with 8 ft. base and projects three feet from the mound. * * * At the half height of the mound four large stones are inserted, the one facing to the south marked "1872 A. W. von Schmidt, Long. 120°, Lat. 42°;" one facing west marked "C;" one facing to the north marked "O;" and the other, facing to the east, marked "N."

From the longitude established at Verdi the one hundred and twentieth meridian was carried to the north shore of Lake Tahoe. In 1873 he began field work on the north shore of Lake Tahoe, set up two signal poles for a range on the one hundred and twentieth meridian, and noted where the prolongation of this meridian struck the mountains and a snow patch on the hills south of Lake Tahoe; then, having procured the steamer *Truckee*, on a calm day he went across the lake, keeping in line by means of the range, and put up a flag at the point of landing. He states:

I next proceeded to take observations of Polaris * * * . Having laid off the true meridian, I proceeded to observe my fire signals and flag at the northerly end of the lake, and found that by moving my position at the south end of the lake two chains to the west from the flag set up at the point of landing I was on the true 120th meridian.

I continued these observations for three days and nights in succession, using flag signals by day and fire signals by night, until I became satisfied I was on the true meridian as brought down from Verdi, where it had been established by telegraph, namely, the 120th degree of longitude west from Greenwich.

1. LONGITUDE OF VERDI, ONE HUNDRED AND TWENTIETH MERIDIAN, 1872.

In 1872, at the request of another Department, the Superintendent of the United States Coast Survey directed Assistant George Davidson to determine the one hundred and twentieth meridian at the crossing of the Central Pacific Railroad. This was done by the interchange of telegraphic longitude signals at Washington square, San Francisco, the old Coast Survey station of 1869, and a station established to the east of Verdi by Mr. S. R. Throckmorton, Aid, United States Coast Survey. Six nights' exchanges of signals were obtained, and personal equation was determined on five nights by the observers. The one hundred and twentieth meridian was located by triangulating a distance of something like 2 miles west from the astronomic station. This work was tested in 1889, when the primary longitude of the United States reached Verdi, and the difference was less than 3 feet.

In the report of the surveyor-general of California for 1890, page 15, the following statement is made by Grunsky and Minto:

The *initial point of the Von Schmidt survey was the observatory station occupied by Prof. George Davidson at Verdi in 1872*. From this point the position of the 120th degree of longitude west from Greenwich was established, and thence the meridian line was extended northward to the 42nd degree of north latitude and southward to Lake Bigler. The accuracy of the work along this part of the boundary of the State has never before been brought into question; but the results of our work, as hereinafter shown, indicate that, although the point near Verdi was correctly established, the line marked by monuments as the boundary is 1 609 ft. too far west at the northern shore of the lake.

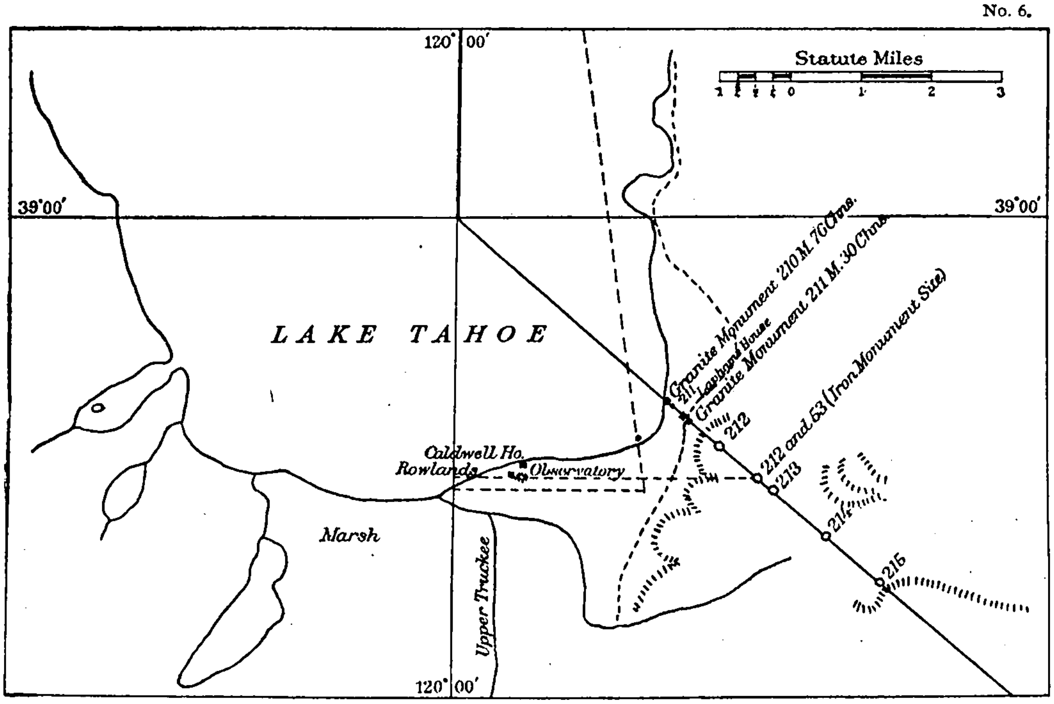
Finding the shore near the one hundred and twentieth meridian unfit for instrumental work, Von Schmidt ran east 77·55 chains on a course N. 89° 58′ 30″ E.; thence north 13·25 chains, where he set up blocks and mounted the meridian telescope and zenith sector for both latitude and longitude observations. He made the latitude of this station 38° 56′ 45″ by observations on Polaris and the sun with sextant and zenith sector, and the longitude 119° 58′ 55″.

His azimuth line was calculated by using the intersection of 120° with 39° at Lake Tahoe and Lieutenant Ives's determination of the Colorado River end, longitude 114° 36′ 00″, latitude 35°. He then ran 454·77 chains on a course N. 89° 58′ 30″ E. from the one hundred and twentieth meridian in latitude 38° 56′ 45″, making the longitude of this point on the azimuth line 119° 55′ 13″·6. From this point he ran toward Lake Tahoe N. 48° 51′ 59″ W. 137·14 chains to the lake shore, which is calculated to be 317·63 chains from the "initial corner in Lake Tahoe."

2. MONUMENTS NEAR LAKE TAHOE.

At the lake shore he "set a cut-granite monument, 10½ inches square at the base, 8½ inches at the top, 6 feet long, 2 feet in the ground; marked same with cut letters

No. 6.



Von Schmidt. 1873

on the northwest side, 'O. 210 miles 76 chains 7 links;' SE. side, '1873;' NE. side, 'Nev.;' and SW. side, 'Cal.'" This stone was fully identified in 1893, and it may be plainly seen that "1873" was changed from "1863," showing that it was one of the monuments placed by Houghton and Ives in 1863.

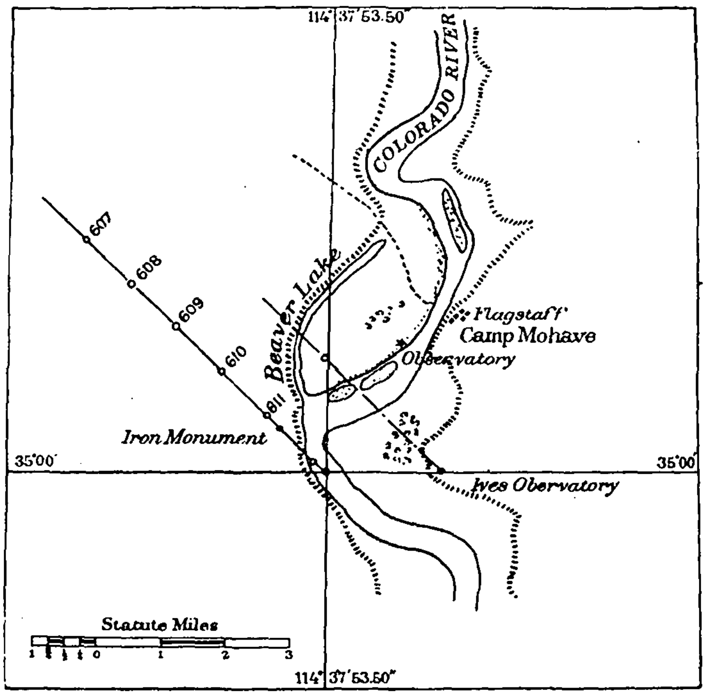
At 211 miles 30·02 chains he "set cut-stone granite monument on southeast side of road leading to Carson and Virginia City. Monument 10½ inches square at base, 8½ inches square at top, and 6 feet long, set 2 feet in the ground. Marked same, NW. side, 'O. 211 miles 30 chains;' NE. side, 'NEVADA;' SW. side, 'CALIFORNIA;' and SE. side, '1873.'" This stone has never been disturbed; 1873 was changed from 1863, as is plainly seen by inspection. The Coast and Geodetic Survey longitude pier of 1893 was placed 61½ feet south and 33 feet west of this monument.

The field notes continue:

> On 212 miles 53·21 chains to point on lat. 38° 56′ 45″ brought up from 120th degree of west longitude, where I perpetuated Observatory Station No. 1 by setting up cast-iron monument 8 ft. long, 12 inches square at base, 6 inches at top, 2 ft. in the ground, in rock mound 8 ft. diam., 4 ft. high. Raised letters cast on monument as follows: NW. side, "O. 212 miles 53 chains;" NE. side, "Nev.;" SW. side, "Cal.;" and SE. side, "Lat. 38° 56′ 45″, Long. 119° 55′ 13″, 1873." A. W. Von Schmidt, U. S. Astronomer and Surveyor.
>
> Also marked pine tree 8 inches diam. on NW. side, "O. 212 miles 53 chains 21 links;" NE side, "Nev.;" SW. side, "Cal.;" and SE. side, "1873."

This tree was found as described in 1893. It then appeared to be about 8 inches in diameter, but the marks proved its identity. The cast-iron monument, however, was never put in place, as there was no evidence of its existence. The point is very difficult to reach, from the steepness of the mountain side, and on account of the weight of such a monument it could never have been carried there without building a road, unless it had been made in sections so as to permit its being packed on animals or men.

No. 7.



Von Schmidt, 1873

No other monuments southeast of this iron monument were looked for in 1893.

3. COLORADO RIVER TERMINUS.

Transferring now to the Colorado end of the line, and referring to Von Schmidt's field notes:

> "*On 612th mile.*"—* * * 59 chains 87 links. To point selected for perpetuating Astronomical Station No. 5 on the Colorado River, and as witness to corner in same. Set cast-iron monument, 6 inches square at top, 12 inches square at base, 6 ft. long, 2 ft. in ground, with raised letters cast thereon, viz: N.W. side, "O. *611 miles 59 chains*;" N.E. side, "Nev.;" S.W. side, "Cal.;" S.E. side, "1873. A. W. von Schmidt, U. S. Astronomer and Surveyor." (Report Surveyor-General California. 1890.)

This monument was found in 1893. In 1899, after the prolongation of the Von Schmidt line to the Colorado River by means of several mileposts that were recovered, the iron monument was found to be about 150 meters northeast of the line. In proof of the fact that it no longer stands in the position originally intended for it, the following letter is taken from the Report of the Surveyor-General of California for 1890, p. 29:

FORT MOJAVE, ARIZ., *March 17, 1890.*

To Hon. SURVEYOR-GENERAL OF THE STATE OF NEVADA.

SIR: As the iron corner post between the State of Nevada and the State of California was washed over the bluff into the river by the last overflow of the Colorado River, and would surely have been lost in the next overflow, I went to work and hired ten Mojave Indians to get it out of the water and to dig a wagon road up to the bluff, and with my team hauled it up and reset it again still farther back from the river, so it is safe now from an overflow.

As I have been at considerable expense and trouble to replace it, you will please do me the favor to write and let me know how to proceed in getting pay from the State for my trouble, and oblige, yours, etc.,

W. H. SAILSBURY.

NOTE.—The above letter is contained in the report of the surveyor-general and State land register of the State of Nevada for the years 1877 and 1878.

J. E. JONES,
Surveyor-General and State Land Register.

"*On 613th mile.*"—29 chains 96 links to the intersection of north latitude 35° with middle of the channel of the Colorado River, at longitude 114° 37′ 53″·5 west from Greenwich.

From north latitude 39° to the center of the channel of the Colorado River, at latitude 35°, the total measured distance is 405 miles 26·52 chains; calculated distance is 405 miles 5·73 chains; difference 20·79 chains.

Total distance from Oregon to the Colorado River is 612 miles 24·96 chains.

Field notes connecting my random line with true line at the Colorado River.

I found my observatory station on random line on right bank of the Colorado River to be in latitude 35° 01′ 53″·43 north, longitude 114° 36′ 45″·45 west from Greenwich. * * *

From this point to reach latitude 35° north at a point due south the difference is 0° 01′ 53″·43= 173·75 chains. I therefore ran as follows (var. 14° 45′ E.):

West 17·46 chains; thence
South 20·28 chains to shore of Colorado River; thence
West 15·93 chains; thence
South 10·13 chains to river; thence
West 52·32 chains; thence
South 30·33 chains to river; thence
West 29·86 chains to slough; thence
34·55 chains across slough; thence
44·13 chains to bluff; thence
South 113·01 chains to 35th degree north latitude,

Making the total from observatory station on random line, southing, 173·75 chains; westing, 128·74 chains. At this point set a cottonwood post 6″ x 6″ x 6 ft. long, marked on north side, "1873"; south side, "Lat. 35°;" east side, "Von Schmidt, U. S. Surveyor." Made mound of earth and stone 6 ft. diameter.

* * * * * * *

I then ran east on 35th degree north latitude 23·00 chains to point selected for triangulating across the Colorado River, at which point I set a cottonwood post 7″ x 7″ square, 7 ft. long, marked on N. side, "1873"; south side, "Lat. 35°;" east side, "Von Schmidt, U. S. Survey."

Made mound of stone 8 ft. diameter, 3 ft. high, set stone 9″ x 18″ x 18″ on mound by side of post. Marked stone, "Lat. 35°, 1873," V. S. Also deposited stone in mound 5″ x 5″ x 12″, marked

"Lat. 35°." * * * This point and mound are on a prominent point, and can be seen from the river, and from all sides.

* * * * * * *

These two posts were well preserved in 1893 and 1899. The east 35° latitude post is the one used for azimuth, triangulation, and determination of latitude by observation with the zenith telescope in 1893.

When Lieut. J. C. Ives established the Colorado terminus in 1861, presumably, the river was on the eastern side of the alluvial bottom, and his longitude of the center of the river was given as 114° 36′ at the thirty-fifth degree of north latitude. In 1873, when Von Schmidt reached the Colorado River, the bed of the stream had changed to the west side of the bottom, making a difference of 143 chains along the thirty-fifth degree. Being in some doubt as to whether he should take the center of the river as he found it or adopt that of Lieutenant Ives, he referred the matter to the Commissioner of the Land Office, the Hon. Willis Drummond. A copy of both letters is here inserted:

SAN FRANCISCO, CAL., *October 9, 1873.*

HON. WILLIS DRUMMOND. *Washington, D. C.*

SIR: I beg most respectfully to make the following statement and to ask for instructions as to what your department considers the intersection of the thirty-fifth degree of north latitude and the middle of the channel of the Colorado River.

In striking my azimuth from the thirty-ninth degree of north latitude and one hundred and twentieth meridian to the thirty-fifth degree of north latitude and the middle of the channel of the Colorado at longitude 114° 36′, as given by Lieutenant Ives (assuming his point for a matter of convenience as a random line), I found on reaching the Colorado that while my line came within 20 chains of a perfect closure on Ives's old point the channel of the river was not there, but had materially changed.

To show the change in the bed of the river I forward you herewith two sketches, one showing the position of the river in 1863 (1861, probably), as per Lieutenant Ives's topographical sketches, and the other as I found it in 1873.

The Colorado at this point runs between two banks formed of gravel wash, distant from each other an average of 2 miles. Between these gravel banks it is all sand, and the main channel of the river changes through this sand bed at pleasure. The two sketches show its relative position on the thirty-fifth degree of latitude in 1863 (1861?) and 1873; the difference is 1 mile 63 chains. I was credibly informed by United States officers at Mohave that the river constantly changes its channel at the point indicated in the sketches. The camp sutler at Mohave also informed me that the river bed at this point had changed back and forth twice since his stay there—about twelve years. What I desire your opinion on is whether I shall recognize the intersection of the thirty-fifth degree of latitude with the old channel of the river as it was established by Lieutenant Ives, or the intersection of the thirty-fifth degree of latitude with the present channel as I now find it.

I have been led to make this inquiry of you for my guidance in the matter from the fact that the subject has been the cause of much adverse discussion among the surveyors and scientific men here, leaving me in great doubt as to my duty in the matter.

Very respectfully, yours,

A. W. VON SCHMIDT,
United States Surveyor and Astronomer, Eastern Boundary California.

(Land Office, vol. 4. California Record, p. 312.)

DEPARTMENT INTERIOR, GENERAL LAND OFFICE,
Washington, D. C., October 22, 1873.

A. W. VON SCHMIDT, Esq., *San Francisco, Cal.*

SIR: I have received your communication of the 9th instant asking what this office considers the intersection of the thirty-fifth degree of latitude with the middle of the channel of the Colorado

River, and whether you shall recognize the old channel of the river or the present channel as you now find it. * * *

In reply I have to say that, under the circumstances, in reference to the changes in the river channel at different times, and the fact that Lieutenant Ives's survey has never been returned to or recognized by the Department, your obvious duty will be to consider the intersection of the thirty-fifth degree of latitude with the middle of the channel of the river as you find it by your own determination and survey. * * *

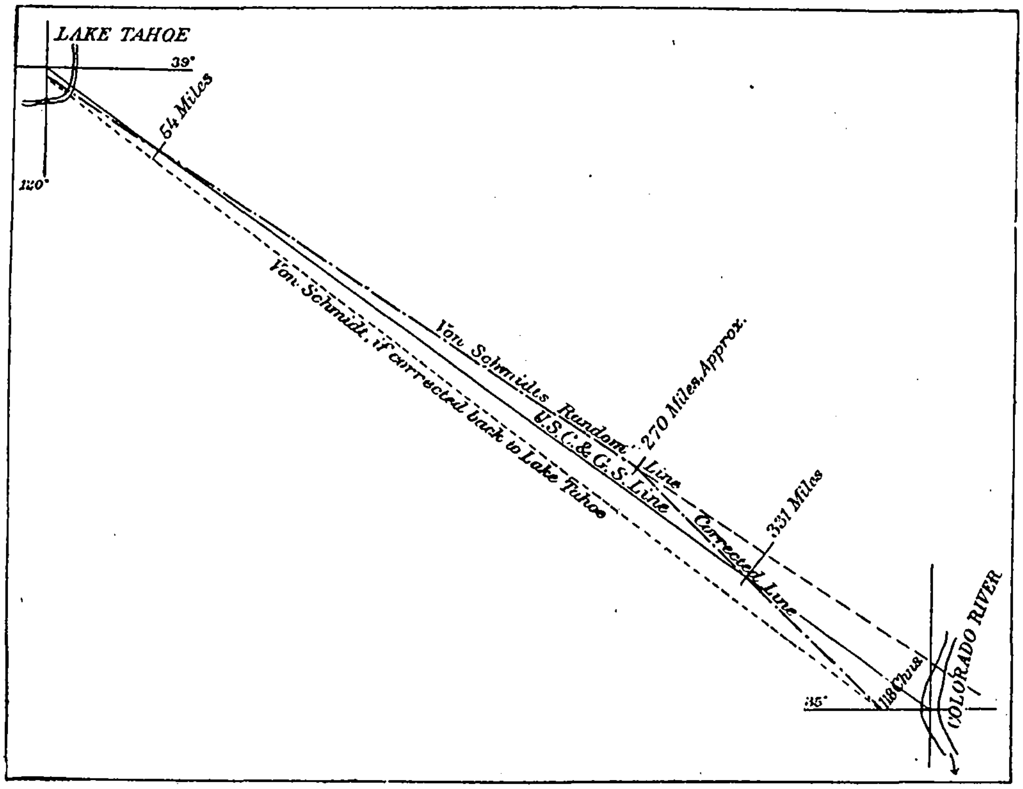
Very respectfully, your obedient servant,

WILLIS DRUMMOND, *Commissioner.*

Copies of the two sketches are shown here. (See illustrations Nos. 4 and 5.)

In compliance with the requirements of the Commissioner a correction to the west

No. 8.



Von Schmidt and C. & G. Survey lines.

along the thirty-fifth degree of latitude of 143 chains was to be made from the terminal as located by Lieut. J. C. Ives in 1861, and of 118 chains southwest of the random line run by Von Schmidt, namely, 20 chains to the southwest, being the error of closure on the Ives point; and 98 chains to the southwest, being the amount of correction due to the shifting of the river between 1861 and 1873.

This correction of 118 chains—nearly 1½ miles—to the southwest at the Colorado River terminus of the Von Schmidt random, was not distributed proportionately along the entire line from the Colorado River to Lake Tahoe, but was limited to a distance of about 130 miles from the Colorado River, or approximately one-third of its length, making a line with an angle in it. On account of this failure to correct the line all the way back, the United States Coast and Geodetic Survey line, which started about one-third of a mile to the northeast of the Von Schmidt line at Lake Tahoe, crossed it twice, once at a distance of 54·3 miles from Lake Tahoe, in Sweetwater Valley, and again at a distance of 331·3 miles from Lake Tahoe, in Mesquite Valley. If the Von Schmidt line had been corrected all the way the Coast and Geodetic Survey line would not have crossed his line at all. As it is it crossed both his random line and his so-called corrected line.

Illustration No. 8 shows clearly the relation of the different lines to each other. The first 270 miles of the Von Schmidt line is simply his uncorrected random, and the remaining 130 miles bends away from the random to the southwest so as to strike the corrected terminal at the Colorado.

While no systematic effort was made to find all of the old marks on the Von Schmidt line, search was made for them from time to time at different points where it could be done without retarding the regular work too much. Enough marks were recovered to reproduce with a fair degree of accuracy the entire line and thus give a comparison of the two surveys. Fifty marks were recovered as shown in the tabulated description.

In his field notes relating to the oblique part of the eastern boundary of California, Von Schmidt makes the following statement:

> I next proceeded to lay off azimuth of transit line running in a southeasterly direction from the thirty-ninth degree of north latitude, where it intersects the one hundred and twentieth degree of west longitude in Lake Tahoe, to where the thirty-fifth degree of north latitude intersects the middle of the channel of the Colorado River. To do this, it was necessary to know the longitude at the terminus in the Colorado River. There being no telegraphic facilities at that point, I concluded for the time being to assume the longitude of that place as determined by Lieutenant Ives in 1863 (1861–?) * * * run a line to Ives's point, then establish the intersection of the thirty-fifth degree of north latitude with the middle of channel of the Colorado River by a series of observations, correct my line back, should I find error in longitude, and mark and establish the true line in the field, ALL OF WHICH WAS DONE.

The line as reproduced by the Coast and Geodetic Survey fails to confirm the terminal phrase of the above quotation.

The Von Schmidt map was made on a scale of 2 miles to the inch. A photographic copy of the map and a copy of his report and field notes are in the possession of the United States Coast and Geodetic Survey.

INSTRUMENTS.

In his field notes Von Schmidt mentions a meridian telescope, a zenith sector, a field transit, a sextant, and a barometer. His distances were obtained by chaining, when practicable, and by triangulation when the ground was very rough. His method was to measure a chain base at right angles to the line, observe the angle at the other end of the base, but not the small, acute angle at the distant, elevated point on the line. This gave rough distances, but perhaps close enough for the purpose.

I. GRUNSKY AND MINTO, 1889–90.

The Report of the Surveyor-General of California for 1890 contains the copy of "An act to provide for the correction and establishment of the eastern boundary of the State of California, and to appropriate money therefor," approved February 26, 1889 (pp. 11 and 12); the letter of instructions to C. E. Grunsky and William Minto, civil engineers, and the report of these engineers to the surveyor-general (pp. 14–40).

They were directed to use the primary line, Lola to Round Top (91 038·53 meters= 56·6 miles, nearly) of the United States Coast and Geodetic Survey as a base for triangulating Lake Tahoe and for connecting, by this means, with points on the Von Schmidt line on the north end of the lake and on the southeast shore.

The iron boundary monument on the north shore of the lake was found to be in—

Latitude 39° 13′ 19″·30,
Longitude 120° 00′ 20″·45,

showing this monument to be too far west 20″·45=1 609 feet. The granite monument on the southeast shore of the lake was found to be in—

Latitude 38° 57′ 25″·06,
Longitude 119° 57′ 05″·90.

The longitude of the State line in latitude 38° 57′ 25″·06 by calculation with the azimuth 311° 19′ 36″·99 as furnished in 1890 by the United States Coast and Geodetic Survey, for the azimuth of the State line at the intersection of 39° latitude and 120° longitude is made to be—

Longitude 119° 56′ 14″·33,

a difference of 51″·57 or 4 073·3 feet. So the conclusion is drawn that the meridian boundary at the north end of the lake is 1 609 feet too far west, and the first stone on the lake shore making the oblique boundary is 4 073·3 feet too far west. They state as follows:

"Having, as above set forth, ascertained the longitude of a point on the State line in the same latitude as the granite monument on the southeastern lake shore, the survey was continued from this granite monument as follows:"

"N. 89° 59′ 43″·79 E. * * * 4 073·3 feet to a point (J′) on State boundary line in the same latitude as the granite monument on the lake shore (J). Set a pine post*. * * * Made a stone mound around post, thence on the boundary line with an azimuth of 131° 21′ 58″·94 toward Lake Tahoe * * * 70·46 chains to shore of Lake Tahoe, bearing north and south, set a tamarack post*. * * *"

From the point (J′) which is on the State boundary line, and 4 miles 39·64 chains distant from the point o in the lake where the thirty-ninth parallel of north latitude is intersected by the one hundred and twentieth degree of longitude west from Greenwich, the survey of the State boundary was continued in the direction toward the intersection of the thirty-fifth parallel of latitude with the Colorado River as follows:

"With the same azimuth above noted for this point, azimuth 311° 21′ 58″·94, ascending steep mountains bearing NE. and SW. and noting all distances as though measured from the above-named point in Lake Tahoe * * * 16 miles 77 chains, west fork of Carson River, 30 feet wide runs N. 20° E. Beyond which this survey could not be extended owing to lack of necessary funds."

*These two posts were found in 1893, the one on the lake shore lying on the sand, but identified by the marks, and the other one still in place.

The determination of the iron boundary monument on the north shore of Lake Tahoe by the United States Coast and Geodetic Survey in 1893 was—

Latitude 39° 13′ 19″·18,
Longitude 120° 00′ 21″·94,

which makes the monument 21″·14 = 1 727 feet too far west.

The stone monument at the north end of the lake was found to be in

Latitude 39° 13′ 17″·25.
Longitude 120° 00′ 21″·96.

The work at the Colorado end of the line was done in September, 1889, by William Minto, assisted by L. H. Taylor. Mr. Minto says:

"The work of determining the longitude of the intersection of the middle of the Colorado River with the thirty-fifth degree of north latitude was much simplified by the action of the United States Coast and Geodetic Survey."

This "action" was the determination of the latitude and longitude of the Needles, a station on the Atlantic and Pacific Railroad about 12 miles south of the thirty-fifth degree of latitude.

Latitude 34° 50′ 18″·17.
Longitude 114° 36′ 11″·04.

A meridian line was also marked from the longitude pier to a point on the mesa about 300 meters south by the United States Coast and Geodetic Survey. The report continues:

"In September, 1889, the Coast and Geodetic Survey station thus established was connected by a system of triangulation with the monuments established by Col. A. W. Von Schmidt on the thirty-fifth parallel of north latitude, as determined by him in running the State boundary in 1873. The Von Schmidt monuments found standing were the two posts designated in his field notes as being on the line of the thirty-fifth degree—one on the bluff west of the river and 20·76 chains west of his intersection of the middle of the river by the said parallel of latitude, and the other 23·00 chains farther west, both in mounds of stone and earth and marked as described in his field notes. There is also a stone marked, as the notes describe it, "L 35° N" in the mound around the most easterly post."

* * * * * * *

"Station was found to be in latitude 35° 00′ 23″·39 and in longitude 114° 39′ 23″·61, and the terminal point L of the Von Schmidt boundary survey of 1873 is in latitude 35° 00′ 23″·39 and in longitude 114° 39′ 07″·08."

"Incidentally the latitude and longitude of the flagstaff at Camp Mojave was also established by this work: Latitude 35° 02′ 30″·22, longitude 114° 37′ 14″·48."

"As nearly as could be determined from the Von Schmidt survey of 1873, the Colorado River from L to L′ had a southeasterly course, and this course as nearly as it could be determined was made the basis of the computation of the longitude of the intersection of the thirty-fifth degree of latitude with the center line of the Colorado River in its position of 1873. The latitude 35° 00′ 23″·99 and longitude 114° 39′ 07″·08 of the point L, with an azimuth 322° 32′ 25″·65 from L to L′, the latitude of L′ being 35° 00′ 00″, established the longitude of L′ at 114° 38′ 45″.30, and the distance from L to L′ was found to be 907·97 meters."

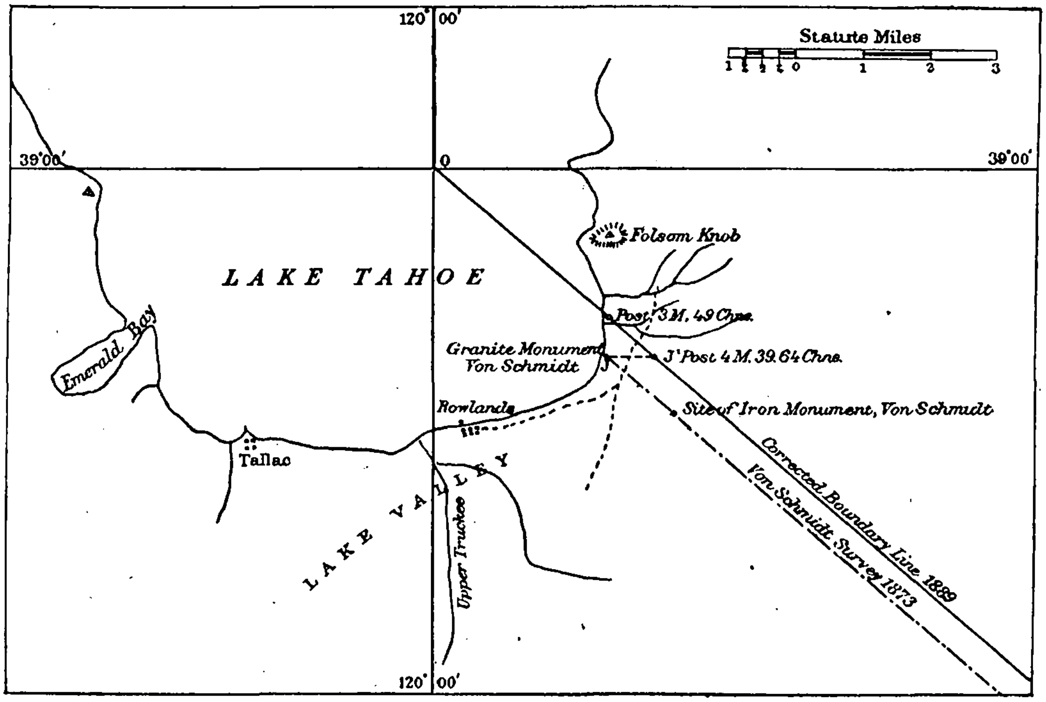
"The boundary line from Lake Bigler southeastward to the Colorado River must therefore connect a point in latitude 39° 00′ 00″, longitude 120° 00′ 00″, with a point at the Colorado River in latitude 35° 00′ 00″ and longitude 114° 38′ 45″·30."

"From Colonel Von Schmidt it was learned before the above field work was undertaken that he was directed by the department in authority to make the center line of the Colorado River as he found it in 1873 the objective point of his survey, and not the river as it might have been at the date of the admission of California. It was for this reason that L′ was established as above noted. The correct azimuth of the boundary line northwestward from the point L′ is 134° 33′ 09″·29, and this line, which the above work indicates as the corrected position of the State boundary, passes about 414 feet to the southwest of the Von Schmidt terminal point L.

*   *   *   *   *   *   *

As soon as the results of the work at the Colorado River became available, a calculation of the azimuth and length of the line from the point in Lake Bigler to the Colorado River was made, at our

No. 9.



Grunsky and Minto line, 1889.

request and for our use, by Charles A. Schott, of the United States Coast and Geodetic Survey, and reported by him as follows, under date of January 6, 1890:

"Azimuth from Lake Bigler end of line to the Colorado River end 311° 19′ 36″·99. Distance 651 056 meters = 404·551 miles."

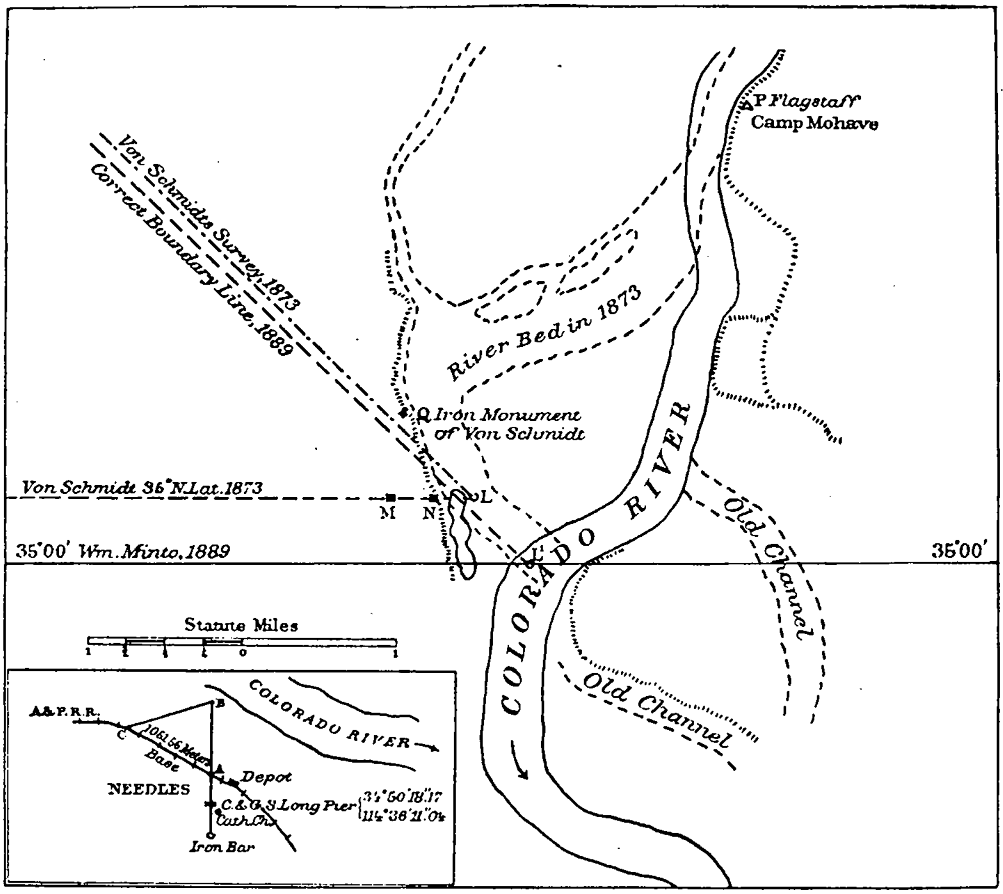
"Azimuth from the Colorado River end of the line to the Lake Bigler end 134° 33′ 09″·29." * * *

Three copies each of two maps are filed herewith and made a part of this report, as follows:

Sheet No. 1.—State Boundary Survey. Map of the boundary line of California near Lake Bigler, showing position of the United States Coast and Geodetic Survey primary stations Lola and Round Top, and the triangulation work of June and October, 1889; also the boundary line as surveyed and marked in the field by A. W. Von Schmidt in 1872 and 1873, and the position of the boundary line southeastward from the lake as surveyed by C. E. Grunsky and William Minto in 1889 and 1890, under instructions from Theo. Reichert, State surveyor-general.

Sheet No. 2.—State Boundary Survey. Map of the boundary line of California at the intersection of the thirty-fifth degree of north latitude with the Colorado River, showing the position of the United States Coast and Geodetic Survey Station Needles, and the triangulation work of William Minto in September, 1889, done under directions from Theo. Reichert, State surveyor-general.

No. 10.

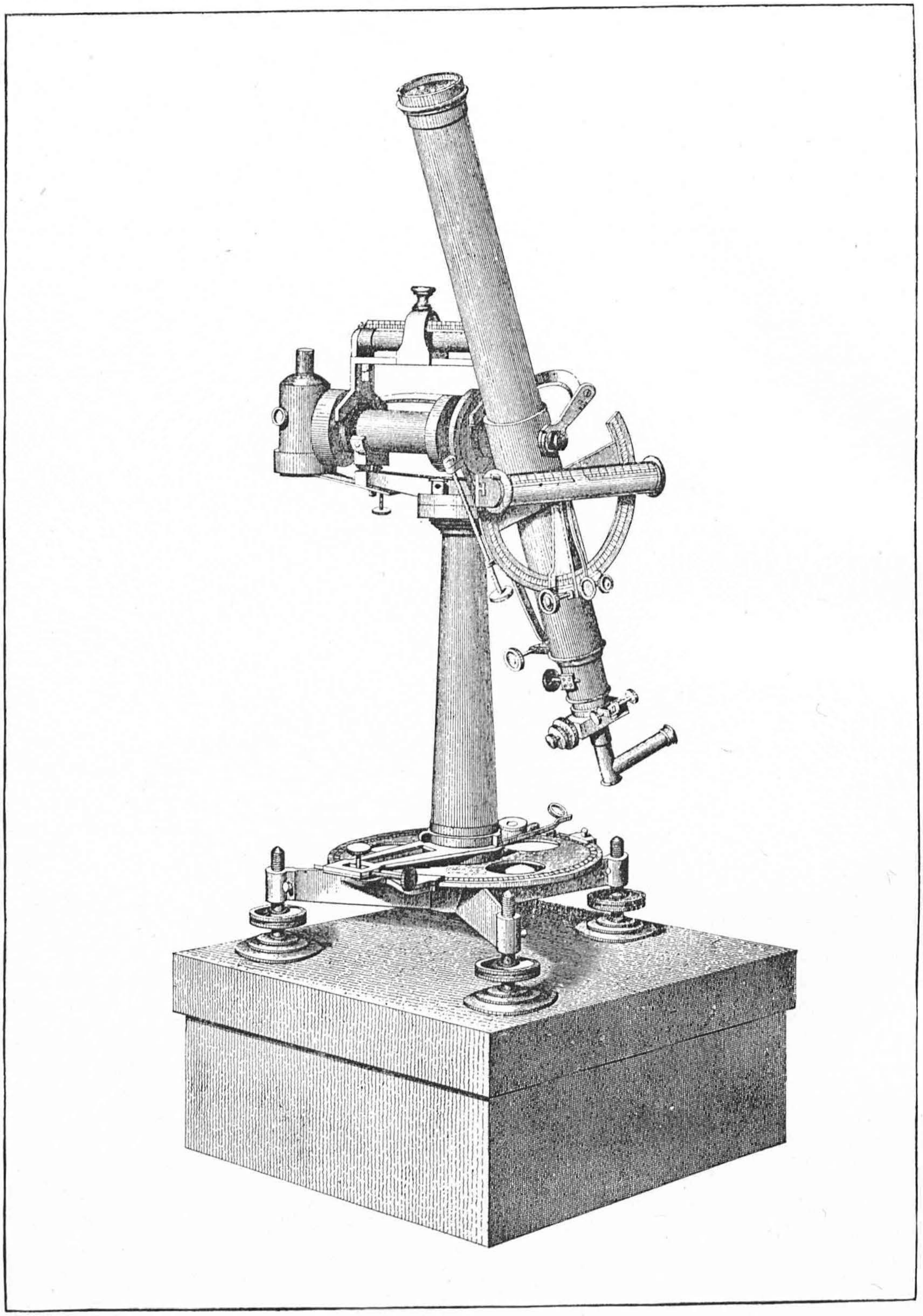


Grunsky and Minto line, 1889.

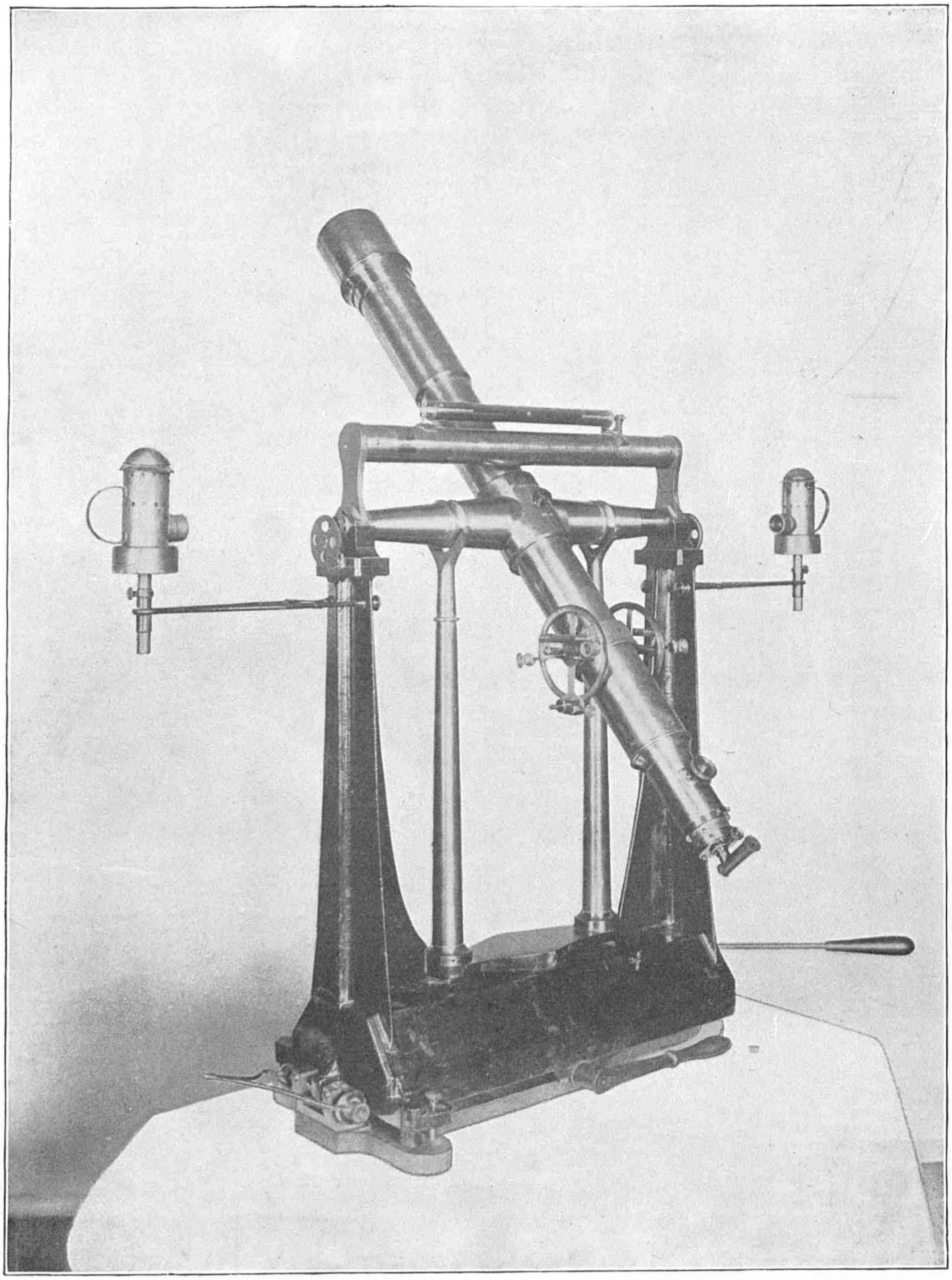
Blue prints of these two maps are in the Office of the United States Coast and Geodetic Survey, Washington, D. C. Reduced copies of them are shown above.

III. UNITED STATES COAST AND GEODETIC SURVEY LINE—1893–1899.—CALIFORNIA AND NEVADA OBLIQUE BOUNDARY.

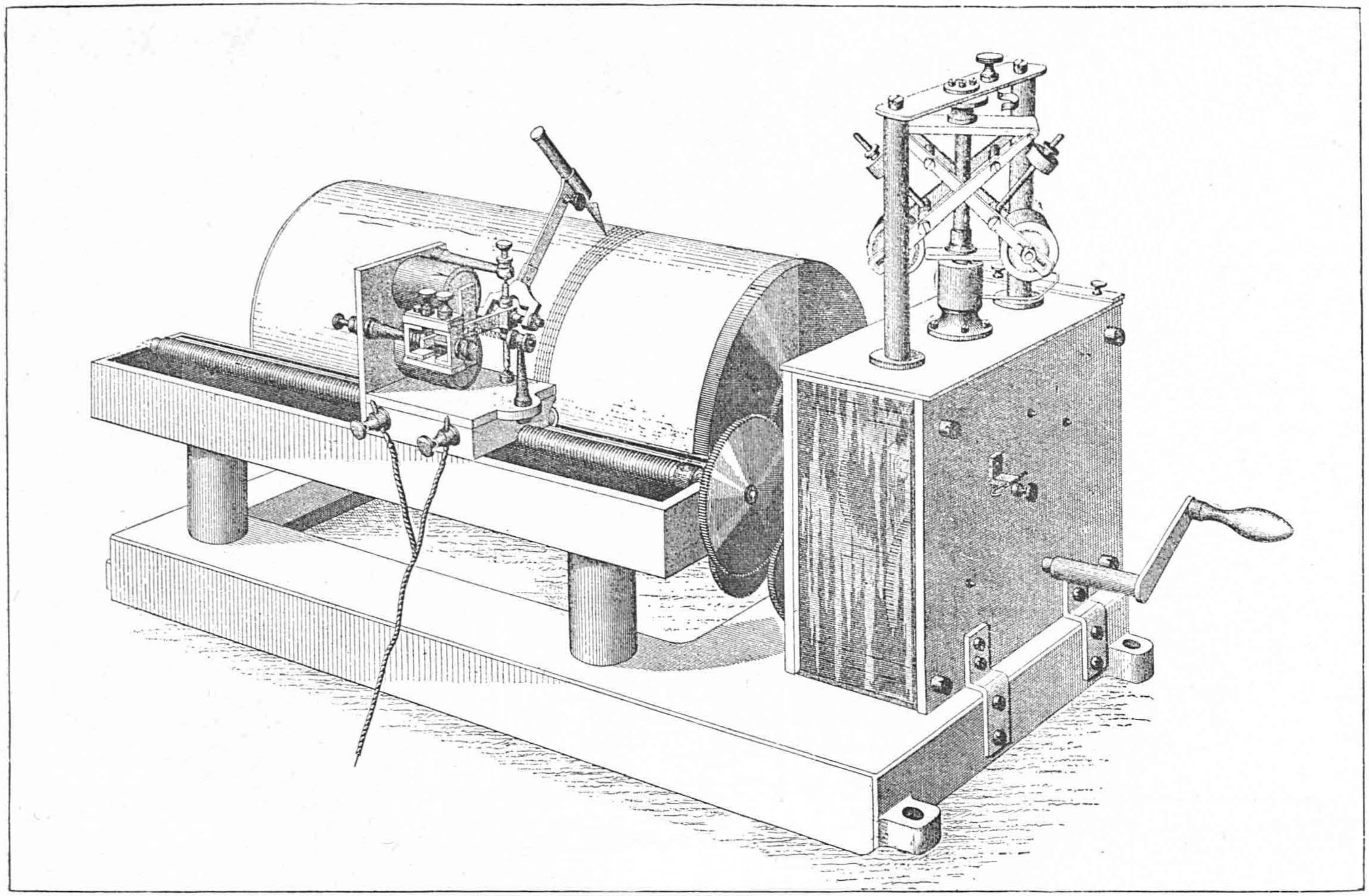
The oblique boundary between the States of California and Nevada begins at the intersection of the thirty-ninth degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich and runs southeasterly to the intersection of the thirty-fifth degree of north latitude with the Colorado River. The first of these points falls in Lake Tahoe about 3·6 miles from the southeast shore; the second was taken as midway between the bluff or stable banks of the stream. These



ZENITH TELESCOPE.



PORTABLE TRANSIT.



CHRONOGRAPH.


TREASURY DEPARTMENT
U. S. COAST AND GEODETIC SURVEY
HENRY S. PRITCHETT, SUPT.
OBLIQUE BOUNDARY
BETWEEN
CALIFORNIA AND NEVADA
LAKE TAHOE TO COLORADO RIVER
C. H. Sinclair, Assistant, Chief of Party
W. B. Fairfield, A. L. Baldwin.
H. F. Flynn and F. W. Edmonds.
Assistants
1893 to 1899
Statute Miles
0
1
2
3
4
Note
The topography was sketched by C.H. Sinclair and F. W. Edmonds in 1899.
The boundary is shown by a solid line and the Von Schmidt line by long and short dashes.
The monuments are shown enclosed in circles and numbered from Lake Tahoe southeastward
The projection and line points are based on geodetic data, while the azimuth of the line is on astronomic data. There is a large local deflection in latitude at Lake Tahoe, and in both latitude and longitude at the Colorado.
Observatory Point
Tahoe City
Tuckee River
LAKE TAHOE
(6225 feet)
McKinneys
Bellevue
Murphys
Rubicon Point
Emerald Bay
Azimuth Mark
Tallac
Cave Rock
Zephyr Cove
Castle Rock
Genoa
CARSON VALLEY
LAKE VALLEY
From Genoa
Grunsky and Minto 1889
U.S. Coast and Geodetic Survey
1893-1899
Von Schmidt 1873
Houghton and Ives 1863
Lake Shore Station
Bijou
Rowlands
120th Meridian
Upper Truckee
School House
Baldwin
Dresslar
Dilueli
Barber
Bald
High Peak
Lake
Holbrook
Gold Hill
From Gardnerville
To Wellington
To Coleville
West Walker River
Sage Brush
Desert Creek

banks are 2·75 miles apart along the thirty-fifth degree, and the river changes from one side of its bed to the other during the different periods of high water, which prevails usually in the months of May, June, and July, when the snow is melting in the mountains. It 1861 the river was on the east side of the alluvial bottom; a slough, or lake, the remains of an old channel, is still there. In 1873, when Allexey W. Von Schmidt reached the Colorado River with his survey of the boundary line, the river was on the west side of the bed; a small lake still exists on that side also, showing the old channel. In 1893, when the Colorado River terminus was located by the Coast and Geodetic Survey, the center of the stream coincided very nearly with the middle point between the permanent bluff banks. This was during the high water in the month of June. In 1899 the river was practically in the same position as it was in 1893. When the party completed the tracing of the boundary in January, 1899, it was during the period of low water, and while the middle point came on a low sand flat, a rise of 1 foot in the water would have covered this flat and brought the middle of the stream and the middle point between the permanent banks nearly into coincidence. The water was less than 3 feet deep in the channel at that time.

A. INSTRUCTIONS TO PROF. GEORGE DAVIDSON.

The letter of instructions to Prof. George Davidson, Assistant, United States Coast and Geodetic Survey, from the Superintendent, dated April 17, 1893, giving the general method of procedure and defining the position of the Colorado River terminus, is here inserted, with a few slight changes:

UNITED STATES COAST AND GEODETIC SURVEY,
OFFICE OF THE SUPERINTENDENT,
Washington, D. C., April 17, 1893.

Prof. GEORGE DAVIDSON,
Assistant, United States Coast and Geodetic Survey, San Francisco, Cal.

SIR: Congress having provided for a resurvey of that part of the boundary line between California and Nevada which extends from a point in Lake Tahoe to the Colorado River, and for the re-marking of the same, the general direction of the field operations connected with the work is placed in your hands. Assistant C. H. Sinclair and Subassistant W. B. Fairfield have been instructed to report to you for active duty upon this survey. Their experience and skill is such that it is believed that your presence in the field will not be necessary, except occasionally for purposes of inspection or for making personal examination of the more difficult parts of the field work.

This boundary, as defined by act of Congress, is a "straight line" joining two points. One of these points is astronomically defined, the other only partially so, it being dependent for its longitude on the location of the Colorado River. The actual location of these two points, the termini of the line, is a necessary preliminary. As much of the present season as is necessary will be devoted to this part of the work. The amount of money available during the present fiscal year is $5,000, and about the same amount can be used during the fiscal year 1894. It is not desirable, therefore, to put two parties into the field, and, besides, the different climatic conditions obtaining at the two ends of the line make it advisable, at least for the present, to begin with one party at the southeastern terminus, rather lightly equipped, so that the expense of transfer to the vicinity of the lake on the approach of extremely hot weather will be small.

Mr. Sinclair and Mr. Fairfield will doubtless be able to accomplish all that is necessary for the location of the terminus near the Needles by June 1, or perhaps a little later. They should then proceed to Lake Tahoe and locate the first monument of that end of the line. In the meantime, the coordinates of the termini having become accurately known, the azimuth of the line can be computed and plans can be formulated for the execution of the chain of secondary triangulation necessary to its exact location.

Beginning with the southeastern end of the line, the method used in locating that terminus should be essentially as follows:

By definition this point is at the intersection of the thirty-fifth degree of north latitude with the Colorado River. From this point the line proceeds, according to the constitution of the State, "along the middle of the channel of said river;" from which it must be inferred that said point is itself in the middle of the channel of the Colorado River. At the latitude of 35° the river flows between two well-defined bluffs, separated from each other by a distance of 2¾ miles. Between these the actual bed of the river vibrates from time to time, now being near one side and now near another.

In 1860 Congress passed an act appropriating money for a survey of this boundary line, and in this act the line is defined as "beginning at the intersection of the thirty-ninth parallel of north latitude and the one hundred and twentieth degree of longitude west from Greenwich and proceeding in a southeasterly direction in a straight line to the point where the thirty-fifth parallel of north latitude crosses the Colorado River." This is, perhaps, the latest definition of the line, and it would be proper to assume that the southeastern terminus must be determined by the position of the river at the time of the passage of the act. As throwing light upon this point, the only information available here at this time consists of a published map of [Lieutenant] Ives's exploration survey or reconnaissance of 1858 and a map of his survey of (1863) 1861? (see sketch No. 1, and No. 4), the latter having doubtless been made for the purpose of locating the boundary line. In the former his latitude, as shown on the map, is in error a little more than one minute, according to his own record for his nearest astronomical station. If this correction is made, the two maps show the river in essentially the same position. It may be inferred, therefore, that its bed did not change materially from 1858 to (1863) 1861?, and that these maps show it practically as it was in 1860, the date of the act of Congress.

If the latitude as shown in the later map is not seriously in error, the thirty-fifth parallel was along the bed of the river for a mile or more, as the river at that time and place ran nearly west to east across the valley separating the bluffs between which its bed is confined. From this it appears that all of the conditions to which this terminus is subjected will be satisfied by assuming it to be *midway between the two bluffs between which the Colorado River flows, on the line of* the thirty-fifth degree of north latitude. Two points in latitude 35° north on these bluffs, equidistant from the point agreed upon as the terminus of the line, should be carefully determined and well marked.

This definition will, therefore, be adopted as furnishing the most equitable, the most prominent, and hence the most easily reproduced location of the southeastern terminus. Besides, it is believed to be historically correct and in accord with the act of Congress of 1860.

It may be assumed that the iron monument placed in 1873 will afford a first approximation to this point. An astronomical station should be established near it, and latitude observed. It should be connected by triangulation with the Coast and Geodetic Survey astronomical station at Needles. An azimuth should also be observed to connect with the triangulation. Having the latitude and longitude of this point, the location of the thirty-fifth degree of north latitude on the bluffs of the river may be determined and the proper position of the first boundary monument completed. For this purpose the azimuth of the line may be assumed to be 134° 33′. The monument should be located on hard high ground on the bluff of the river, as near as may be, so that any defect in azimuth may have little effect. Before leaving it will be well to set up another monument in the line, say a mile or two away.

In the execution of the work at Needles it will doubtless be necessary to establish a camp in the vicinity of the terminus of the line. It is not believed, however, that the outfit need be very extensive or expensive.

If possible, such wagons and animals as are needed should be hired at the Needles or Mohave, as it will not be found necessary to transport them to the northern end of the line. If necessary to purchase them, they may be taken away after the work is done, and kept where it may be done at the least cost. Possibly much of the outfit for this camp can be furnished from the stores now on hand and under your charge in San Francisco. Mr. Sinclair has, at my request, prepared an estimate of the cost of doing the work at this point, which he will submit to you for your consideration. The object in view is the equipment of the party in such a manner that there will be no loss, and as far as possible nothing to dispose of when the work is completed.

At Lake Tahoe it is assumed that the party will not need a camp, unless the astronomical work should be completed in time to take up some of the geodetic work before the close of the season.

This work is not immediately necessary, however, although a necessary and important part of the complete scheme.

At Lake Tahoe the work will consist of the verification of the location of the "initial boundary monument." Establishing an astronomical station near it, latitude will be observed and longitude determined by the most convenient and available method. It is understood there is a telephone wire connecting Tallac with some telegraphic point, as Carson City or some other station already occupied for longitude by the Coast and Geodetic Survey. If this is the case, telegraphic connection can doubtless be obtained with little difficulty. Three nights' exchange of signals, with another three nights after exchange of observers, will give sufficiently accurate results.

If Tallac fails, the line to Glenbrook may be utilized, and if found absolutely necessary a temporary line may be erected connecting Genoa and the astronomical station on the shore of the lake. In case of either of the first two places being used, the longitude of the station may be determined by using heliotrope or powder signals, exchanged with Tallac or the transport of chronometers from Glenbrook on the lake; or it may be found cheaper to connect the astronomical station directly with telegraph connected by temporary line.

The azimuth of this end of the line may be assumed to be 48° 41′, but the result of the fixing of the southeastern terminus will make a revision of this value possible.

The location of a monument at the beginning of the line is impracticable owing to the fact that it is in Lake Tahoe, but with the observed latitude and longitude of the astronomical station and the azimuth of the line, the distance from the station to the nearest point on the boundary may be computed. It will be desirable to make this initial point as near the lake as may be, and also to establish a second point on the line at some distance from the first.

At the conclusion of this part of the work, should the season and available funds permit, some geodetic work may be undertaken before leaving the vicinity of Lake Tahoe. The position of Tallac should be determined by using the base Freels and Round Top and the new astronomical station. The old and the new initial boundary monuments should be connected with Freels and Tallac. It is understood that Tallac will be easy of occupation, but that Freels will offer more difficulties. It is believed, however, that it can be easily occupied with special equipment or camp outfit.

You will know better than anyone else what is required for the occupancy of Round Top. A single day of fair weather at each of those stations will be sufficient. Magnetics should be observed at each station. The work of locating the two termini of the boundary line will probably extend through the summer months, and when it is entirely completed it will not be too early to begin preparations for pushing the work from the southeastern point.

A secondary triangulation, with sides 20 to 40 miles in length, and closely clinging to the lines, is to connect the two ends. It is hoped that the work of locating the termini can be so conducted as to leave a considerable fund available for the execution of this work during the coming autumn and winter, beginning at the Colorado River.

This will require a tolerably extensive outfit in the way of camp equipage and working force. Just what this should be can be better known, it is believed, after the experience gained in the execution of the above instructions. You will, of course, avail yourself of all sources of information relating to the subject, and be ready to submit plans and estimates in advance of the time for beginning operations in the field. As $5 000 can be expended before July 1, and as it is believed that the party in the field, first at Needles and afterwards at Lake Tahoe, will not require so large an amount up to that date, you will endeavor to expend such balance as is available before July 1 in the purchase of portions of the field equipment for the triangulation party. As before stated, but one party can be kept in the field, but it is possible that by active work during the coming winter such advance may be made from the southern end that the operations of that party will not be cut off by high temperature in the early summer.

Mr. Sinclair has estimated for the pay of a recorder at $45 per month, and in selecting some one for this position it is very desirable to secure some young man who is a graduate from the engineering or physics courses in one of your two leading institutions of learning, as it is from this class that the professional corps of the survey should be recruited as opportunity is offered from time to time.

When the results of the observations at the two termini are in hand it will be possible to finally compute the lines, after which general instructions for the execution of the scheme of triangulation can be prepared.

Finally, these instructions are not to be considered as unalterable, and this is especially so with regard to details, in which you must be largely governed by local conditions. In case you think it necessary to make any considerable departure from the general scheme indicated above, you will as soon thereafter as possible explain such deviation and give your reasons for the same. While it is expected that the work will be of such a character as to assume absolute confidence in the result, it is not thought necessary to maintain in its execution that high standard which is regarded as essential to the success of our primary triangulation. The instrumental equipment need not be so elaborate, nor the observations so often repeated. Much money has already been expended in the location of this line, with unsatisfactory results. It is our ambition, first, to do the work so that it will never need to be done again, and second, to show that with our organization, instrumental equipment, corps of skilled observers and professional esprit, we can execute a piece of work like this at a less cost than any other body of men, especially those temporarily created under the authority of a "joint commission,', which is itself generally an expensive adjunct, not necessary, and with which we are not burdened.

I trust, therefore, that in submitting a scheme and estimates for the coming triangulation work you will not lose sight of this important consideration, and I believe that through your extensive knowledge of the country and local conditions, together with the excellent opportunities for gaining information which are available to you, you will be able to reduce the cost of the work to as low a limit as is compatible with its proper execution.

Respectfully, yours,

T. C. MENDENHALL, *Superintendent.*

B. LOCATION OF THE SOUTHEAST TERMINUS, COLORADO RIVER.

In compliance with instructions of the superintendent dated April 8, 1893, I went to San Francisco, Cal., early in May to report to and confer with Assistant Davidson, accompanied by Assistant W. B. Fairfield, who was associated with me on this boundary survey from its beginning in 1893 to its completion in 1899.

As the instructions to Professor Davidson state, the thirty-fifth degree of latitude was to be determined by observations (with the zenith telescope); the longitude to locate the center of the river where it crosses the thirty-fifth degree was to be carried up by triangulation from the telegraphic longitude station at the Needles, which was determined in 1889, the distance being about 13 miles; an azimuth was to be observed near the thirty-fifth degree and a point located approximately in the boundary line by using the old azimuth of the line derived from imperfect data of former years. After this, a recomputation of the work was to be made by the office, the error determined of the points approximately placed, and the corrected boundary marks set in position.

Between May 2 and 13 arrangements were completed in San Francisco for executing the work, and on May 13 the party and outfit started to the Needles, Cal., as the base for conducting the field operations.

The party consisted of Assistants C. H. Sinclair and W. B. Fairfield, of the Coast and Geodetic Survey; Mr. G. J. Kammerer, recorder; William Diercks, foreman; and George Simons, hand, brought from San Francisco, and Sam Costello, hand, hired at the Needles, who also did the rough cooking required at the astronomic station. Mr. Fairfield succeeded in hiring a buckboard with a pair of horses at the Needles for reconnaissance, signal building, and triangulation between the Needles and the thirty-fifth degree of latitude.

Upon reaching the Needles steps were taken to secure a team for hauling the instruments, observing tent, lumber for the platform, cement to construct the pier, and other material up to the thirty-fifth degree of latitude, about 13 miles over a rough, sandy road on the west side of the Colorado River.

Before doing this I made a preliminary trip with the mail carrier to Fort Mohave, then converted into a school for Indians, the distance being nearly 18 miles over a sandy road on the east side of the river. The officials at the school were very obliging, furnishing me with a boat and men to cross the river and visit the iron monument that was supposed to be the terminal mark of Von Schmidt's line run in 1873.

Fort Mohave was too far from this point, being on the wrong side of the river, so the idea of living there was abandoned. I therefore returned to the Needles and on May 19 moved up to the thirty-fifth degree latitude post of Von Schmidt by team. This place was the nearest known position to the latitude required. Two of these posts were set in 1873 to mark the parallel of thirty-five degrees, and the east one, which is on a bluff of sand and gravel about 50 feet above the water and overlooking the alluvial bottoms of the river, was selected as a triangulation and azimuth point. Just 5·87 meters due west of this eastern post, a latitude pier 17 inches by 17 inches by 5½ feet high was built of concrete during the afternoon of our arrival at the thirty-fifth degree. An observing tent 8 by 10 feet was erected on a platform to shelter zenith telescope No. 6, which was used to make the observations. The latitude was determined by 97 observations on 20 pairs of latitude stars on May 22, 23, 25, 27, and 28—five nights—and value of micrometer on 43 H. Cephei through lower culmination on one night, May 29. Time was observed with the zenith telescope to determine the error of pocket chronometer Karr No. 1012.

The latitude was determined by what is commonly known as Talcott's method. Two stars are selected on different sides of the zenith and nearly at equal distances from it; the difference of zenith distance is measured by means of a delicate micrometer, noting the level and the approximate time of culmination of each star; only the differential refraction is introduced.

Upon the completion of the latitude preparations were made for determining the azimuth, which was done in the usual manner by measuring the angle between a fixed terrestrial mark and the moving star, noting the chronometer time when pointing on the latter, and referring the observations to the meridian, thus determining the angle between the plane of the meridian and the terrestrial mark. These azimuth observations were made on Polaris "at any hour angle," June 2, 3, and 4, by me, using an 8-inch theodolite No. 153, reading to 5″ by 2 verniers; on June 22, 23, 24, and 25 further measurements of the azimuth were made by Assistant W. B. Fairfield with Gambey theodolite No. 20, a 10-inch instrument reading to 5″ by 4 verniers. Thirty-seven separate results were obtained for this azimuth.

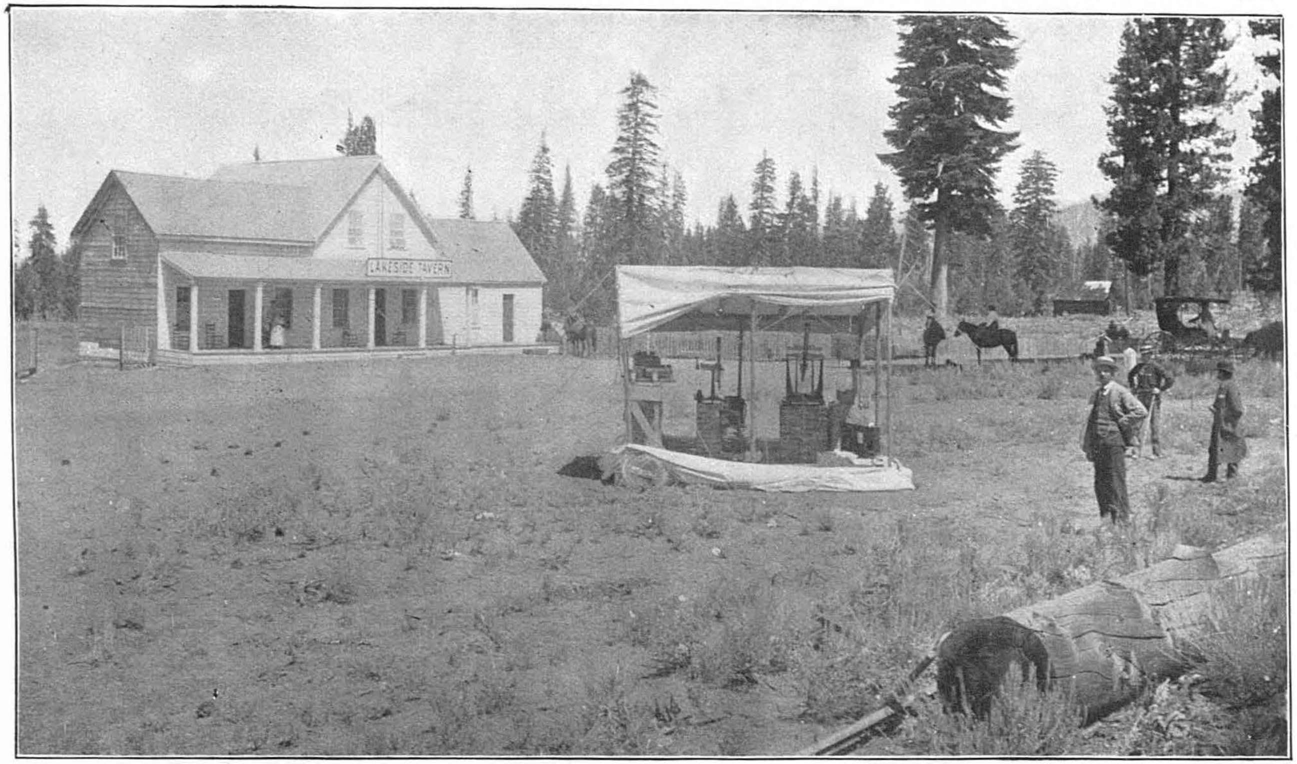
In order to determine points for the topography near the thirty-fifth degree of latitude a base of 462·5 meters was measured twice with a 30-meter steel tape, and a small scheme of triangulation developed, which also served to get the distance across the river. The field computations of the latitude showed that the thirty-fifth degree of latitude post of Von Schmidt was in 35° 00′ 15″·16, or that the point was about 467 meters too far north. This distance was laid off to the south, and 3 redwood posts, each 4 inches by 4 inches by 6 feet, were placed to mark the thirty-fifth degree, 2 of these on the west side of the river and 1 on the east bank in Arizona. Each of these posts has carved on it *Lat. 35°. 1893. C. G. S.* The 2 posts on the west bank are 440·07 meters apart. The most easterly is 83 meters from the foot of the bluff and 100 meters from the shore line of the lake (old channel). The post on the Arizona or east side of the river is 135 meters from the foot of the bluff and 140 meters from the shore line of the lake (another old channel). The posts were placed on the high bluffs (40 to 50 feet) which overlook the trees on the river bottom. They were surrounded with mounds of stone and sand and each has a stone under it with a drill hole in the top to mark the point. The distance between the 2 posts nearest the river on the east and west banks is 4 580 meters; from foot of bluff to foot of bluff is 4 362 meters; one-half of this is 2 181 meters, the distance to the center of river, or the middle point between the bluff banks. Von Schmidt marked his thirty-fifth degree of latitude by 2 cottonwood posts, 1 on the bluff and the other 462·8 meters west. Both were found in good condition. The post near the river was carefully removed; a stone with a drill hole in it was placed 2 feet below the surface for an underground mark, and another stone placed over this with a drill hole in it for a surface mark. This station was used both as a point in the triangulation and for observing azimuth. Upon completing the azimuth observations the post was set back in its old place, a large nail driven in the top, and centered over the point below. A mound of stone and sand was built around the post. This post is also the north end of a meridian, the south end being 468·62 meters distant, marked by a drill hole in a block of concrete. A small pile of stone was placed over it.

The topography includes a mile on each side of the thirty-fifth degree of latitude, on a scale of $\frac{1}{10000}$, covering an area of 7 square miles. It was executed by means of a small plane table, partly by me and partly by the recorder, Mr. G. J. Kammerer, for the purpose of defining clearly the bluff line along the river, which is the only stable shore line of the Colorado River at and near the thirty-fifth degree of latitude. These bluffs are formed of sand, gravel, pebbles, and bowlders washed down from the mountains. They are devoid of vegetation, except greasewood and sagebrush. They vary in height from a few feet to 70 or 80 feet, and sloping down toward the river are deeply furrowed into ravines by heavy rains, giving the appearance of numberless embankments or dumps from mines at right angles to the general direction of the stream, which has washed around the end of these embankments during high water, keeping the river ends precipitous.

The alluvial bottoms are from 2 to 3 miles wide, the soil being a sandy loam rising several feet above the river, but generally submerged during the time of high water. The growth is chiefly willow, interspersed with cottonwood and mesquite. Some of the land is cultivated by Indians; there are also a few ranches owned by whites.

The current is very swift and the channel changes rapidly during high water. Sometimes from 20 to 30 feet of the bank will be cut away in a day. The topographic sheet shows approximately the rate of change during the short time we were in that locality. In 1893 the east bank was being cut away. Trees from 5 to 12 years old were swept away like twigs. Lakes or remains of old channels are numerous.

After the preliminary computations had been made posts were set to mark the approximate position of the oblique boundary line on firm ground. The first of these was 2 080 meters north and 293 meters west of the Von Schmidt east latitude post, and 3 646 meters northwest of the center of the river. The second post is 2 250 meters northwest of the first post. These two posts are redwood, 4 inches by 4 inches by 6 feet, placed in the ground about 2 feet, with a mound of stone and sand around each. The one nearest the river has carved on it S. E. LINE POST, C. G. S.; the other N. W. LINE POST, C. G. S. All of these marks were of a temporary character, awaiting the Office computations of the observations before being permanently placed.



Von Schmidt stone, 1873.

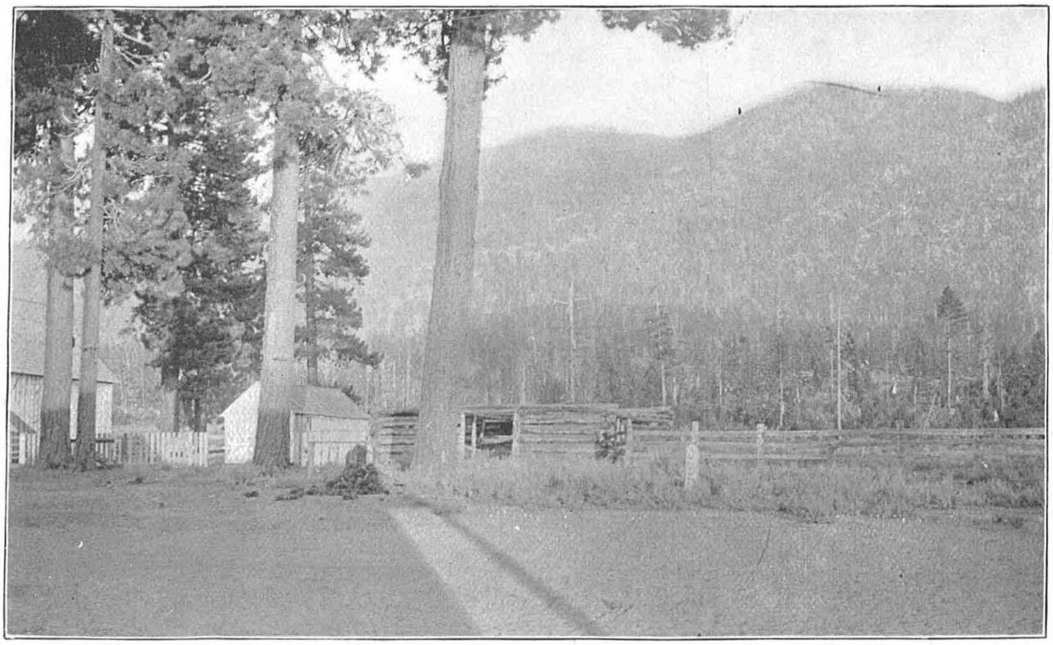
ASTRONOMICAL STATION AT LAKE TAHOE, 1893.

VON SCHMIDT BOUNDARY MONUMENT—"211 M. 30 CHS."

No. 16.

VON SCHMIDT BOUNDARY MONUMENT—"211 M. 30 CHS."

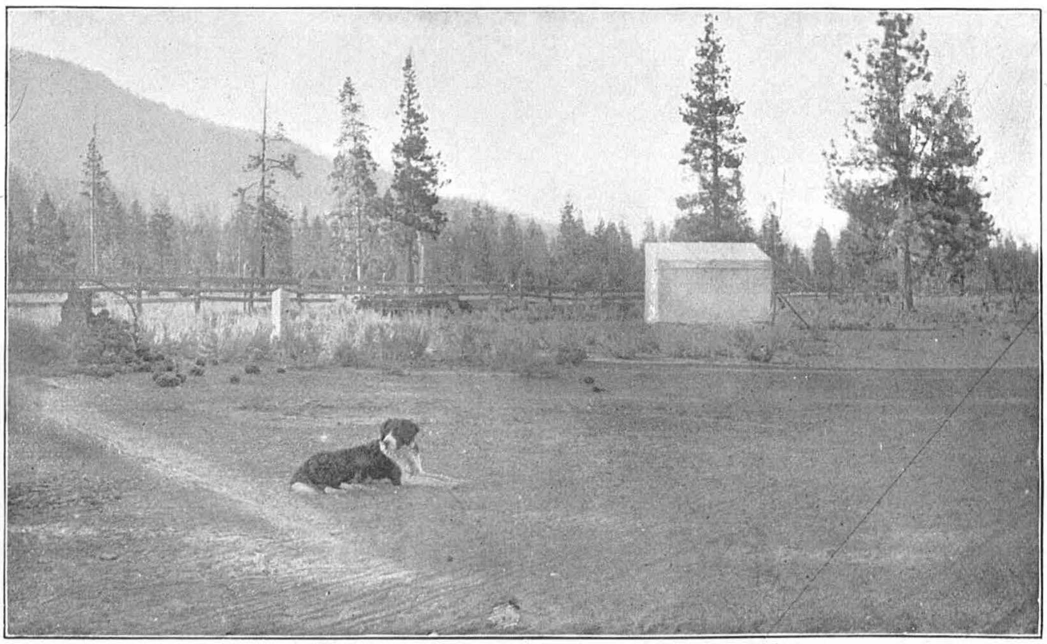
No. 17.



Line, 1893. Line, 1873.

VON SCHMIDT BOUNDARY MONUMENT—"211 M. 30 CHS." LOOKING SOUTHEAST.

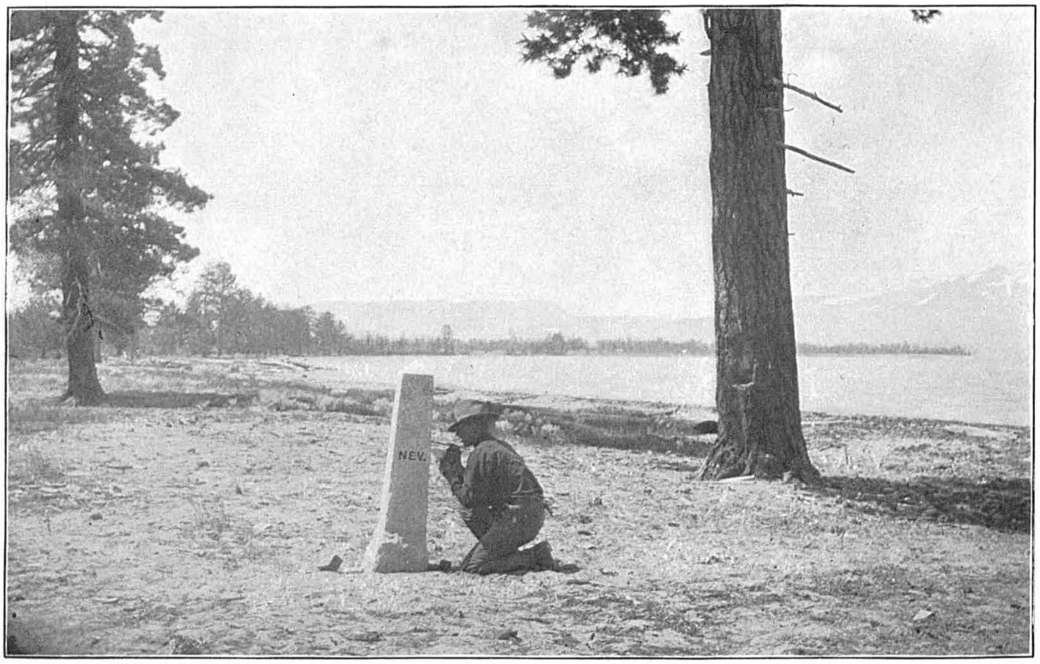
No. 18.



Longitude station.

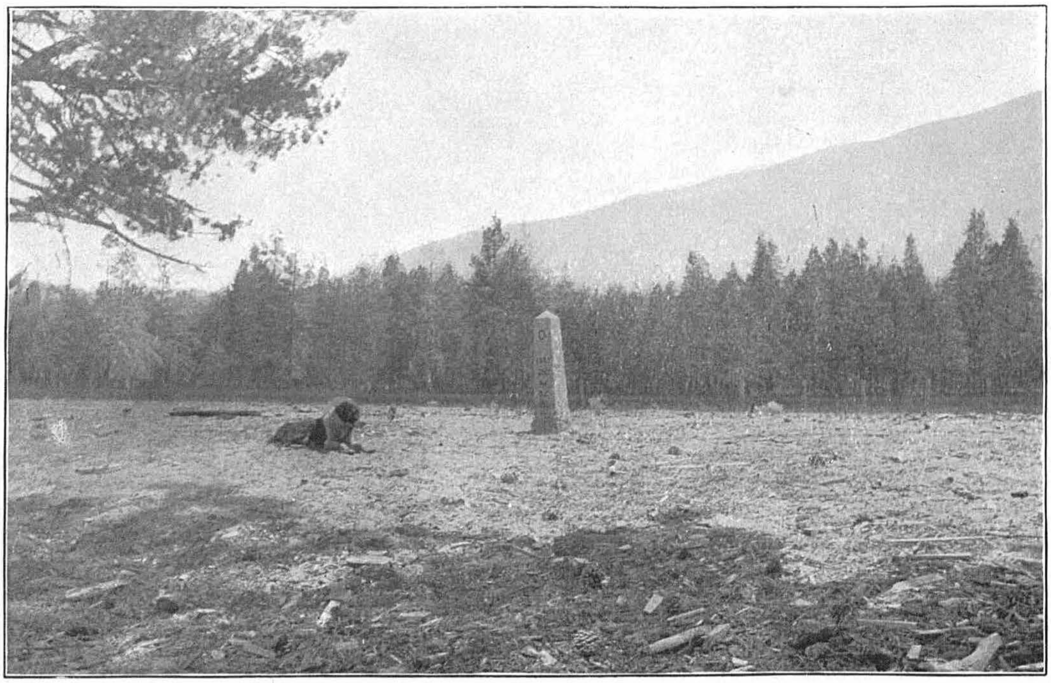
VON SCHMIDT BOUNDARY MONUMENT—"211 M. 30 CHS." LOOKING SOUTHWEST.

No. 19.



VON SCHMIDT BOUNDARY MONUMENT—"210 M. 76 CHS." LOOKING SOUTHWEST.

No. 20.



VON SCHMIDT BOUNDARY MONUMENT—"210 M. 76 CHS." LOOKING NORTHEAST.

The triangulation from the astronomic station at the Needles to carry up the longitude to the thirty-fifth degree was executed by Assistant W. B. Fairfield. He measured a base of 1 709·326 meters in length four times—twice in the day and twice at night—with a steel tape 100 meters long, under a strain of 10 kilograms. Posts were driven every 10 meters to support this tape, and the contacts were made on pieces of tin nailed on top of the 100-meter posts. Two thermometers were read during the measurements. The day temperatures ranged from 98° to 116° and the night temperatures from 69° to 86°. The base line was leveled by Mr. G. J. Kammerer, and also connected with the rail of the Atlantic and Pacific Railroad at the Needles. This latter point was given by the railroad authorities as 477 feet above the Southern Pacific Railroad datum, which is the level of high water in San Francisco Bay, 5·7 feet above the level of mean low low water at Fort Point.

The distance between the Needles and the thirty-fifth degree east post of Von Schmidt was covered by two quadrilaterals. The latitude at the Needles was by this means connected with that at the Von Schmidt post and showed a difference of 9.19 seconds of arc, or 283 meters, due to local deflection.

The operations near the southeast terminus of the oblique boundary were completed by June 30, 1893, and the party returned to San Francisco to prepare for taking up the work on Lake Tahoe near the northwest end of the oblique boundary.

C. LAKE TAHOE OR NORTHWEST TERMINUS, 1893.

Preparations for this work were in progress from early in July to the 25th of the month. Horses, mules, wagons, harness, bedding, tents, instrumental outfit for longitude, latitude, azimuth, and triangulation were procured and shipped to Carson City; finally, the party left for the same point July 25.

The first step to be taken was the determination of longitude at a point on the Von Schmidt boundary of 1873 near Lake Tahoe. This was done by using Carson City as a base and connecting the lake station with it by the telephone line, which runs from Carson City to Glenbrook and thence along the shore of the lake to Bijou and Tallac, for exchanging longitude signals. The station used at Carson City was the latitude pier erected by me in 1889, $0^{m}·803$ north and $8^{m}·015$ east of the transit pier in the observatory of Mr. C. W. Friend. A rough wooden building was erected to shelter the instrument. The station on Lake Tahoe was placed in the open area on the east or front side of the Lakeside Tavern, formerly the property of Mr. Lapham, but in 1893 occupied by Mr. E. B. Smith.

This station is 61½ feet south and 33 feet west of the second granite monument from the lake shore, set by Von Schmidt in 1873 to mark the line at the road. This monument is "211 miles 30 chains" from the Oregon boundary. On one side is "CALIFORNIA," the other "NEVADA," and on the southeast face is "1873," evidently changed from 1863. The stone has a good foundation in gravel soil, and was in a vertical position.

The location of the longitude station was selected with reference to the telephone line from Carson City to Bijou. The use of this was given us by the owners.

The longitude pier was built of brick laid in cement, 2½ feet in the ground and 3 feet above. The top is 17 by 25 inches. After the astronomic work was completed the pier (called "Transit" in the triangulation records) was coated over with Portland cement, and a granite slab 17 by 25 by 6 inches placed on top. The station mark is a copper bolt in top of the slab. In 1899 all of this cement coating had been destroyed by frost, and, to prevent the bricks from disintegrating, a concrete coating made of cement and broken stone was placed around this pier.

A latitude pier 17 by 17 by 40 inches was erected 50 inches due west of the transit pier for the zenith telescope (No. 6), but it was removed after completing the observations, except the brick foundation about a foot below the surface.

Upon the completion of the astronomic stations, longitude signals were interchanged between Carson City, where Professor Davidson made the observations, and Lake Tahoe on August 3, 4, 6, 7, 8. After this Professor Davidson went to Lake Tahoe and I went to Carson, and signals were again interchanged on August 9, 10, and 11, which completed the determination.

The longitude determination was made in the following manner: Both stations were fitted up with instruments as near alike as possible; the same stars were observed at both stations, so as to eliminate errors of right ascension; after half the observations were completed the observers changed places to eliminate the personal equation. The observations were made on two time sets divided into two groups containing each four time stars and an azimuth star. Eight levels were read during each time set, or 16 during the night's work. The two time sets gave two independent corrections for the chronometer, and hence a rate so that the chronometer corrections might be applied to the epoch of interchange of signals between the two stations. About 30 signals were sent in each direction and recorded on the chronographs which are arranged for double speed. The time observations were recorded at ordinary or single speed.

On August 16 zenith telescope No. 6 was mounted on the latitude pier at Lake Tahoe, and the latitude was determined by 108 observations on 22 pairs of stars during five nights—August 16, 17, 18, 19, 20—and value of micrometer on δ Ursæ Minoris through upper culmination with chronographic record on August 21.

A primary azimuth was determined by Assistant George Davidson about seven-eighths mile northwest of Lakeside Tavern, on the shore of Lake Tahoe, with 20-inch theodolite No. 115, and introduced in the triangulation computation.

Immediately after the observations were completed the preliminary computations of both latitude and longitude were made for field purposes.

Early in September a base of 930 meters was measured with a steel tape on the shore of the lake and a scheme of triangulation developed and executed for the topography and for locating a point approximately on the boundary due north of the longitude station ("Transit"). The following data for determining this point were available:

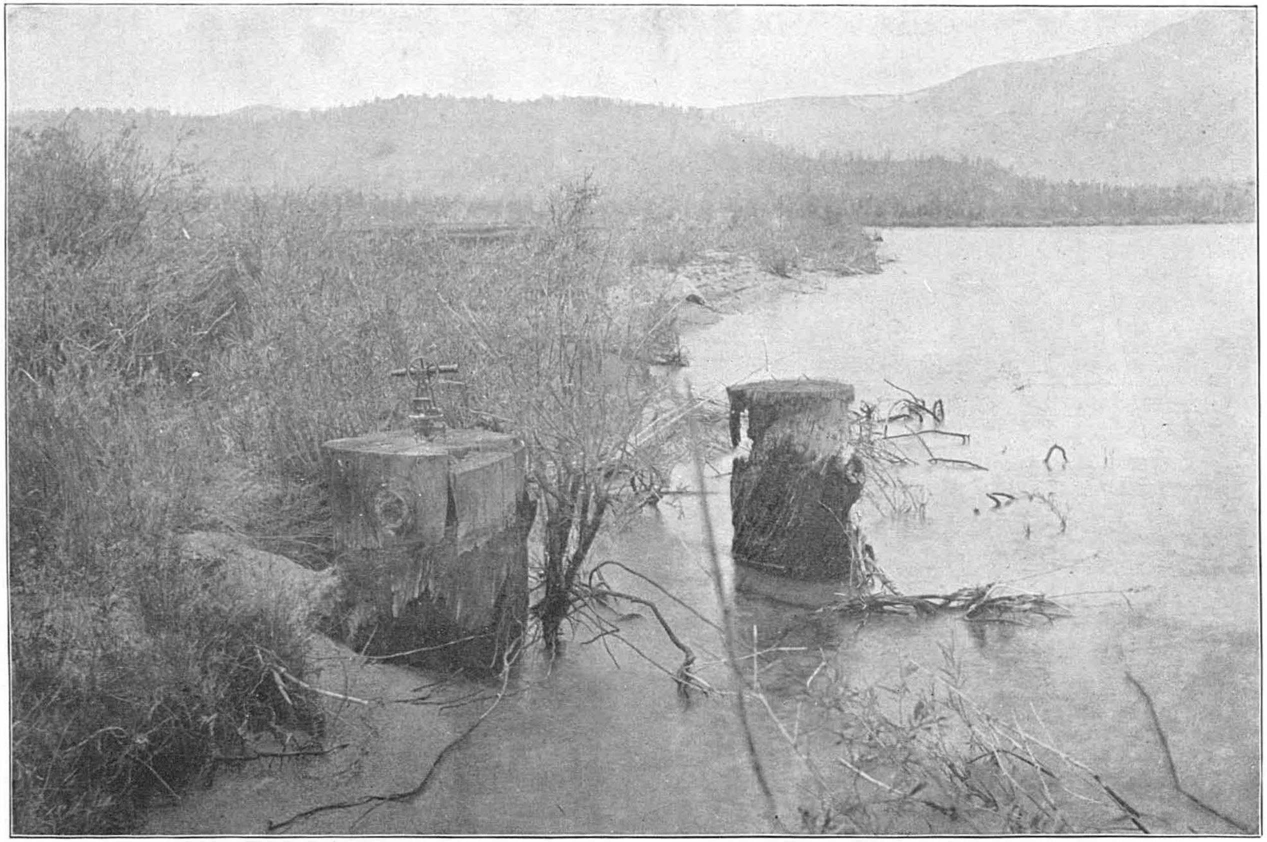
(1) The observed latitude;

(2) The observed longitude;

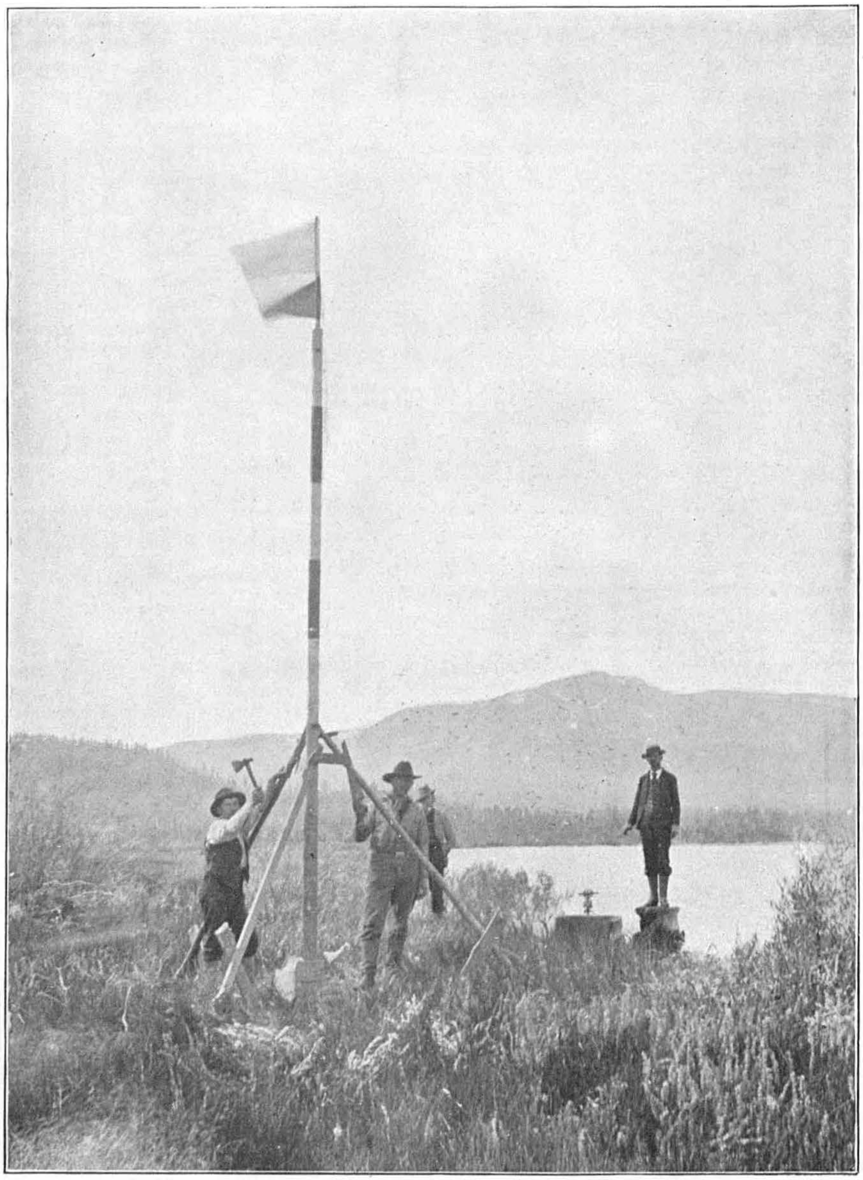
(3) The approximate azimuth 311° 19′ at the intersection of 39° latitude and 120° longitude furnished by the United States Coast and Geodetic Survey Office from former determinations of the Colorado River terminal.

The preliminary computations showed that the longitude station was 790.9 meters due south of a point on the oblique boundary.

The meridian used in the preliminary work was laid off with the astronomic transit, and the distance, 790.9 meters north of the longitude pier, was measured with a steel tape; the point thus located was called "Turning Point 1893." It was marked by



OLD INSTRUMENT BLOCKS, UPPER TRUCKEE RIVER.



Upper Truckee Station.

OLD INSTRUMENT BLOCKS, UPPER TRUCKEE RIVER.

a block of granite with a copper bolt in the top. This station was occupied with a 10-inch Gambey theodolite and the preliminary azimuth of the line was laid off and three other points were placed approximately in line and marked:

(1) "Initial stone 1893" on the lake shore, block of granite with copper bolt.
(2) "Road 1893," west side of main road, block of granite with copper bolt.
(3) "Mountain 1893," drill hole in stone on mountain 2·29 miles distant.

A meridian stone (granite) was placed 507·2 meters north of the longitude pier. It is in the east-and-west cut made by Grunsky and Minto in 1889, from Von Schmit's lake-shore stone, or 210 miles 76 chains monument. Another granite meridian mark was placed about 390 meters south of the longitude pier. Each of these was marked by a copper bolt in top with cross lines.

Five boundary marks established by Von Schmidt in 1873 were recovered, all in good condition:

(1) The granite monument on the shore of the lake, called "Lake shore stone" in the records, marked "210 miles 76 chains" on the northwest face, "1873" (changed from 1863) on the southeast face, "NEV." on the northeast, and "CAL." on the southwest face. This monument was in loose sand and leaning somewhat. A crib work of logs was placed around it after the stone was made vertical.

(2) A square wooden post set in the marsh to mark 211 miles.

(3) Granite monument on the southeast side of the road in front of Lakeside Tavern, marked "211 miles 30 chains," counting from Oregon, date changed from 1863 to 1873, and with "CALIFORNIA" and "NEVADA" on their respective sides. (See illustrations Nos. 15 and 16.)

(4) Wooden post to mark 212 miles, on the foothills.

(5) Tree marked "212 miles 53 chains," to preserve the site of Von Schmidt's observatory on the southeast shore of the lake.

The field notes of Von Schmidt state that this point (5) was marked by an "iron monument." I failed to find anything but a pine tree 8 inches diameter, marked "212 m. 53 ch. 21 lks.," "1873," "CAL.," and "NEV." The iron monument could not have been carried to that place except in sections, on account of the steep grade and rough mountain side. It was never set in place.

No search was made for Von Schmidt's line marks southeast of this point, as they were too far from our base of operations. This line (Von Schmidt) is blazed through the woods very clearly, and may be traced without any difficulty.

While executing the topography the line of 1863 was identified by means of a fence running along it and trees with blazes cut on them and traced nearly to the mountain summit. No marks were near the lake, but a wooden post without marks about 10 by 10 inches, 6 feet long, was found in the fence line just west of the Placerville road. The post was badly decayed at the ground and ready to fall. I learned afterwards that the two granite monuments now on the Von Schmidt line of 1873 were formerly on this line. The date 1863 was changed to 1873, as is clearly shown by inspecting the figures. These granite monuments are 6 feet long, 2 feet rough cut with base dimensions about 12 by 12 inches, and 4 feet dressed, being 10½ inches at the bottom and 8½ inches at top, and terminating in a flat pyramid.

Near the triangulation point, "Upper Truckee," three-eighths mile west of the mouth of the Upper Truckee River, two wooden blocks were found that had evidently been sawed off from a large tree about 2½ feet in diameter and used as instrument supports, presumably by Von Schmidt in 1873. These blocks were in the last stages of decay, and were nearly obliterated by a storm in September, 1893. The most westerly block was in the water, the lake having encroached upon the south shore. Two good photographs were obtained of these blocks.

The post set by Grunsky and Minto in 1889 to mark their boundary near the shore of the lake was found lying on the ground and photographed without disturbing it.

A second post set by them "4 073·3 ft." due east of the "Lake Shore Stone" of Von Schmidt was also found and determined on the topographic sheet No. 2151, scale 1:10 000. No other marks set by these engineers were looked for.

Several of the section trees of the land survey were included in the topography.

A number of the triangulation points along the lake shore toward Bijou and Rowland's were permanently marked with stones having drill holes in the tops.

A block of granite with a copper bolt and cross lines on top and with "120°" cut on its north face, was set on the low, narrow, grassy rim of firm land separating the marsh of the Upper Truckee River from the lake. This stone is three-eighths mile east of the mouth of the Upper Truckee River. It has about 18 inches exposed above ground.

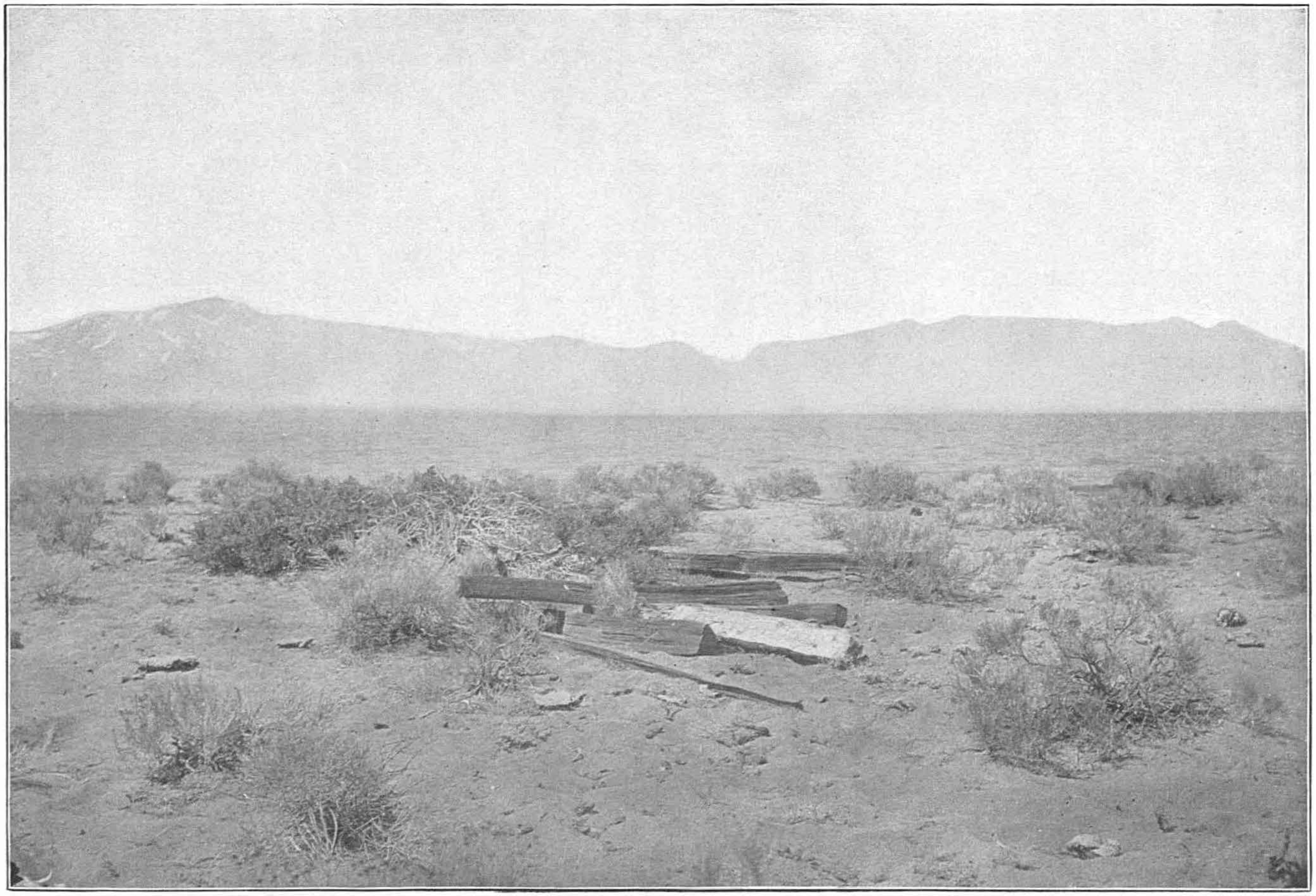
While I was engaged at the southeast end of Lake Tahoe, Assistant W. B. Fairfield executed the triangulation necessary to connect the primary work depending on the Yolo base, with the small triangulation executed by me. He used for this purpose the line "Lola–Round Top," 91 038·53 meters in length, and gradually contracted the scheme until he finally joined my work on the line "Folsom–Lake Shore Stone," 3 017·08 meters in length, differing from my rough determination with a steel tape base only 0·3 meter, which is sufficiently close for topographic purposes.

The following comparisons show the local deflection:

	Latitude.			Longitude.		
	°	′	″	°	′	″
"Lake Shore Stone" (astronomic data) determined from observed φ and λ 1893	38	57	34·854	119	57	05·125
Lake Shore Stone (geodetic data) from Yolo base triangulation	38	57	25·059	119	57	05·992
Difference or local deflection			9·804			0·867

On the Colorado River the difference between the latitude observed at Von Schmidt's 35° latitude post (astronomic) and the latitude brought up from the Needles (geodetic) 12 miles south by triangulation is 9″·13, as shown below.

	Latitude.			Longitude.		
	°	′	″	°	′	″
Von Schmidt's east latitude post, astronomic or observed	35	00	15·020			
The same, geodetic, from Lake Tahoe	35	00	14·640	114	39	31·710
			0·38			
The same, geodetic, from Needles	35	00	24·150	114	39	23·055
			9·51			
Difference or local deflection			9·13			8·655



GRANSKY AND MINTO POST OF 1889.

The country traversed by the boundary, as shown on the topographic sheet 1:10 000, has the following characteristics:

Near the shore the soil is chiefly sand from the disintegration of the granite forming the surface rock of the mountain range. The slope is gradual up to the foothills, which begin three-fourths of a mile from the shore. Beyond this the country is very much broken by hillocks and small peaks, having both sides and summits covered with masses of granite. This continues for three-fourths of a mile farther, rising at 1½ miles from the lake to an elevation of some 600 feet above its surface, where the steep side of the mountain is reached. The rise continues to an altitude of 3 300 feet above the lake.

The sloping ground and many of the little valleys are cultivated where water can be procured for irrigation. Several small mountain streams are utilized for this purpose, but the supply is not very abundant. All of this region was covered with a splendid growth of sugar pine, pitch pine, tamarack, white fir, and white cedar. Most of the original forest has been cut and the timber used in the mines of Virginia City and the neighboring towns. This industry necessitated the building of two narrow-gauge railroads—one at Bijou, the southern end of the lake, with several branches running through the timber, and the other at Glenbrook, to carry the lumber from the lake up to the summit, whence a flume conveyed it to Carson City, the nearest point to the railroad running to Virginia City and Reno. Two steamers were employed to tow rafts of logs to the sawmills and the barges, laden with wood from Bijou and other points on the lake, to Glenbrook.

In 1898 the narrow-gauge railroads were torn up and removed to the northwest side of the lake. For years the lake has been a summer resort. Many hotels have sprung up to meet this demand. A railroad now connects Tahoe City with Truckee, and a large steamer carries the mail and excursion parties around the lake during the summer.

Mr. Frank W. Edmonds acted as telegraph operator at the Lake Tahoe astronomic station, was recorder to Professor Davidson in observing the primary azimuth, and assisted in the preliminary computations and building of signals for triangulation and the topographic work.

Mr. G. J. Kammerer aided Assistant Fairfield in his triangulation. Among the many who rendered service and showed us courtesies may be mentioned Mr. C. W. Friend, of the Carson City observatory; Bliss Brothers, representing the Virginia and Truckee Lumber Company and owners of the telephone line from Carson City to Glenbrook; also the owners of the telephone lines from Glenbrook to Bijou and Tallac Hotel. No charge was made for using this line, and free transportation on the steamers plying between Glenbrook and Bijou was given us.

The season closed about November 1, and the party returned to Carson City for the purpose of storing the outfit and putting the animals out to winter. The party reached San Francisco from Carson City on November 3, 1893, and was disbanded. Mr. Fairfield and I remained in San Francisco, working on the records, until November 26, when we started to Washington.

D. FIELD OPERATIONS OF 1894.

During the winter of 1894 the office computations of the work executed at the Colorado River and Lake Tahoe termini were made, and the party was directed to resume operations on the California and Nevada oblique boundary, beginning at Lake Tahoe and running southeast in tracing the line. The great railroad strike beginning June 28, 1894, and continuing about a month, prevented us from getting into the field by July 1.

1. INSTRUCTIONS.

The following instructions of May 16, 1894, show the general scope of the field work:

TREASURY DEPARTMENT,
UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C., May 16, 1894.

C. H. SINCLAIR,
Assistant, Coast and Geodetic Survey, Washington, D. C.

SIR: After completing the Tacoma-Seattle longitude work and the necessary computations at San Francisco relative thereto, you will please arrange, in conference with Assistant Davidson, for the resumption, on July 1, of work on the California and Nevada boundary line.

You will begin at the Lake Tahoe end of the boundary and first observe an azimuth for the determination of its direction. This azimuth may be observed at a point 805·15 meters due north of the longitude station, which point is the intersection of the meridian of the longitude station with the oblique boundary. Calling T 0 the initial point in Lake Tahoe, and T 1, T 2, etc., the points in the line proceeding southeast, and C 0 the initial point in the Colorado River, and C 1, C 2, etc., the points in the line proceeding northeast, the azimuth—

$$\text{T 0 to C 0} = 311° \; 14' \; 36''·6$$

and the azimuth

$$\text{T 1 to C 0} = 311° \; 16' \; 39''·8,$$

hence the back azimuth

$$\text{T 1 to T 0} = 131° \; 16' \; 39''·8.$$

Having obtained the direction of the line, you will range it out with a theodolite, establishing points on the lake shore, road crossings, and summits, so that from any principal line mark two others, one forward and the other backward, may be visible. These line marks should be placed from 1 to 5 miles apart, according to the character of the country.

The distances between the principal line marks will be measured by small triangulation, continuous as far as practicable, and intermediate distances may be obtained where triangulation is impracticable by tape measures and telemeter.

Assistant W. B. Fairfield will be assigned to your party, and has already been instructed to report to you on July 1, at Lake Tahoe, after having attended to the purchase of necessary outfit.

Mr. Fairfield will execute, under your direction, the triangulation, and attend to the sketching of the topography, while you are engaged on the ranging out and marking of the line; but as your work will probably progress more rapidly than his, you will, from time to time, discontinue temporarily your line work and assist in the triangulation.

Latitude and longitude observations will be made at or near the intersection of the Carson and Colorado Railroad with the boundary, and an azimuth will be observed at said intersection. According to the railroad map the station named "Queen" is very near the boundary.

The magnetic elements should be determined at Carson City and Lake Tahoe, and the magnetic bearing of the boundary line should be observed at all monuments and triangulation stations occupied. For the latter purpose a compass declinometer may be used.

Assistant George Davidson will exercise general supervision over the work, and you will confer freely with him and keep him fully informed as to the progress of the work, but you will have control over your party funds and will submit your accounts, journals, and monthly reports directly to this office.

Your estimates for monthly expenses, etc., will be approved, but the amount of the allotment (probably $5 000) can not be fixed until after the passage of the appropriation bill by Congress. You will be duly notified hereafter of the amount of your allotment, and on its exhaustion you will, without further instructions, disband party, make suitable provision for the care of the public property in your charge, and proceed to Washington, D. C., and report to me in person at this Office.

Mr. Fairfield will also proceed to Washington, and his traveling expenses and your own, and all necessary expenses of the work, will be covered by these instructions.

Respectfully, yours, T. C. MENDENHALL, *Superintendent.*

2. AZIMUTH OBSERVATIONS SOUTHEAST END LAKE TAHOE.

In compliance with these instructions the party left San Francisco on July 27 for Lake Tahoe and reached the field of operations on the 31st, after getting together the animals, wagons, instruments, and other outfit stored in Carson City at the close of the preceding season. In June, Assistant W. B. Fairfield had gone to Carson Valley and purchased additional mules for our complement of team and pack animals.

From the new determination of the termini a more correct knowledge of their geographic position was obtained and a recomputation of the direction of the oblique boundary was made. The new azimuth was about five minutes less than the preliminary one used in 1893, and the new distance north of the longitude pier to reach a point on the oblique boundary was 805·15 meters instead of 790·9 meters.

The meridian was extended north of the old position of 1893 14·25 meters, and a large block about 16 inches in diameter and 7 feet long was cut from a dry pine log and planted 2½ feet in the ground as a support for the azimuth instrument (theodolite No. 82, 10-inch Gambey).

Azimuth was determined on August 3, 4, and 5 by means of ten sets on "Polaris at any hour angle." The terrestrial mark was placed at Folsoms Knob, distant 2½ miles. After computing the azimuth, the angle of the line was laid off and a point was located on the shore of the lake 460·7 meters distant and called "Initial 1894." The azimuth station itself was called "T 1." Another point, T 2, was set from the azimuth station 377·9 meters southeast on the road from Bijou to Glenbrook and Carson City (from Placerville to Carson Valley). These two points were marked with stones having copper bolts in top, moved from the preliminary points set in 1893. The theodolite was then transferred to the point on the shore of the lake, "Initial 1894," and a point was located on the mountain, T 3, 3 946·4 meters distant.

The theodolite was after this moved up on the mountain, where a camp was established. The stations T 3, T 4, T 5, T 6, and T 7 were successively occupied, the distances between them being as follows: T 3 to T 4, 263·4 meters; T 4 to T 5, 988·6 meters; T 5 to T 6, 652 meters; T 6 to T 7, 602 meters. Thus, in ranging out 4 miles, it was necessary to set up the theodolite five times in order to get over the summit of the mountain, which rises to 9 517 feet above the sea, or nearly 3 300 feet above the lake.

3. RANGING OUT THE LINE—ORGANIZATION OF PARTY.

The party was now divided into three sections. One under Mr. Fairfield, who had charge of the triangulation for determining the length of the line, the magnetic observations, and topographic sketching. The other two sections were the ranging-out section with the theodolite, under my immediate charge, and the forward section, which cooperated with me, under Mr. A. W. Cuddeback, who went ahead to locate points in line by means of a pocket heliotrope. Two heliotropes were used to get in line, one at the theodolite and one with the forward party, both parties being provided with a code of signals. The length of sight was limited only by the topographic features.

4. CARSON VALLEY—ANTELOPE MOUNTAINS—SWEETWATER MOUNTAINS.

From T 7 a number of points were located in Carson Valley, and as far away as T 22, on the summit of the Antelope range, a distance of 20·4 miles. The theodolite was then moved back to T 6 because it was higher, and T 32 was lined in on the east slope of the "Middle Sister," in the Sweetwater Mountains, 43·7 miles from the instrument. This was a very long sight, the longest recorded, to my knowledge, up to that time, of lining in a point, but it was exceeded by the next sight from T 32 to T 60 on the White Mountains.

The theodolite was moved from T 6 to T 32, and a number of points put in on the back line to the northwest as far as T 23 on the southeast slope of the Antelope Mountains.

It required three days to move from Lake Tahoe to the Sweetwater Mountains. The camp outfit and instruments were carried up on pack animals to a spring on the northwest side of the "Middle Sister," about a mile from the station.

5. WHITE MOUNTAINS.

From T 32 the White Mountains loomed up conspicuously, and as the season for stormy weather was approaching I sent the forward section directly to this distant place, and succeeded in getting a point located in 1 hour 40 minutes from the time the heliotrope was first seen. This long sight of 68·8 miles was made on a small pocket Steinheil heliotrope, with a mirror 1¼ inches by 1 inch, and the signals were clearly interpreted at that distance. This point was T 60, the southeast limit of our work for the season, 116·2 miles from the shore of Lake Tahoe.

The forward section returned after this to T 42, working back toward the theodolite station T 32. This point T 42 was nearly 27 miles from T 32 and almost 42 miles this side of the White Mountains. Points were located on all of the important intervening ridges back to T 32. The theodolite was afterwards moved to T 42, and points were placed on the ridges and roads to T 49, 16·5 miles southeast.

In order to reach T 49 it was necessary to cross the desert, a distance of 30 miles, without water. The route was from Aurora by Spring Peak across the desert to Adobe Meadows, at the east end of which is a large spring, making an excellent camping place. The instrument was set up at T 49, and points were lined in as far as T 53. The latter was then occupied and T 54 put in, so point by point until T 59 was reached, which marks the crossing of the Carson and Colorado Railroad, about 110 miles from the shore of Lake Tahoe.

Assistant W. B. Fairfield had charge of the triangulation, as before stated. It was decided at the beginning of the season to carry a scheme of triangulation along the line, with sides from 1 to 5 miles in length, to get the distances and control the work. The base for this purpose was obtained by contracting the primary work from "Round Top"–"Lola" to the requisite dimensions near Lake Tahoe. As the line could be ranged out more rapidly than the triangulation could be executed, I stopped the ranging from time to time and assisted in the triangulation, reconnaissance, and signal building.

The angular measures were made with a 6-inch Gambey reading to 5″, a 10-inch Gambey reading to 5″, and a 7-inch Buff and Burger theodolite reading to 10″. The party consisted of 11 men, all told; 23 animals, of which 5 were saddle horses and 18 were mules; 2 large wagons and 1 thoroughbrace, with a pair of mules. The party during this season was able to subsist on the country, at the ranches and small hotels. Provender, such as hay and grain, was generally procured in the immediate neighborhood of the work. Owing to frequent moves, the field operations were more in the nature of a reconnaissance than regular triangulation. During the season 60 points were established on the random line and 35 additional triangulation points were fixed.

Upon the completion of the triangulation the entire outfit was taken back to Carson City, the instruments and wagons stored, and the animals quartered for the winter. While this was being done, the magnetic elements were determined on three days with theodolite magnetometer No. 17 and dip circles No. 23 at Carson City, in the grounds of the "Pavilion," and in the meridian of the transit of Mr. C. W. Friend's observatory, one square south. The station was marked by a stone with a drill hole in the top. The magnetic elements were also determined on three days at the Lakeside Tavern, southeast end of Lake Tahoe, at a point 25 meters due south of the longitude pier of 1893, with the same instruments, just after the station at Carson City was completed.

The season closed and the party was disbanded on November 27, and Mr. Fairfield and I started to Washington on December 8, after getting the records in shape at the suboffice in San Francisco.

E. FIELD OPERATIONS, 1895.

1. INSTRUCTIONS.

TREASURY DEPARTMENT,
OFFICE OF THE COAST AND GEODETIC SURVEY,
Washington, D. C., May 15, 1895.

C. H. SINCLAIR,
Assistant, Coast and Geodetic Survey, Washington, D. C.

SIR: You will please make your arrangements to resume the survey of the California and Nevada oblique boundary, beginning at the point where operations were suspended last season.

The plan of operations will be the same as that of last season, except that it is not considered necessary at this time to determine longitude, latitude, and azimuth at the railroad crossing, since it is not required for the successful prosecution of the survey. A tape-line base, however, is to be measured at the railroad crossing and connected with the triangulation.

Assistant W. B. Fairfield will be associated with you in this work, and will execute the triangulation, topography, and magnetics, as he did last season.

Both you and Assistant Fairfield are authorized to purchase round-trip tickets to San Francisco, as thereby considerable expense will be saved.

At the close of the season both of you will report to me in person at Washington.

These instructions cover all necessary expenses of travel, transportation, and field operations incurred in their execution.

If necessary, an additional Aid will be sent you later.

Respectfully, yours,

W. W. DUFFIELD, *Superintendent.*

P. S.—In place of the additional Aid mentioned above, Mr. A. L. Baldwin, Assistant, will be assigned to your party.

Before leaving Washington for the West in 1895 I had written to Professor Davidson, who was in charge of the suboffice at San Francisco, and requested him to secure for me a few trustworthy men; consequently we were not long detained in San Francisco, but on June 3 proceeded to Carson City, Nev., where the outfit was stored and the animals had been left for the winter.

A few days were spent in shoeing the animals, repairing wagons, harness, and making other preparations for the season's work, and then the party started for Bertrand's ranch, near Benton, Cal., at the crossing of the Carson and Colorado Railroad, near the end of the 1894 work, about 160 miles distant. As the animals were fresh from the pasture the journey was made by easy stages to prevent making the shoulders of the mules sore and in order that the teams might be in good working condition upon reaching the scene of operations. About a week was consumed in making the drive. Our outfit comprised two 6-mule wagons, one thoroughbrace drawn by two mules, and two double buckboards, five saddle and pack animals in addition, making twenty-three animals and twelve persons in the party. Three other mules were purchased during the season. The buckboards proved to be a most serviceable addition to the outfit. With them, by using the large wagons as the bases of supply, camps were made in difficult places for a short time, and the pack animals were employed where the buckboards could not travel.

2. BASE AND AZIMUTH, WHITE MOUNTAINS.

The party reached the starting point on June 13. Next day preparations were made for measuring a base with a steel tape and an azimuth for the triangulation. Azimuth was measured at T 59, on Polaris, June 14 and 15 with theodolite No. 82, 10-inch Gambey, time being determined with the same instrument and with theodolite No. 159, a 7-inch Buff and Berger. On Sunday night, June 16, the base was measured twice with 100-meter steel tape No. 153, using a straight reach of the railroad and laying the tape along the rails. This base was 1 080·14 meters in length; the temperature was noted by two thermometers laid on the rail.

The base was connected with the triangulation by Assistant Fairfield, who occupied several points to the northwest for this purpose.

The organization of the party was in three sections similar to that of last season. The triangulation, topographic sketching, and magnetic observations were placed in charge of Assistant W. B. Fairfield. The forward section, for ranging out the line, was under Assistant A. L. Baldwin, who cooperated with me directly by going ahead and selecting the location of points on ridges or at the proper distances in the valleys. The direct ranging out and interpolating points was under my charge.

3. CROSSING THE WHITE MOUNTAINS, FISH LAKE VALLEY, SYLVANIA MOUNTAINS, GRAPE VINE MOUNTAINS.

The first station occupied by me for ranging out the line was T 60 (see illustration No. 42), the most southeastern point located during the preceding season on the bold north front of the White Mountains, which stand across the line as a formidable barrier about 13 000 feet above sea level. It is an exceedingly difficult station to reach, owing to its altitude and precipitous sides. The footing is very insecure in many places, on account of loose sand, and the difficulties were increased by the rarefied atmosphere. On Monday, June 17, a start was made for the summit, and camp was pitched at night at the highest water that could be found, in a little spot made green by the melting snow. Next morning we moved upward, slowly, as far as the animals could be induced to go, then, dividing the load between three of us, we reached the station after five hours arduous climbing, where it was necessary to shovel away the snow in order to get a forward sight. Patiently we waited for the heliotrope to flash from the forward party, and at last when it came they were on the wrong mountain, about 3 miles too close. It was too late for them to climb the next mountain that day, so there was nothing left us but to descend to our camp and repeat the trip.

When the ascent was made the next day the forward party was seen to be on the right mountain about 9·7 miles southeast in an air line, but as this station was 9 286 feet above the sea and the climb above the valley was about 4 000 feet, it was slow work for them and they were not in place until the afternoon, when a point was lined in at T 64 and two of us packed to the animals the observing tent and theodolite before dark and spent the night at our improvised camp. Next day the pack animals were brought over from the Queen mine and all of the effects were moved back to Bertrand's ranch, where the large wagon had been left.

By getting an early start and driving late the team was able to move in one day as far as McNett's ranch, nearly 40 miles, and not very far from T 64. Next day we went to a running stream for camp and carried the theodolite up to T 64, and a point was lined in back at T 61, about 6·6 miles to the northwest. This was on June 22, and from this time until July 4, points were lined in from T 64 back to the northwest and all across the Fish Lake Valley as far as T 79 in the Sylvania Mountains, nearly 37 miles to the southeast.

When the outfit was moved from T 64, we went to Piper's upper ranch, Oasis, Cal., near the south end of Fish Lake Valley, where the forward section was waiting for us. Beyond the Sylvania Mountains is a region difficult to operate in on account of the scarcity of water and provender. After due consultation, Mr. Baldwin started on an exploring expedition through this region on July 7, and I moved up to T 79 with the theodolite so as to be ready for the forward ranging. Mr. Baldwin flashed a heliotrope from the highest point of the Grape Vine Mountains on the 11th, 40 miles distant, but it was too late in the day to get a point, and one could not be located until the 15th, near T 89, owing to scarcity of water and long distances from his base of supplies. In the meantime I was able to line in points near by and to make reconnaissance and erect signals for the triangulation.

The forward party, after putting in two intermediate points, returned from their expedition on the 19th, and it was then decided to bring up the triangulation and get the entire party together before advancing through the region to the southeast. Mr. Fairfield was carrying the triangulation over the White Mountains, and, while I worked from T 79 to the northwest, Mr. Baldwin operated about 20 miles northwest of me and formed a junction with Mr. Fairfield. We were thus able to put three triangulation parties in the field.

Arrangements were also made for sending hay and grain to the southeast, a very necessary precaution, as it had to be hauled from Fish Lake Valley. An extra 6-horse team was hired for this purpose, because our own teams were utilized in distributing provender to the different mountain stations and hauling supplies from the railroad at Bishop.

By August 10 the triangulation had been brought up, provender sent to the southeast, and the parties moved in the same direction. Points having been lined in at T 85 and T 86, I moved forward to the Grape Vine Mountains, passing through the head of Death Valley via Sand Spring, where Mr. Fairfield was engaged in triangulation and putting in a few line stations. The only tree at Sand Spring was a sickly mesquite that made no shade, and the extremely high temperature was most trying to the members of the party as well as to the animals, which were exposed to the broiling sun. The first water beyond Sand Spring is at Staininger's ranch. A second ranch owned by the same man is nearer the Grape Vine Mountains closer to the boundary line. There was a small supply of alfalfa hay at this place, making it a good base from which the work could be conducted. The party remained there until all of the back triangulation was brought up and a forward point lined in for advancing across the Grape Vine Mountains. Although the next spring in the Grape Vine Mountains was less than a day's travel by trail from Staininger's, it required three days to get the teams around, and a distance of 65 miles was traversed. The route was from Staininger's to Thorp's mill, 18 miles; thence to Oasis, Nev., or Beatty's, 28 miles; thence to Big Springs about 19 miles, up in a cañon just at the east foot of the sharp summit called "Nye" in our triangulation, the next to the highest in the Grape Vine Mountains. Grain and hay were sent in advance to this spring, the party reaching there on September 5, moving up from Beatty's ranch with buckboards and pack animals, so as to leave the big teams available for hauling supplies.

From here the ranging was advanced to the southeast end of the Great Amargosa Desert, T 90 having been put in from T 89, T 91 from T 90, and T 92 from T 91. T 92 was a very commanding station. From it points were lined in all across the desert as far west as T 105, about 60 miles distant, the farthest point reached during the season, being on the mountain range dividing Ash Meadows from Pahrump Valley, called by Von Schmidt Chung-up, or Waterless Mountains.

Upon leaving Big Spring the party moved to Oasis, Nev. (Beatty's ranch), and then 8 miles to the next running water. From there it was 40 miles to a water hole, near Franklin Well, dug in the old bed of the Amargosa River, which comes out in Death Valley. Most of this distance is through deep sand, making it a trying trip for the mules with a heavy wagon. Mr. Baldwin had preceded the main party to the water hole and cleaned it out as well as dug it deeper so as to get an abundance of water. While waiting for me to come up he made a reconnaissance, erected signals, and selected a base for checking the triangulation.

Upon reaching this place it was decided to close the season's operations after bringing up the triangulation and measuring a base and azimuth, because it would have required more than a month to complete another reach of the line, and funds were not sufficient for that purpose. Accordingly, while Mr. Fairfield was bringing the triangulation through the Grape Vine Mountains and the Little Amargosa Desert, Mr. Baldwin undertook the central portion and I executed the triangulation at the southeast end as far as T 105 high, the farthest point in the scheme to the southeast, nearly 275 miles from the shore of Lake Tahoe.


N. E. Cairn
Desert Creek
Mahogany
sage brush
West Sister
From Wellington
Sweetwater
Clinton Mine
Sweetwater Ranch P.O.
School House
Sweetwater Creek
Conway Ranch
To Aurora
East Walker River
Fulstone Ranch
From Bridgeport
West Walker
Lone
Sugar Loaf
Rough Creek
Dry lake bed
Bald Peak
Bodie Creek
AURORA
Aurora Peak
Humboldt Stack
Del Monte Stack
Spring Peak
Toll Road
BODIE
Bodie Bluff
Desert
Cedar
Sage brush
sandy
To Adobe Meadows
Hontoun Valley
Sounding Rock
Orden

4. BASE AND AZIMUTH, GREAT AMARGOSA DESERT.

On October 4, with the assistance of Mr. Baldwin, a base of 1 494·9 meters in length was measured twice, at night, with 100-meter steel tape No. 153, over rolling ground near the southeast end of the Great Amargosa Desert.

I also measured an azimuth at T 101 east, on October 8 and 9, using "Polaris at any hour angle," with Buff and Berger theodolite No. 159.

All of the triangulation was completed by October 10, and arrangements made for starting toward the railroad at Bishop, Cal., by October 14. The route was from Franklin Well (or rather a water hole southeast of it) to Oasis, Nev., "lower water," 40 miles; thence to the "upper water," 8 miles, where one day was spent in getting our effects loaded. From there to Thorp's mill, 28 miles. The water at this well was very bad at that time, but since then the mill has been repaired, the well cleaned out and found to contain excellent water, but no provender is to be had there. The next stopping place was Lida, 35 miles, where there is good well water, but a very uncertain supply of provender. A small store at this place keeps a few supplies for miners. The next move was to Fish Lake Valley, Oasis, Cal., or Piper's ranch, 24 miles, where all kinds of supplies may be procured; provisions in small quantities, hay in abundance, and generally grain. From Thorp's mill a light team may proceed over the mountain grade by State Line Mills, near Oriental post-office, to Tule Cañon, Pigeon Springs, and Palmetto to Piper's ranch. From Piper's it is 40 miles to Big Pine and 15 miles farther to Bishop. Good water is found at Gilbert's, 12 miles from Piper's, and, also, at the tollgate on the pass 10 miles from Big Pine. We reached Bishop, 190 miles from Franklin Well, on Sunday, October 20. Here the animals were put out for the winter, the wagons stored, and the rest of the outfit was taken to Carson City by rail to be overhauled. We were in Carson City on the night of October 23. As many of the men as could be spared were discharged; the others were set to work overhauling, repairing, and oiling the harness, saddles, etc., and making out the inventory.

5. MAGNETICS AT LAKE TAHOE AND CARSON CITY.

As Mr. Fairfield found it necessary to reoccupy some of the triangulation points on Lake Tahoe, I made use of this opportunity to redetermine the magnetic elements at the magnetic station established in 1894 near Lake Side Tavern, southeast end of Lake Tahoe, 25 meters due south of the longitude pier. This magnetic station was marked by a block of granite standing 10 inches above ground with cross lines cut on top. All of the magnetic elements were determined on three days with theodolite magnetometer No. 20 and dip circle No. 21.

After this the magnetic elements were determined on three days in the "Pavilion" grounds, Carson City, at a new station established about 50 meters east of the 1894 station, so as to be free from the influence of the railroad track. Azimuth was observed at this station on one night, and a meridian line marked with two cut granite blocks, 8 by 8 by 30 inches, with a deep cross on top, in the Pavilion grounds, which is county property, and therefore may be preserved.

By the time this work was done, Mr. Fairfield had completed his observations on Lake Tahoe, and after duplicating the records the final start was made on the night of November 12, and I proceeded to Washington and reported to the superintendent.

The work done by Assistants Fairfield and Baldwin can not be commended too highly. They were practically in charge of their sections, dependent upon their own good management and intelligence for subsisting their men and animals and executing the work, which was done in most satisfactory manner. Their cooperation in the work was always cordial and effective.

F. FIELD OPERATIONS OF 1898–99.

There were several reasons for not resuming work on the boundary line until 1898, the chief of which was the small amount of money available for this survey. Owing to the intense heat during the summer along the southern part of the line, it was considered more advantageous to execute the work during the fall, winter, and spring. After running the random line and triangulating it to obtain the length, it was necessary to correct the line back to Lake Tahoe on the supposition that the random would not strike the terminal post at the southeast end near the Colorado River. It was, therefore, not advisable to undertake the survey until the funds were sufficient to do all of this. Under any circumstances it was necessary to take the outfit back over the line as far as Bishop to winter the stock, so it would have been bad management to return and not work back. This working back or correcting the line made it necessary that the party should be provided with not less than $10,000, and until 1898 that sum was not available.

1. INSTRUCTIONS.

A copy of instructions is here inserted:

TREASURY DEPARTMENT,
OFFICE OF THE COAST AND GEODETIC SURVEY,
Washington, D. C., October 1, 1898.

C. H. SINCLAIR,
Assistant, Coast and Geodetic Survey, San Francisco, Cal.

SIR: In conformity with my telegram of October 1, you will please submit estimates for the continuation of the survey and temporary marking of the California and Nevada boundary. Mr. Walter B. Fairfield, assistant, and Mr. F. W. Edmonds, will be directed to report to you for duty.

You are hereby authorized to make the necessary preparations and to put your party in the field without awaiting notice of the formal approval of your estimates.

The general scheme outlined in your statement of April 19, 1898, which contemplates the use of cut stone when practicable for marking the boundary, is approved, and the details of marking the boundary in the most permanent manner possible within the appropriation are left to your own judgment.

The appropriation for this work is as follows: "For surveying and temporarily marking that portion of the eastern boundary of the State of California, commencing at and running southeastward from the intersection of the thirty-ninth degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich, ten thousand dollars."

These instructions cover all necessary expenses of travel and transportation incurred in their execution.

Respectfully, yours,

HENRY S. PRITCHETT,
Superintendent.

2. ORGANIZATION OF PARTY AND TRAVELING TO THE FIELD.

As a preliminary step toward the resumption of the California and Nevada oblique boundary survey, I went to San Francisco on October 1, from Utah, and after the end of my leave of absence, October 15, was engaged in making preparations for field work. Assistant W. B. Fairfield, who had been engaged in primary triangulation in southeastern California, found me in San Francisco. Mr. Frank W. Edmonds, who was made an assistant in July, 1899, was also added to the party. A few trustworthy men of long experience in our survey work were engaged in San Francisco, and on October 20 the party left for Carson City, Nev.

Reaching Carson City the next day, the work of overhauling the outfit, selecting and shipping it from the storeroom, occupied us until the 22d. On Sunday, the 23d, the party went by rail to Bishop, Cal., where the animals were in pasture and the wagons had been stored in 1895. We reached Bishop October 24, and were employed until the 30th in shoeing the animals, repairing the wagons, getting supplies, and perfecting arrangements for taking a large party through 210 miles of country, for the most part desert, uninhabited, and with but few watering places.

The start on the long journey was finally made on October 31. The party consisted of 11 persons, 2 6-mule wagons, 1 thoroughbrace and 2 double buckboards, besides 5 saddle horses and 3 extra pack mules, a total of 26 animals. There were two additions to the party later on, making 13 persons in all. The experience gained in former seasons was of use in making this trip. As the animals were fresh from pasture they could not be driven hard at first for fear of making their shoulders sore and breaking them down. Moreover, the distances traveled were, to a great extent, regulated by the watering places. Once only 8 miles were traveled; another day it was necessary to make 35 miles; after several hard days in succession the teams were allowed to rest an extra day, so it was not until the morning of November 12 that the party reached the scene of operations, after a journey of nearly 210 miles from Bishop.

The organization of the party was similar to that of the preceding season, viz, the ranging section under my immediate charge, the forward section under Mr. Frank W. Edmonds, and the triangulation under Assistant W. B. Fairfield. All three sections assisted in this last work according to the need of bringing it up with the ranging of the line.

3. ASH MEADOWS, STEWART VALLEY, PAHRUMP VALLEY.

The first working camp was at Mound Spring, near the southeast end of Ash Meadows, on the road to Pahrump Valley, and 6 miles north of the last station located in 1895, called T 105, which was the first to be occupied this season as a ranging station. Arrangements were made to have hay and grain hauled to this spring from Manse, a ranch in Pahrump Valley, 24 miles southeast. This ranch supplied the party with hay and grain for 100 miles, and without it we would have incurred heavy expense in hauling supplies from the railroad and from Fish Lake Valley by team.

On Sunday, November 14, with one member of the party I went over the line to the northwest, putting up signals for back ranges at T 103 and T 101, the latter nearly 16 miles from T 105. On the 14th the theodolite was moved to T 105 and mounted for ranging in line points to the southeast. The same day the forward section went over the mountain to Stewart Valley to get a point. The distance driven was very great and the mountains exceedingly rough, so it was not until late in the afternoon that the heliotrope was seen about 3 miles away along the mountain top. Unfortunately the sun was cut off by a near mountain before the position could be obtained, and the forward section had to drive until 11 o'clock that night before reaching a stopping place. Next morning the forward party gave two points in line to the southeast, T 107 and T 108, 7 and 10 miles away.

4. MESQUITE VALLEY, STATE LINE MOUNTAINS, IVANPAH VALLEY.

In the meantime Assistant Fairfield, who had gone forward to reconnoiter and erect signals for triangulation, was lined in at T 106, 3 miles distant on a very rough mountain, using a pole for that purpose. Point after point was ranged in up to T 116, 34·5 miles distant, on a small ridge at the south end of Pahrump Valley. The ridge cut off all view across Mesquite Valley, but did not obscure the State Line Mountains, nearly 61 miles distant. To this place the forward section was sent, and on November 22 a point was located by heliotrope at T 123 from T 105. This was the second longest sight on the entire line.

The theodolite was next moved ahead to T 123, passing the ranch at Manse, where Mr. Flynn joined the party and went with us to Sandy and to Bullock's Well, 6 miles from the station on State Line Mountains, where supplies had been sent. The day after leaving Sandy the instrument was taken up to State Line Mountains at T 123, and next day Mr. Edmonds began working back to the northwest, giving me a point in line near Sandy post-office, about 14 miles distant. Mr. Edmonds himself first went to T 116, 26 miles away, to enlarge the signal and to show a heliotrope in line, so as to make sure of an object to point on for the back ranging. By November 30 all of this portion of the line had been completed back to T 117, after which Mr. Edmonds went to the southeast in Ivanpah Valley.

On December 2 and 3 four points were lined in to the southeast—T 125, T 126, T 127, T 128. On December 5 it was cloudy, and no ranging could be done without sunshine, but angular measures were made for triangulation at T 123, and Mr. Flynn was engaged in erecting signals and observing angles to the northwest. On December 7 T 130, 26 miles distant, was located on the New York range of mountains near Vanderbilt, the limit of seeing to the southeast.

For three days, December 8, 9, and 10, snow storms and heavy rains prevailed so that but little could be accomplished; the party not having provided stoves, suffered severely at night during this period. On December 11, 12, and 13 the thermometer stood at 10°, 12°, and 14° in the early morning, temperatures rarely experienced in that southern country, according to the statement of miners.

5. DRY LAKE WELL, NEW YORK MOUNTAINS, MANVEL, CASTLE MOUNTAINS.

Before moving forward to the New York Mountains two quadrilaterals to the northwest of State Line Mountains and one to the southeast were completed by my section, to help along the triangulation. On December 20 the party moved ahead to Manvel, via Dry Lake Well, the only water on the road. On December 22 we reached Malpais Springs, on the southeast slope of the New York Mountains, and the nearest water to T 130. On the 23d the theodolite was moved to T 130 and T 131 put in. The same day from T 131 a point was located at T 132, on the lofty cliff or butte in the

Castle Mountains, 5 miles distant. On the 24th No. 132 was occupied by the theodolite and No. 133, 4 miles distant, was lined in.

In order to move forward from this place to the southeast at Piute Springs it was necessary to hàul hay and grain there from Manvel, and while this was being done by Mr. Edmonds, Mr. Flynn and I erected signals and observed angles in the triangulation scheme. Mr. Edmonds was ready to resume the lining in by December 30. On that date a point was lined in at T 134, and next day T 135, T 136, T 137, and T 138 were set from T 132, the last being 23 miles distant. The weather continued very cold and windy all of this time.

6. MALPAIS SPRINGS, PIUTE SPRINGS.

While Mr. Flynn was left to complete some of the triangulation near Malpais Springs, and to bring forward the big team, I moved ahead in the buckboard on the east side of the Lewis range of mountains to join Mr. Edmonds with the forward section at Piute Springs, January 2, 1899. He had traveled by the western route from Manvel and it was necessary to cut away the bushes and repair the road in the defile to the eastward at Piute Springs in order to get his team through. This was completed on the 3d, and next day while Mr. Edmonds traveled over to the Colorado River with the thoroughbrace and buckboard by the old government road, I went to the Needles on a saddle horse by the great Piute wash, and sent up hay and grain to the camp near Von Schmidt's east 35° latitude post. On Friday, January 6, the big team that had been left at Malpais Springs crossed the grade and reached the camp on the Colorado River. On January 9 I went to the summit at T 138, overlooking the Colorado River Valley, and lined in T 139 and T 140. Next day, January 10, the last two points, T 141 andT 142, were lined in from T 139, and the work of ranging out the random line was completed.

Six years before a post had been placed by us to mark a point on the oblique boundary nearest to the river crossing of the thirty-fifth degree of latitude. It was with some feeling of interest that this point toward which the theodolite had been directed in 1894 from a similarly placed point in the oblique boundary near Lake Tahoe, about 400 miles distant, was approached. From the lining station, T 139, it could not be seen how near the random line came to this post; but, when returning to camp, a detour was made on horseback to see what the distance was. Gradually, while drawing near, both points came into view, and upon reaching the place it was found that we had come within 150·5 meters of striking the point.

The line passed over altitudes varying from about 500 feet at the Colorado River to nearly 13,000 feet at the White Mountains. It was shown by the observations that the local deflections at the Colorado River end amount to about 9″·19, 283 meters in latitude, and at the Lake Tahoe end to a greater amount. The uncertainty in azimuth at different points on the line may be great; but if so, the errors due to local deflection must have very closely balanced, as proved by the small error at the end of the line—a line ranged out and triangulated for nearly 400 miles.

In 1893 Assistant W. B. Fairfield measured a base with a steel tape at the Needles, and executed a scheme of triangulation to connect the latitude and longitude stations at that point with the latitude station at Von Schmidt's thirty-fifth degree east-latitude post. In order to connect the triangulation brought down from Lake Tahoe with this work a reconnaissance was made, signals were erected, and horizontal angles were observed until a junction was made with Assistant Fairfield, who was working toward the Colorado River from the northwest. This work was completed by January 24, and two days later Mr. Fairfield's section reached the Colorado River camp.

Mr. Flynn took charge of the computations from the time of his arrival, and under his direction were placed those members of the party who could assist him, and such good progress was made that all of the adjusting was completed by February 16, about five weeks after he first reached the Colorado River. During a part of this time I was engaged in sketching the topography of the river from Fort Mohave to the Needles on a scale of $\frac{1}{10\,000}$, using the stations established in 1893 and a small mountain plane table.

Upon completing the computations a comparison of the work brought down from Lake Tahoe could be made with that brought up from the Needles, the line of junction being "Peak—Von Schmidt's East Lat. Post"—3 180·34 meters in length.

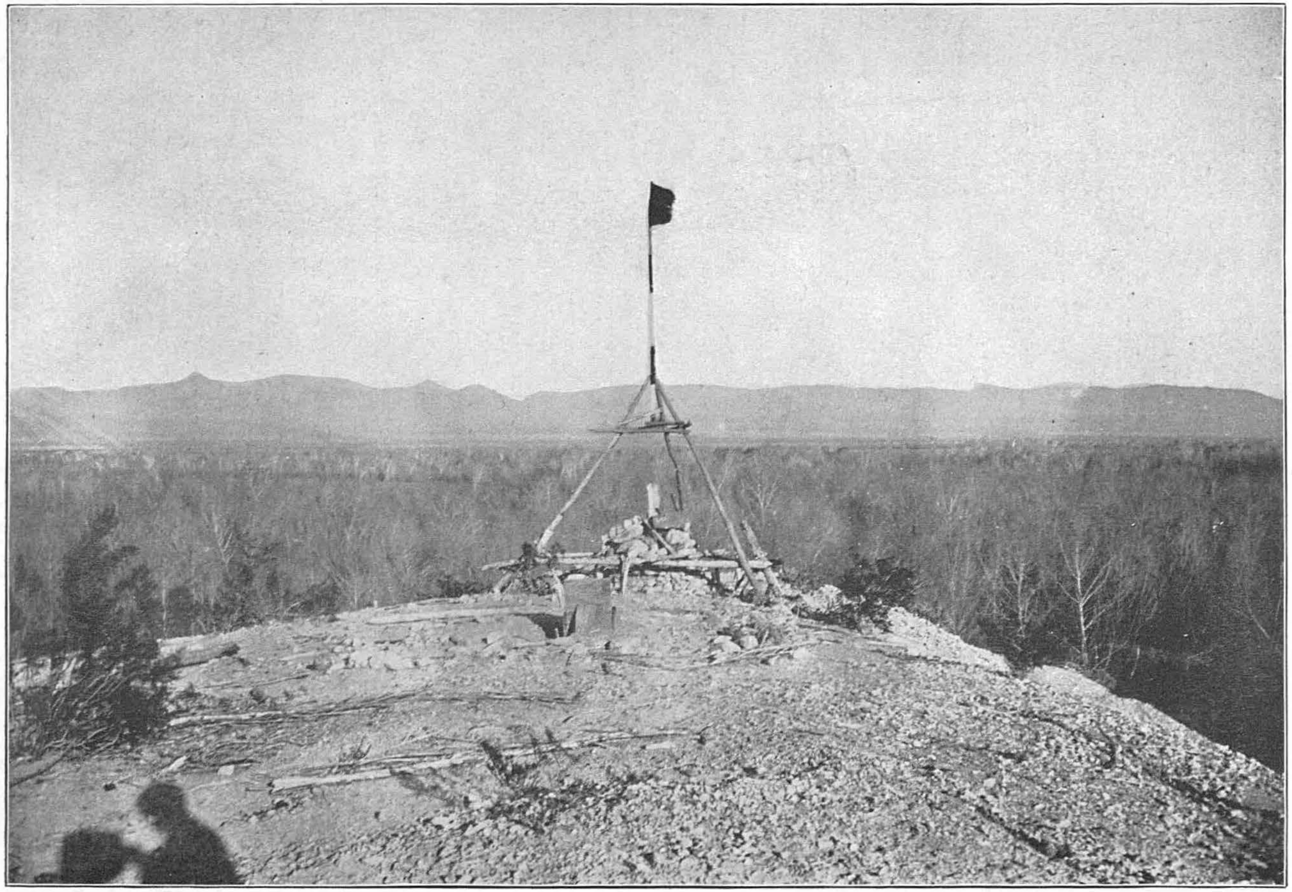
7. COMPARISON OF RESULTS.

The following comparisons will prove interesting:

Length of the line "Peak-Von Schmidt East Lat. Post" from the Needles base . meters . .	3 180·34
Length of the line "Peak-Von Schmidt East Lat. Post" from Lake Tahoe triangulation . . . meters . .	3 180·05
Difference . . . do	0·29
Azimuth of the line "Peak-Von Schmidt East Lat. Post" from that observed at Von Schmidt post . . .	91°26′07″·9
Azimuth of the line "Peak-Von Schmidt East Lat. Post" from Lake Tahoe triangulation . . .	91°25′57″·8
Difference . . .	10·1
Latitude of Von Schmidt's East Lat. Post, observed in 1893 . . .	35°00′15″.020
Latitude of Von Schmidt's East Lat. Post, from Lake Tahoe triangulation . . .	35°00′14″.641
Difference . . .	0·379
Longitude of Von Schmidt's East Lat. Post, from Needles, 13 miles south, 1889, by telegraph . . .	114°39′23″·055
Longitude of Von Schmidt's East Lat. Post, from Lake Tahoe triangulation . . .	114°39′31″·708
Difference . . .	8·653
The random line ranged out from Lake Tahoe, 400 miles distant, passed southwest of the Colorado River terminal post (error of ranging or closure) . . . meters . .	150·5
Length of the oblique boundary, To–Co, computed from astronomic data . . . do	652 020
Length of the oblique boundary, To–Co, measured by triangulation . . . do	651 676·4
Difference . . . do	343·6

When it is considered that the scheme of triangulation along the line was inferior in character, the sides of the triangles varying from less than a mile to 10 miles in length, the angles measured with theodolites having circles 6, 7, and 10 inches in diameter, using 12 repetitions chiefly, upon signals of poor quality, not waiting for favorable conditions, but observing at any hour of the day, the agreement in length (0·29 meter) and in azimuth (10″·1) may be regarded as highly satisfactory.

Quadrilaterals and central figures were carried from one end of the line to the other, and in no instance was a distance in the main scheme left unchecked; but in a



LATITUDE AND AZIMUTH STATION, 1893. VON SCHMIDT 35° LATITUDE POST (EAST POST). LOOKING EAST.

few cases it was found necessary to depend on concluded angles, on account of having mistaken other objects for signals during the observations, when it would have delayed the work too much to go back for a reoccupation of the stations.

8. BASE LINES.

Two intermediate bases were measured as checks upon the triangulation, which therefore depends upon four bases—the Yolo, a primary, from which, through the primary line "Lola-Round Top" (91 038·53 meters in length) was determined the first line in the scheme.

Base.	Length.
	Meters.
Lake shore stone-Folsoms Knob, on Lake Tahoe	3 017·2
The White Mountain base, 109 miles from the first	1 080·14
The Amargosa base, 154 miles from the White Mountains	1 464·93
The Needles base, 152 miles from the Amargosa base	1 709·33

These bases give a fair distribution of checks.

Two intermediate azimuths were observed, one at the White Mountain base and one near the Amargosa base, but the entire line, as ranged out by back and fore sights, depended upon the initial azimuth measured on Lake Tahoe at "Turning point, 1894," where the tracing of the line was started in August, 1894.

G. THE CORRECTED LINE.

The first operation after completing the adjustment and computations of the triangulation was to set the terminal post, located approximately in 1893 from the field computations, in the corrected position. This was done by setting up the theodolite at "S. E. line post of 1893" and laying off the angle to the south from the triangulation, then measuring due south 12·42 meters with a steel tape. The theodolite was then set over this corrected position, and the second point northwest nearly abreast of "N. W. line post of 1893" was lined in by laying off the azimuth of the line as determined by the office computation.

1. TERMINAL MARK AT THE COLORADO RIVER, 35° LAT. POSTS.

The terminal mark on the Colorado River is a mass of concrete 17 by 17 by 18 inches, being a portion of the old latitude pier used at the "Von Schmidt E. Lat. post" in 1893. This was sunk in the ground and has a drill hole in the top to mark the station. On top of this was placed a redwood post 6 inches by 6 inches by 6 feet long, marked "S. E. LINE POST." It is the old post used in 1893. Around the post was built a cairn 10 feet in diameter and 6 feet high. An outer circular wall of stone nearly 20 feet in diameter and 1 foot high surrounded the cairn. Four stones with drill holes were set in the ground just outside of the outer wall, two being in the direction of the line and two at right angles. From the center it is—

	Meters.
To the northwest stone	3·14
To the southeast stone	3·22
To the northeast stone	2·86
To the southwest stone	3·11

This terminal is called No. 142, counting from Lake Tahoe. The second station, called No. 141, about 2 250 meters northwest from No. 142, is marked by a drill hole in a stone set in the ground. On top of this is a redwood post 6 inches by 6 inches by 6 feet, marked "N.W. LINE POST," being the old post used in 1893. A cairn 5 feet in diameter and 4 feet high was built around this post.

The two posts set to mark the approximate thirty-fifth degree of latitude in 1893 were moved to their correct positions also, which was 19 feet due north of the old position of 1893. The marks on these posts were not changed, but under each post was placed a stone with a drill hole in it, and a large cairn was built around each. The west post has a circular trench about 10 feet in diameter dug around it, in addition to the cairn.

2. RETURN OVER THE LINE. REDUCTION OF PARTY.

Having set all of the marks that could be conveniently reached from the camp on the Colorado River, the party began its return over the line to correct it and set the final boundary marks, on Friday, February 17. There were but few places in the first 75 miles where the offsets could be directly laid off with a steel tape. A slight move at right angles to the line often meant changing to a different hill, sometimes nearer and sometimes farther ahead than the station on the random line. When the ground was very rough or mountainous the new points were lined in and the corrected position of the point was located generally by angular measurements.

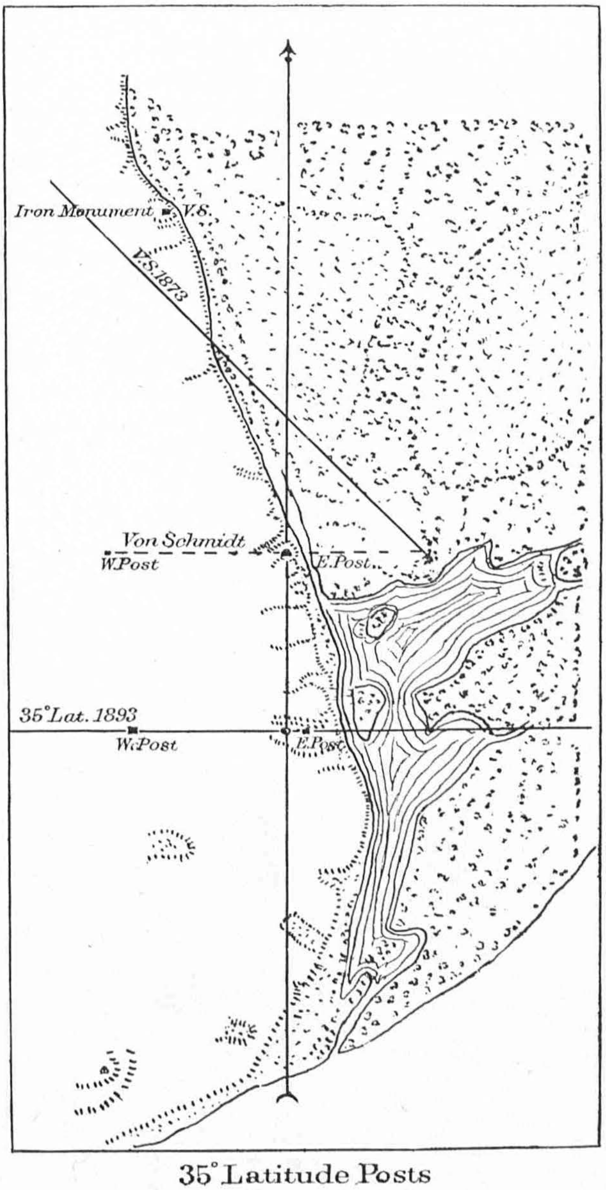
By the end of February the party had reached Manvel on its return. It was found advisable to reduce the party at this time in order to lessen expenses so as to leave money enough to complete the correction of the line. Mr. Flynn was, therefore, directed to take charge of the men and outfit that could be spared, cross the desert to Bishop, Cal., about 300 miles distant, sell 11 animals, one large wagon, and the thoroughbrace, store the rest of the outfit in the Federal building at Carson City, and report to the Superintendent in Washington. By this reduction the monthly expenses were changed from an average of $1 237·22 to $709·86, with 7 men and 14 animals. Such portions of the outfit as were not required in the field were shipped by rail from the Needles and Manvel to the suboffice in San Francisco.

The party made rapid progress in correcting the line for the first 140 miles, because the triangulation signals were all standing and the weather was favorable. To the northwest of this, after striking the Grape Vine Mountains, bad weather prevailed. Snowstorms were frequent and the line had to be reached from springs a long distance off. Where the signals were standing, the muslin, put on three and one-half years before, had disappeared. When the party reached Fish Lake Valley and were working across the White Mountains, snow interfered very materially with the progress, although it was late in April. Early in May the party crossed to the north side of the White Mountains, where the altitudes were not so great and snowstorms were less frequent.

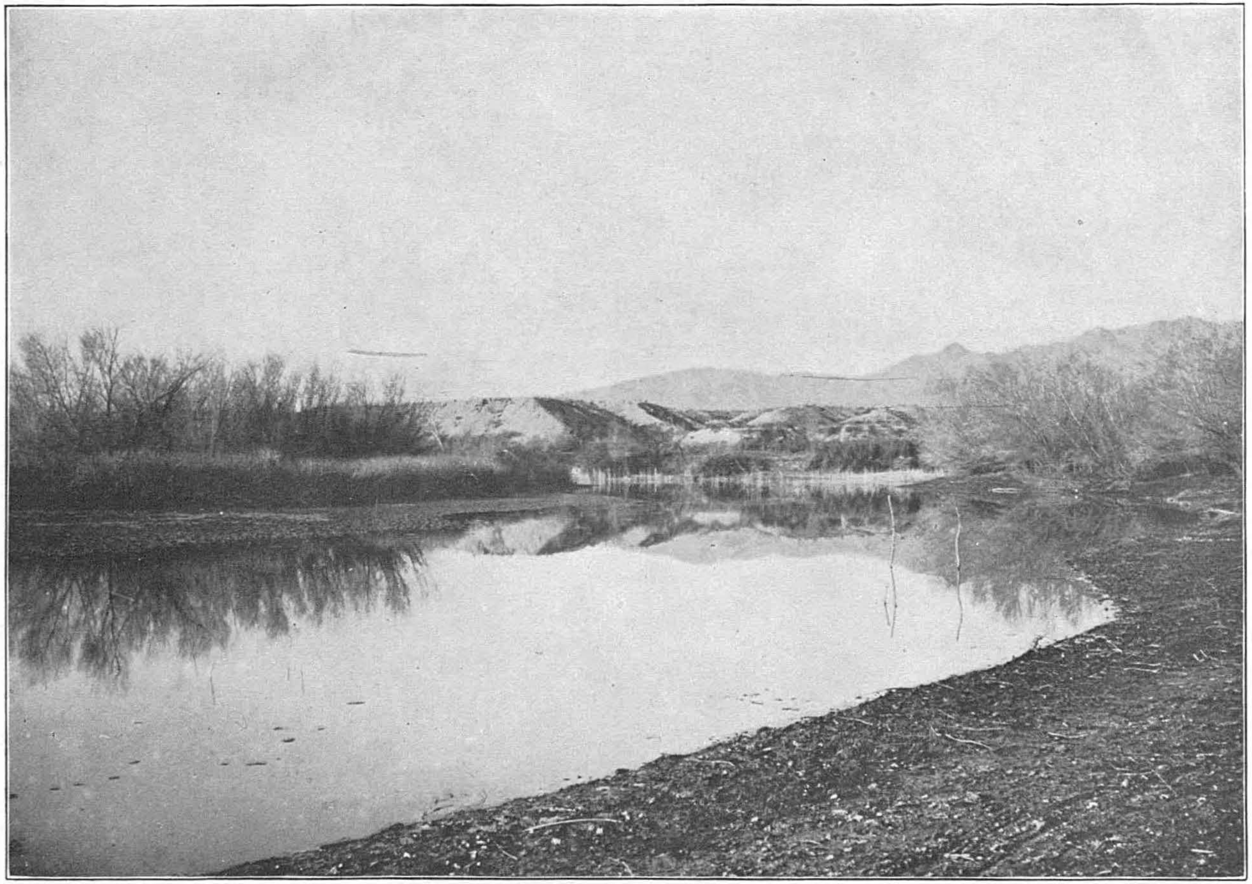
3. TERMINAL MONUMENT, LAKE TAHOE.

By gradual stages the work advanced until Lake Tahoe was reached, and there, on June 12, the stone that marked the beginning of the line on the lake shore was set in concrete, which completed the field operations.

Most of the boundary positions were marked by a post—redwood, cedar, or pine—with a cairn from 3 to 5 feet high around the post. If the point fell in the desert with



35° Latitude Posts



SMALL LAKE AT COLORADO RIVER CAMP. LOOKING SOUTHWEST.

SETTING TERMINAL MONUMENT, LAKE TAHOE.

No. 54.

MONUMENT NO. 1, LAKE TAHOE. LOOKING NORTHWEST.

TEAMS AT LAKESIDE TAVERN, END OF SEASON.

no stones near, a single stone with drill hole in it was used as a ground mark, and a mound of earth or sand was heaped around the post, with a circular trench outside. Eight of the points, Nos. 1, 2, 11, 12, 13, 14, 24, and 27, were marked with granite monuments 6 feet long, 6 inches at top, dressed down 4 feet from the top to 12 inches, and rough cut for 2 feet to set in the ground, weighing about 850 pounds; the top terminated in a flat pyramid. These monuments were quarried near Carson City and dressed in one of the Carson City stone yards. The boundary posts were marked with the letters "C" and "N" on their respective sides, with the number on the northwest. The letters were made with wire nails 1½ inches long driven into the posts. On the stone monuments the letters "C" and "N" were cut, but the numbers were painted. When the line is permanently marked the distances may be cut or cast according to the nature of the material. The present system of numbering the marks is simply for the purpose of identification.

On June 13 the party moved from Lake Tahoe to Carson City, and until the 20th was engaged in making the inventory, packing and shipping the instruments and other outfit to San Francisco, and completing the duplicate records. On June 20 the animals and wagons were sold at public auction, and the same day I went to San Francisco with the remaining members of the party, where they were discharged. I then started for Washington and reported to the Superintendent on June 30.

In former years I have had occasion to refer to the cordial and cheerful cooperation between the different members of the party, without which progress would be slow and success doubtful in work of this kind. Assistant W. B. Fairfield was in charge of the triangulation and he always showed most commendable zeal and interest in executing the work. Mr. Edmonds, who was in charge of the forward section of the line work, proved equal to every emergency that arose. His work required good judgment, foresight, and many sacrifices of personal comfort to get his party through a region sparsely settled. Mr. Flynn joined the party after the work was started, and displayed great energy in taking hold of the reconnaissance, signal building, and triangulation. His principal work was in adjusting the triangulation of the last 130 miles of the line, and this he did with marked success and in a short time, considering the great mass of work involved in abstracting angles, adjusting and computing the triangle sides and geographic positions for the entire season.

In 1893, topographic surveys were made at the Lake Tahoe and Colorado River termini, on a scale of $\frac{1}{10000}$. Only a limited area was embraced in these sheets. In 1899, to show roughly the topography, 14 sheets were used, on a scale of $\frac{1}{40000}$. The work was done chiefly with a small mountain plane table, which was set up on the line and oriented by means of some of the triangulation points. The sketching was executed partly by me and partly by Mr. Edmonds. The altitudes on the sheets were obtained by vertical measures with the theodolite. No elevations on the sheets were obtained with the plane table. Many photographs were taken along the line in 1899, but most of them were injured by a crack in the camera, due to the lofty elevation and dry atmosphere. Magnetics with compass declinometer No. 741 were observed all along the random line.

H. CHANGE OF AREAS.

By comparison with the Von Schmidt line the State of Nevada gains about 321 square miles; California gains about 65 square miles; making a net gain for Nevada of about 256 square miles.

Owing to the barren character of the country traversed, the change of area does not mean a material gain of taxable wealth to either State in arable land. As to the value of mineral wealth involved, that will depend upon future discoveries; at present there are no indications of important changes.

I. MAPS.

The following maps accompany the report (see end of volume):

1. The California and Nevada Oblique Boundary in 7 sections. Scale, 1:120000.
2. Index map showing arrangement of topographic sheets, triangulation, and profile of the random line. Scale, 1:533333.

J. STATISTICS, CALIFORNIA-NEVADA BOUNDARY.

	1893.	1894.	1895.	1898–99.	Total.
Number of signals erected	50	93	114	86	343
Triangulation stations occupied	36	65	90	70	261
Trigonometric points determined	71	106	122	96	395
Horizontal angles measured	532	992	1 179	870	3 573
Horizontal angles, repetitions	7 163	11 769	14 023	9 273	42 228
Vertical angles measured		133	329	619	1 081
Vertical angle measurements		266	658	1 238	2 162
Magnetic stations, compass declinometer		60	38	36	134
Magnetic stations, magnetometer		2	2		4
Stations located on the random line		60	47	38	145
Boundary marks on the corrected line					137
Von Schmidt, 1873, marks recovered					50
Telegraphic longitude, determined	1				1
Latitudes determined, zenith telescope	2				2
Azimuths measured, theodolite	2	1	2		5
Base lines measured, steel tape	3		2		5
Topographic sheets, 1:10000	2				2
Topographic sheets, 1:40000, sketched				14	14
Approximate area sketched square miles					850
Approximate area triangulated do					1 660
Monuments to be placed at 5, 6, 50, and 90					
Average distance of boundary marks, 141 in number, in miles					2·83

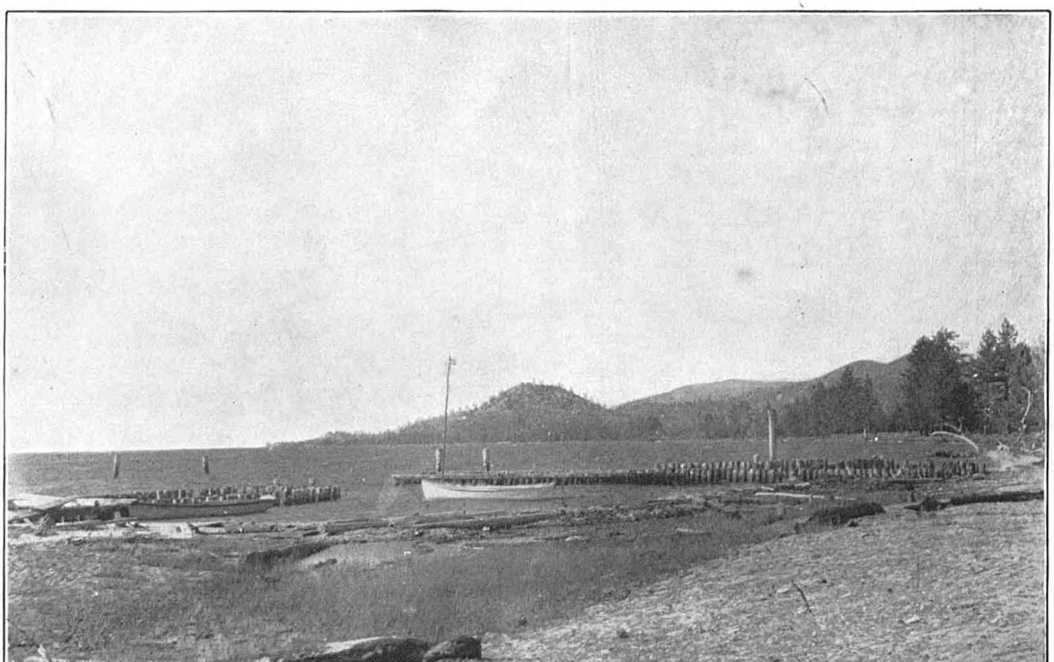
K. APPROPRIATIONS, COST, ETC.

The act making appropriations for sundry civil expenses of the Government for the fiscal year ending June 30, 1893, and for other purposes, approved August 2, 1892, contains the following on page 9:

For furnishing points to State surveys, to be applied, as far as practicable, in States where points have not been furnished, and for surveying and distinctly designating with permanent monuments that portion of the eastern boundary of the State of California commencing at and running southeastward from the intersection of the thirty-ninth degree of north latitude with the one hundred and twentieth degree of longitude west from Greenwich, fifteen thousand six hundred dollars.

ROWLANDS TRIANGULATION STATION. LOOKING WEST.

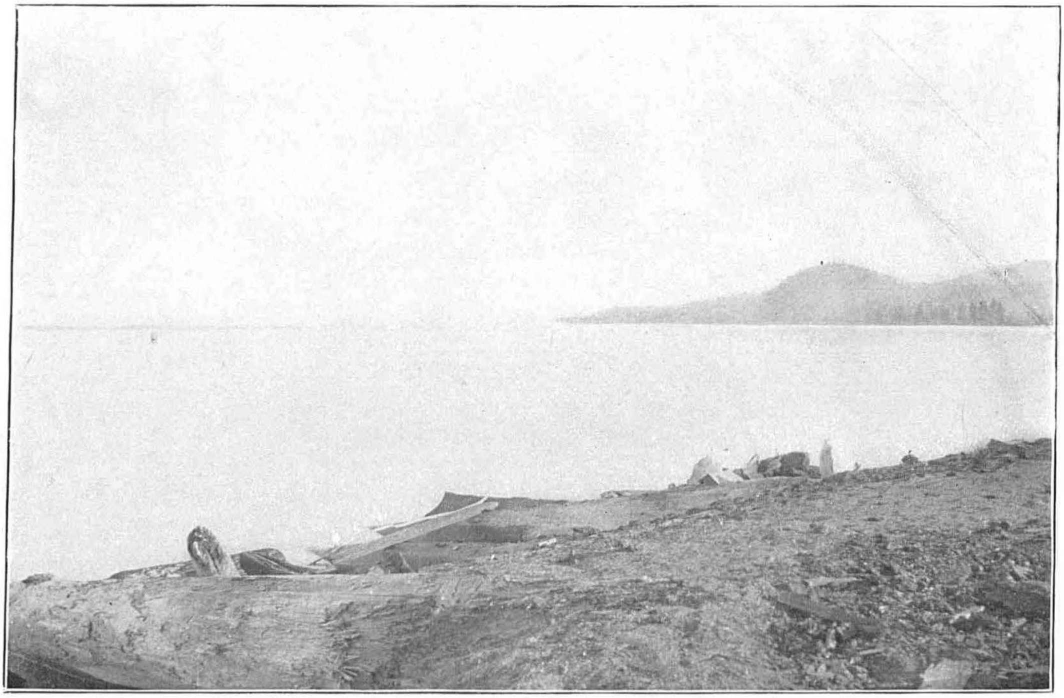
No. 25.



Folsoms Knob.

LAPHAMS WHARF, LAKE TAHOE.

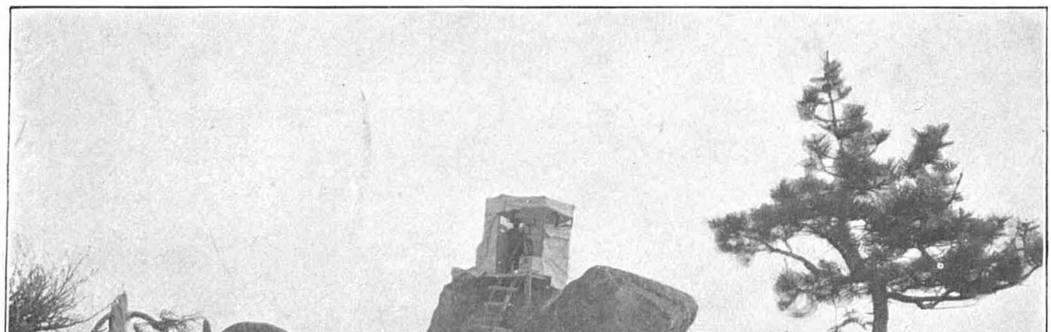
No. 26.



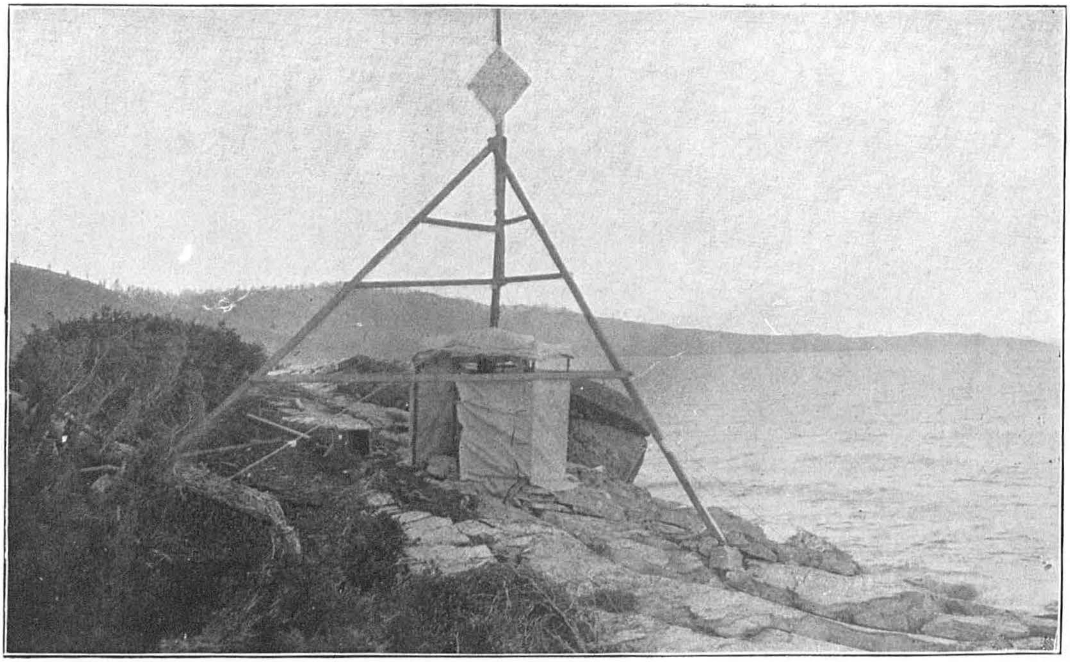
Folsoms Knob.

SOUTHEAST SHORE LAKE TAHOE. LOOKING NORTH.

No. 27.

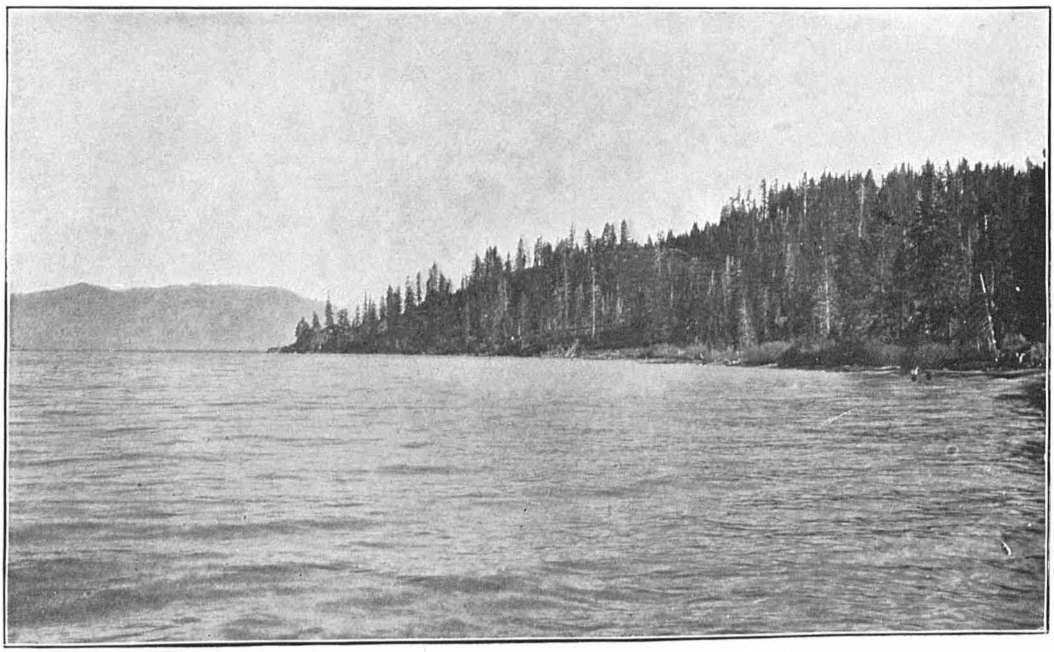


DEADMAN POINT TRIANGULATION STATION.



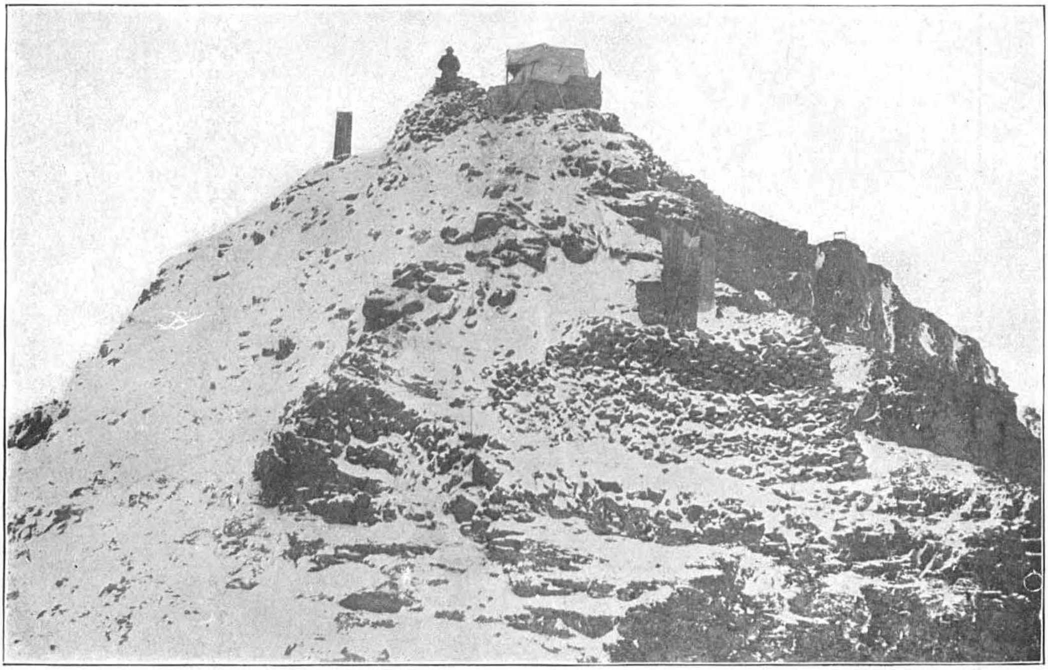
RUBICON POINT TRIANGULATION STATION. LOOKING NORTH.

No. 29.



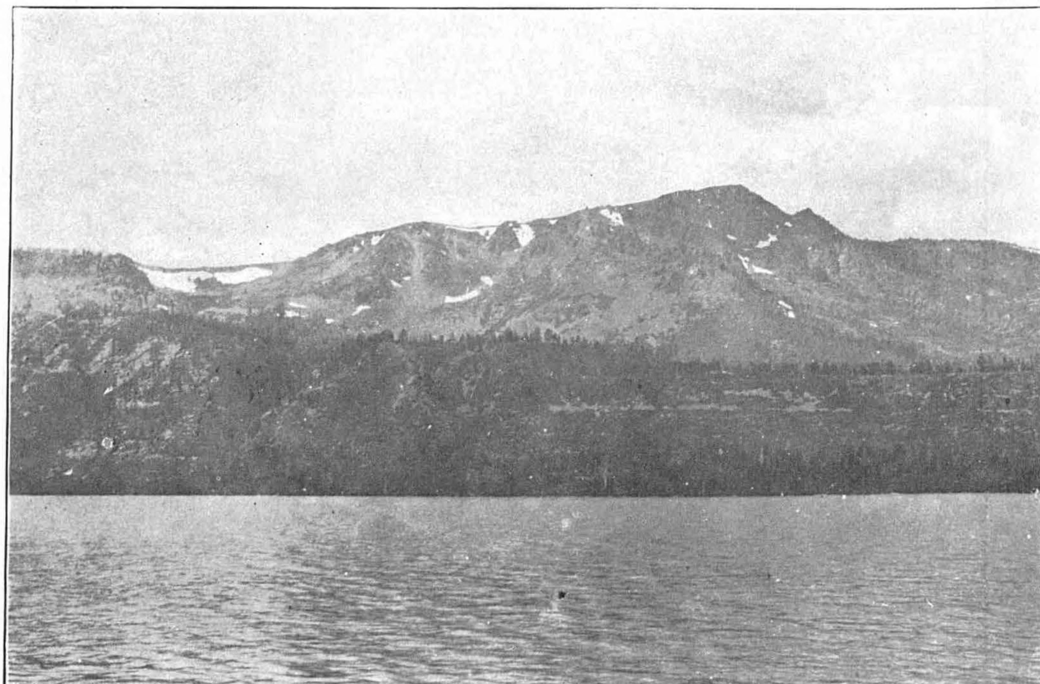
NORTH OF RUBICON POINT, LAKE TAHOE. LOOKING EAST.

No. 30



ROUND TOP TRIANGULATION STATION.

No. 31.



TALLAC PEAK. LOOKING WEST.


FISH LAKE VALLEY
FISH LAKE VALLEY
WHITE MOUNTAINS
EXCELSIOR MOUNTAINS
Von Schmidt's line
Von Schmidt's Line
School House
Leidy Ranch
Pipers Lower Ranch
Oasis Post Office
Pipers Ranch
Sylvania Mining Camp
From Sylvania Mining Camp
From Gilberts
From Adobe Meadows
Bertrands Ranch
Queen Station
To Queen Mine
North Base
South Base
Benton Station
To Benton P.O.
To Bishop
Carson and Colorado Rail Road
R.R. Track
Leidys Creek
Silver Peak Road
Sage brush
Sandy
U.S. Geol. Survey B.M.

Of this sum $5 000 was allotted to the California boundary by the Superintendent.

For the years 1894, 1895, 1896, 1897, and 1898 the bill was substantially the same, except as to the sums allotted.

For 1899 the clause was slightly different, providing—

For surveying and *temporarily* marking that portion of the eastern boundary of the State of California commencing at and running southeastward from the intersection of the thirty-ninth degree of north latitude and the one hundred and twentieth degree of longitude, etc., ten thousand dollars. Approved July 1, 1898.

The temporary character of the boundary marks was made necessary by the fact that the true points could not be located until the line had been traced through to the Colorado River and corrected back along its entire length to Lake Tahoe, and by that time not only was the fiscal year nearly ended, but the appropriation was almost exhausted.

COST.

The cost of the California-Nevada oblique boundary survey, excluding the salaries of the Coast and Geodetic Survey officers engaged upon it, was as follows:

Fiscal year.	Expended.
1893	$4 966·99
1894	4 741·00
1895	5 927·43
1896	5 815·01
1897 (keep of animals, no field work)	421·20
1898 (keep of animals, no field work)	421·20
1899	9 822·97
Total	32 115·80
Equipment sold after completing survey	—1 255·50
Total cost, without permanent monuments	30 860·30

A number of the animals were supplied by the Coast and Geodetic Survey, as they were already on hand, and these were sold at the close of the work in 1899 with the others purchased for the boundary work; but it is proper to state that some of the tents were paid for out of the boundary allotment, which partly offsets the animals sold.

The total length of the line from the beginning in Lake Tahoe to the Colorado River terminus is very close to 405 statute miles, and the cost per linear mile was $76·20. This cost would have been very materially reduced if the appropriation had been sufficient to execute the work with one organization of the party and with no necessity for keeping the animals between seasons. The party was organized and put in the field four separate times, entailing considerable expense for traveling, expressage, and freight. Each time the men had to be trained for their duties and the animals broken in afresh with new drivers, which caused much delay in executing the work.

L. DESCRIPTION OF THE CALIFORNIA AND NEVADA OBLIQUE BOUNDARY.

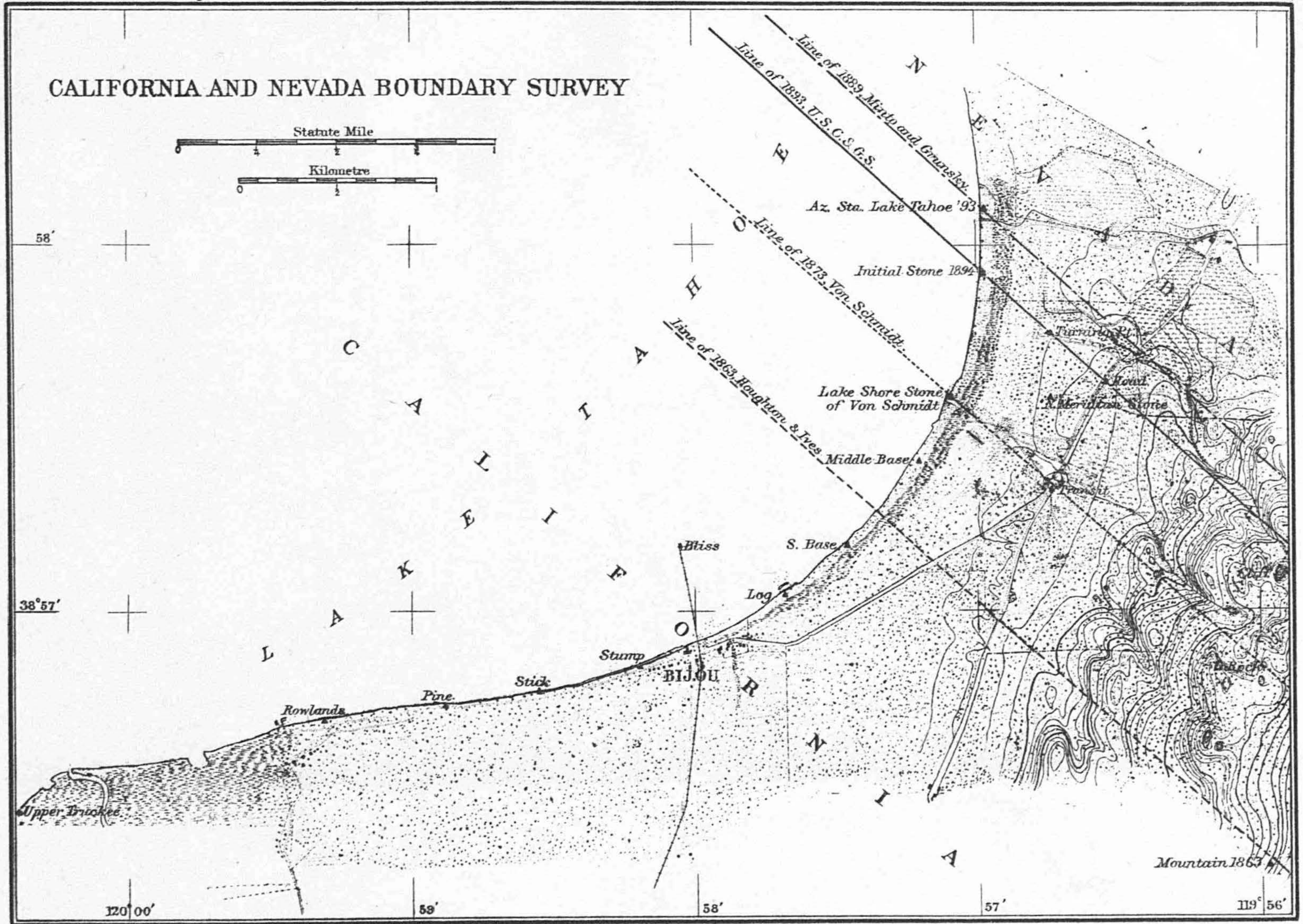
Lake Tahoe lies in the heart of the Sierra Nevada Mountains at an altitude of nearly 6 224 feet, surrounded by summits that rise from a few hundred feet to about 5 000 feet above the lake surface, or approximately 11 000 feet above the sea. The loftier summits are usually snow-capped until midsummer, but there are sheltered spots where the snow remains during the entire year. From the lake shore the ground rises gradually, or is nearly level for a short distance, except where the bold cliffs come down to the water's edge. Some of this ground is cultivated where sufficient water is furnished by the mountain streams for irrigation.

A luxurious growth of pine, fir, tamarack, and cedar covered nearly all of this region thirty years ago, but the greater part of this has been cut to supply the mines at Virginia City and other places with timber, and for general building purposes. Many of the mountains were entirely denuded and the lower lands have left on them little that is valuable for timber. The lake is about 20 miles north and south and 12 miles from east to west. About 3½ miles from the south shore of Lake Tahoe, a little east of the upper Truckee River, and 2 miles from the east shore, between Zephyr Point and "Folsoms Knob," or "Round Mound," the one hundred and twentieth meridian west from Greenwich intersects the thirty-ninth parallel of north latitude, and this intersection marks the beginning of the oblique boundary. The water reaches a depth of something like 1 300 feet at this place. (See ill. No. 3, diagram of depths.)

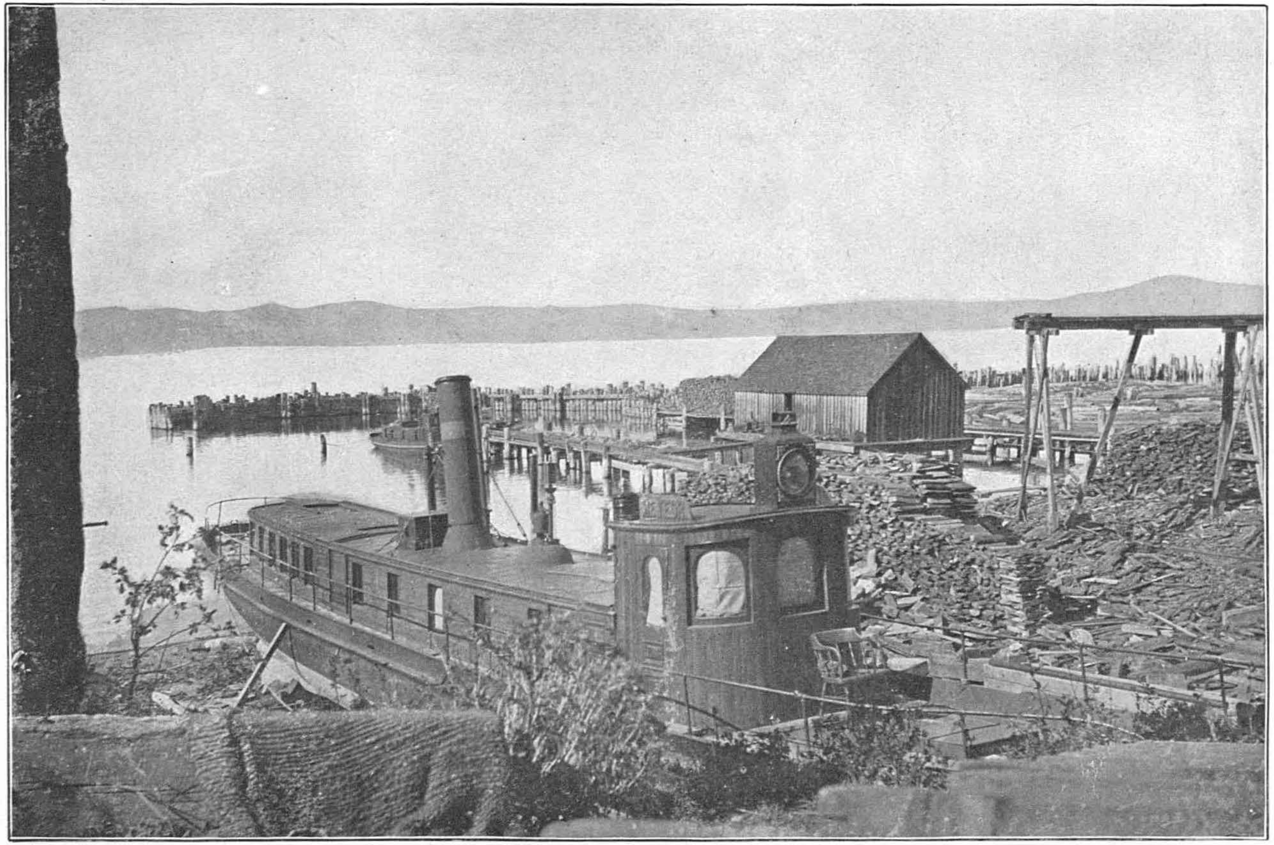
Running to the southeast from the starting point on an azimuth of $311° 14' 36''.6$, the line strikes the shore after traversing the water for a distance of 3·6 miles. The first stone, called No. 1 (distance 3·6 miles from the one hundred and twentieth degree of longitude and the thirty-ninth degree of latitude, altitude 6 230 feet), is a granite monument 6 feet high, of which 2 feet are in the ground near the shore of the lake on a firm strip of sandy soil about 5 feet above the surface of the water. This strip is from 20 to 60 meters wide, running parallel to the shore, covered with thin grass and a few forest pines. Beyond this is a narrow belt of pines and tamaracks, then a marshy place covered with good grass, then a second narrow belt of pines and tamaracks, followed by a sandy reach, gently rolling, with a few bushes and sage brush upon it, up to the azimuth station of 1894, 460·7 meters distant from No. 1, which is still marked, as it it was then, by a block of granite projecting about a foot above ground with a copper bolt in the top. Three distinct shore lines are found northwest of the azimuth station.

From this point to No. 2, which is located on the west side of the road between Bijou and Hobart, the soil is sandy and covered with large timber, partly cut out. No. 2 is a granite monument like No. 1, distant 838·6 meters from it. Crossing the road the line traverses ground from which the first growth of trees was cut, but there are small ones left; then continues over gently rising ground broken by granite-covered hillocks until, at a distance of 1½ miles from the lake and about 600 feet altitude above the lake, the abrupt sides of the steep mountains are reached. From here to No. 3—distance, 1·9 miles, altitude, 9 019 feet on the west top of the mountain—the original forest has not been cut.

Between No. 3 and No. 4 it is only 263·4 meters. The line is still in timber, rising over rough bowlders. No. 3 and No. 4 are marked by pine posts, with cairns. From No. 4 to No. 5 (not corrected on account of deep snow; it should be moved 1·11 meters northeast) the distance is 988·6 meters. The line crosses a level reach thinly covered with trees, then rises at No. 5 to 9 517 feet. From No. 5 the line crosses a hollow, then ascends to an altitude of 9 475 feet to No. 6—distance, 652 meters. (No. 6 not corrected on account of deep snow; it should go 1·26 meters northeast.) From No. 6 the line crosses another deep hollow to No. 7, 604 meters distant, altitude, 9 340 feet.

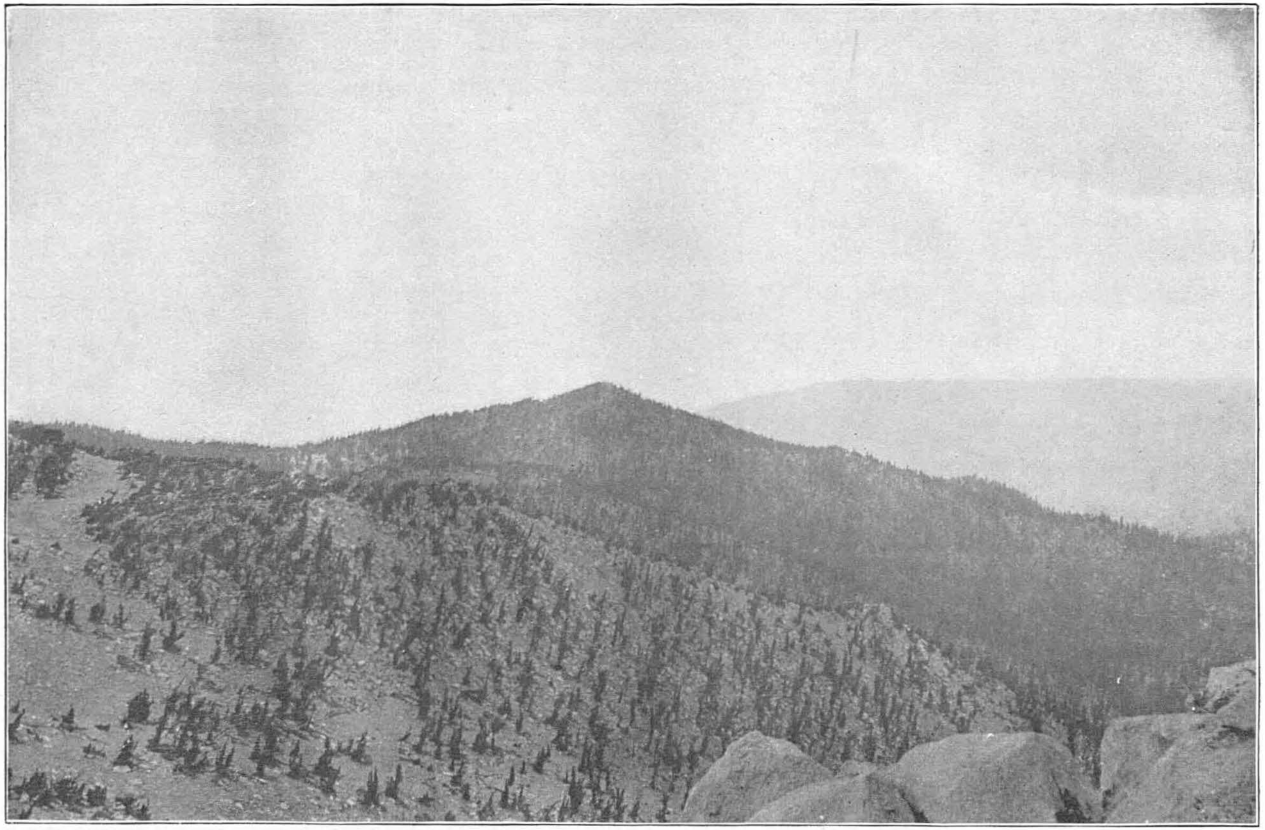


THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.



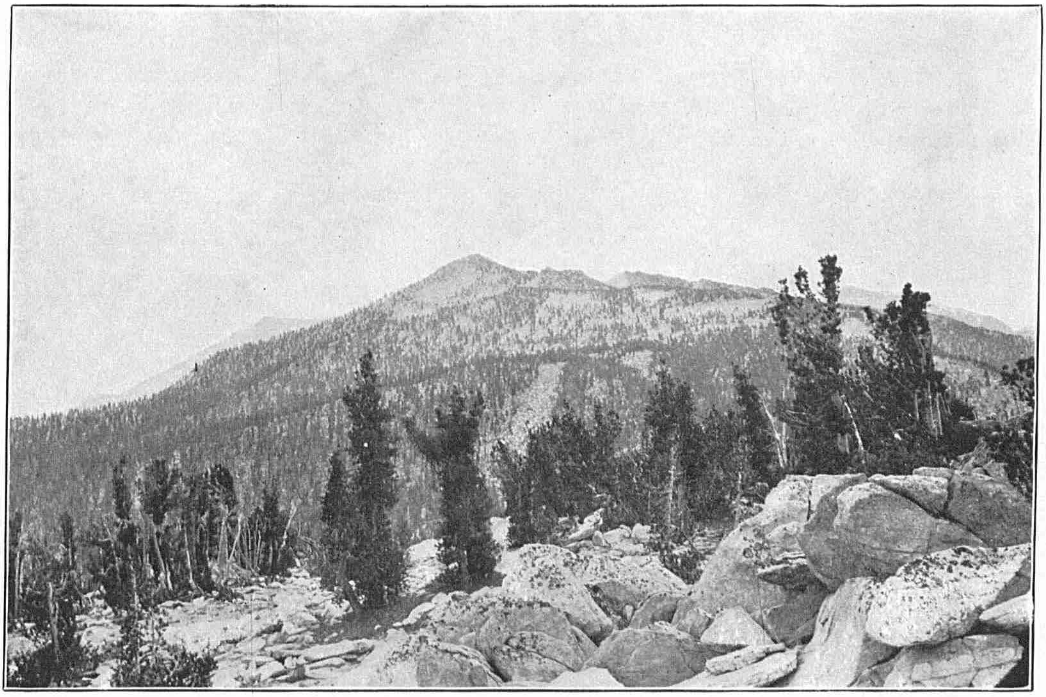
Steamer Meteor.

WHARF AT GLENBROOK, LAKE TAHOE. LOOKING NORTHWEST.



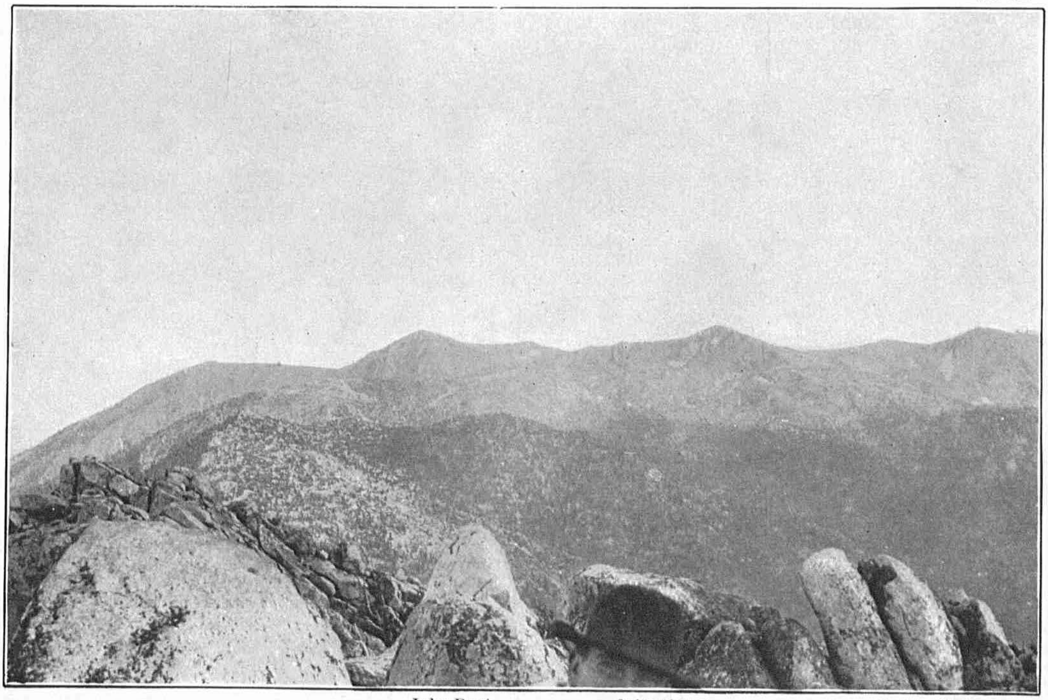
EAST PEAK FROM MONUMENT PEAK.

No. 34.



MONUMENT PEAK FROM EAST PEAK.

No. 35.



Jobs Peak. Jobs Sister. Freels Peak.

LOOKING SOUTH FROM MONUMENT PEAK.

No. 7 is on a large rock just at the foot and on the northeast side of a cliff on the backbone leading up to Monument Peak. The line then descends obliquely across the mountain to Carson Valley along the rough, wooded mountain side to No. 8, 4·6 miles; altitude, 5 214 feet. This point is 4 303 feet below the high summit at No. 5, which is only 5·4 miles northwest. Near No. 8 the timber is thin and small. Beyond No. 8 the line crosses a ravine with running water in it to sandy soil covered with sagebrush, gradually rolling and sloping to the east to No. 9, distant 1·1 miles; altitude, 4 834 feet. Fay's red barn is nearly east. From No. 9 it is still in sagebrush, soil sandy and covered with bowlders to No. 10, 0·9 mile distant, 4 866 feet altitude. Fay's red barn is nearly north; the schoolhouse is northeast. Leaving No. 10 the line crosses stony and sandy soil covered with sagebrush for 0.87 mile to No. 11, 4 801 feet altitude. This point is in the forks of the road and a short distance south of Baldwin's house. A cut-granite monument with broken top, held in place by means of hoop iron, and a cairn around it, marks the point. From here the line crosses sagebrush for a short distance, then enters the pasture land and, continuing in it for 1¼ miles, passing a short distance west of H. Godecke's ranch in the valley to No. 12, distant 1·4 miles; altitude, 4 847 feet. Deluchi's barn is east. No. 12 is a cut-granite monument like No. 1, nearly in the east fence line of the road that runs north and south.

From No. 12 it is 0·35 mile across sandy soil covered with sagebrush to No. 13, also a cut-granite monument like No. 1 on the west bank of the west fork of the Carson River. The altitude is 4 848 feet. Deluchi's barn is nearly north.

Crossing the river the line traverses a pasture field, then up a sagebrush ridge to No. 14; altitude, 4 980 feet; distance, 0·6 mile. This is also a cut-granite monument like No. 1, and between two roads in the valleys northwest and southeast.

Still traversing sagebrush the line crosses a road in a small valley, rises over a hill, crosses another valley, then ascends to No. 15 on the west slope of a thickly-wooded hill covered with sagebrush to No. 16, 1·64 miles distant, altitude 5 460 feet, marked by a post with a cairn around it. From No. 15 the line descends into the valley of a creek called the Middle Fork of the Carson, crossing a road, to No. 16, marked by a post and cairn on the southeast side of the stream in meadow land, 0·45 mile distant, about one-half mile north of Gallanar's house. Leaving No. 16 the line crosses a fence with a road alongside at the foot of a hill, and ascends through scattered pines to No. 17, 1·06 miles distant, and 5 815 feet altitude.

From No. 17 it passes through scattered pines, descending, crossing a road, and after going down a steep declivity strikes the East Fork of the Carson River at No. 18 on the southeast side in the fence line of Kelley's ranch on the southwest side of the road, 1·2 miles distant, and 5 104 feet altitude. The mark is a post within a cairn not far from the bank of the river.

After crossing the road leading to Kelley's house near by, the line rises rapidly through dense pines to No. 19, a bold rocky summit, 0·72 mile distant, altitude 6 027 feet, marked by a post in a pile of stone. Following along the edge of the mountains over very stony ground covered with sagebrush and a few pines, on the west slope of a reddish, rocky bluff is No. 20, distant 0·71 mile, marked by a post in a pile of stone.

From this place there is a steep descent to Bryant Creek, passing O'Reilley's ranch on the northeast side of the house; then up the mountain halfway to the top on the southwest slope is No. 21, 1·77 miles distant, and 6 323 feet altitude.

Following the mountain side for half a mile the line first crosses a deep ravine, then rises over a ridge covered densely with pine, crosses a second ravine, another ridge, bare except for sagebrush, then descending and again ascending for more than a mile, at a distance of 2·86 miles it reaches No. 22, altitude 7 613 feet, on the west slope of the high east and west ridge overlooking the narrow valley of Mountaineer Creek. It is marked by a post of mountain mahogany set in a large cairn.

Crossing an irregular plateau covered with sagebrush, a few scattered cottonwoods and pines, for 2·6 miles, altitude 7 523 feet, No. 23 is found on the east slope of a bold mountain mass overlooking Alkali Lake, Antelope Valley, and Holbrook. It is marked by a pine post in a large cairn northeast of a thick growth of mountain mahogany.

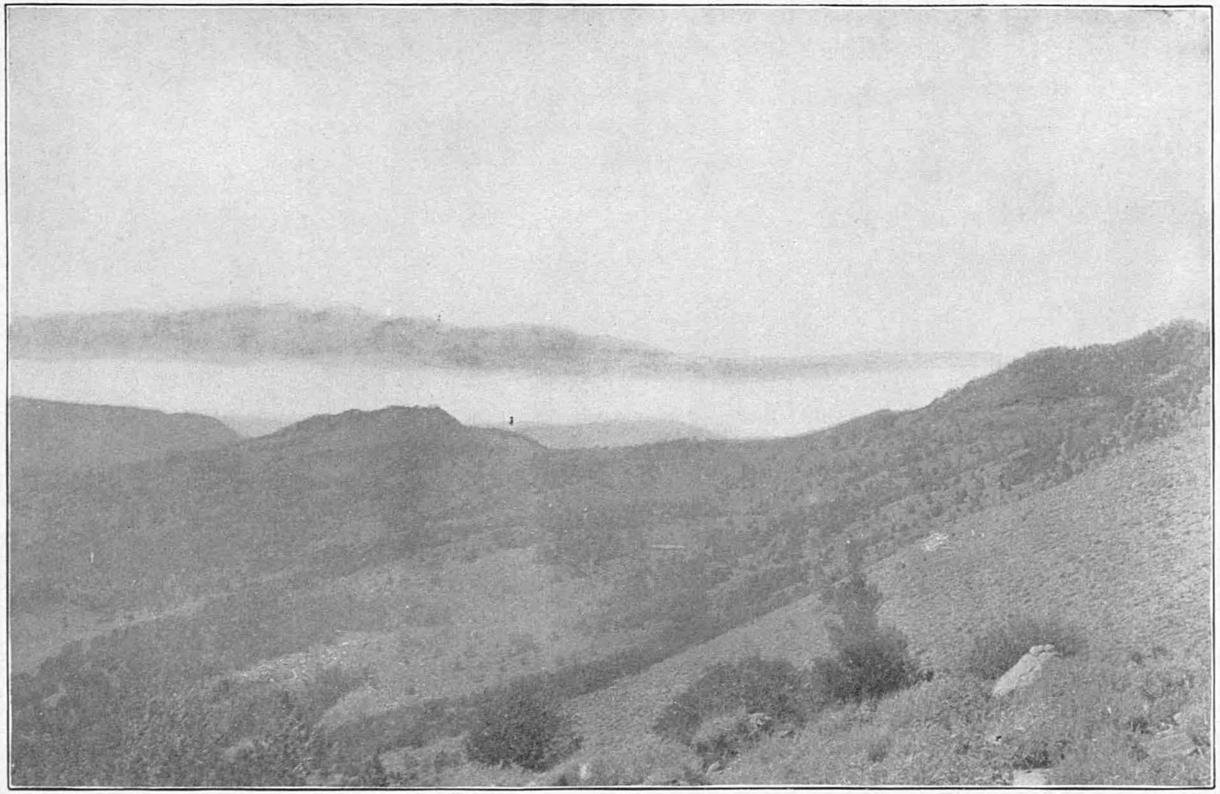
From this point the descent is very precipitous, being more than 2 000 feet, to the cut-granite monument marking No. 24, 1·9 miles distant on the northwest side of the stage road from Coleville to Holbrook, and about one-fourth mile northwest of Alkali Lake.

Just across the lake on a bold hill without timber and very conspicuous from all points, at a distance of 1·45 miles, and 5 304 feet altitude, is the large cairn with a post in it marking No. 25. Following the sage brush-covered hills for nearly a mile, the line crosses the road from Coleville to Wellington, then enters the meadow land, which is marshy for the first half mile and firm beyond, to No. 27, where a cut-granite monument was placed on the west bank of the West Walker River, 2·32 miles distant, and 4 936 feet in altitude. This is the last cut-stone monument; the other marks are posts in cairns or mounds. The stream makes a sharp bend, running north and south, here, and there is a small island that divides the waters. A mound of earth was built around the stone, outside of which was dug a deep circular trench. About one-fourth mile southwest is the fence of Thomas Rickey, the great cattle owner, who controls nearly all of the land in Antelope Valley, cultivating alfalfa and sometimes harvesting 5 000 tons of hay. None of the land in Antelope Valley crossed by the line is under cultivation. No. 26 was only a temporary station, not marked.

From No. 27 the line crosses bottom land for a considerable distance, then rises through sagebrush to No. 28, 2·32 miles distant; altitude, 5 112 feet.

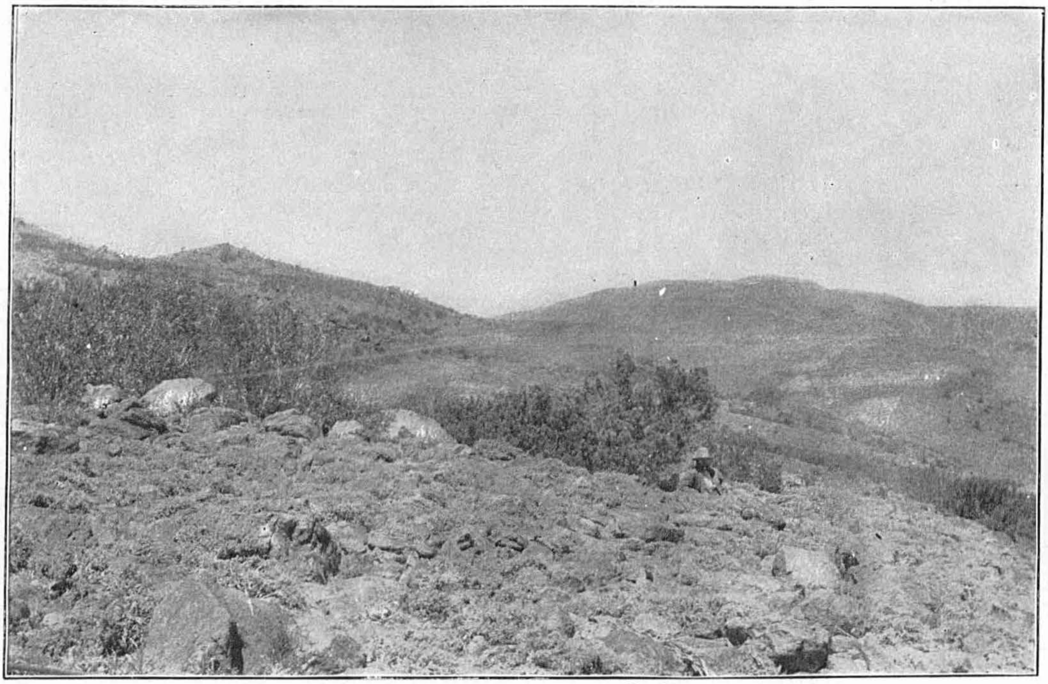
No. 28½ is to mark the crossing of the Wellington and Topaz road, 494·5 meters distant, and through sagebrush. The line rises over the sagebrush slope to the foothills of the Sweetwater mountains and strikes a wooded ridge covered with nut pine at No. 29, distant 4·66 miles from No. 28½; altitude, 7 480 feet. At an altitude of 7 963 feet, and a distance of 2·32 miles, the line reaches No. 30, on a bare ridge, except sagebrush. It then crosses a wooded ridge, a second valley, then ascends to an altitude of 8 643 feet at No. 31, 1·25 miles distant.

From this point the line descends into the rough ravine of Desert Creek, three-fourths of a mile distant, crosses a low ridge into a small valley, which it traverses for 2 miles, and then begins the steep ascent of the "Middle Sister," in the Sweetwater mountains, crossing on the east slope over very rough, loose stone until it reaches No. 32, distant 3·85 miles, and at an altitude of 10 556 feet. The northwest slope has a belt of pine trees, but the summit is loose stone. Von Schmidt placed a small flag pole farther up the backbone to the southwest, which was in good condition after twenty years' exposure to the weather. A large cairn is also on the summit nearly 10 feet high, built of flat stone carefully laid. This is about one-fourth of a mile southwest of No. 32. The undergrowth on the summit is Manzanita.



No. 7. No. 21.

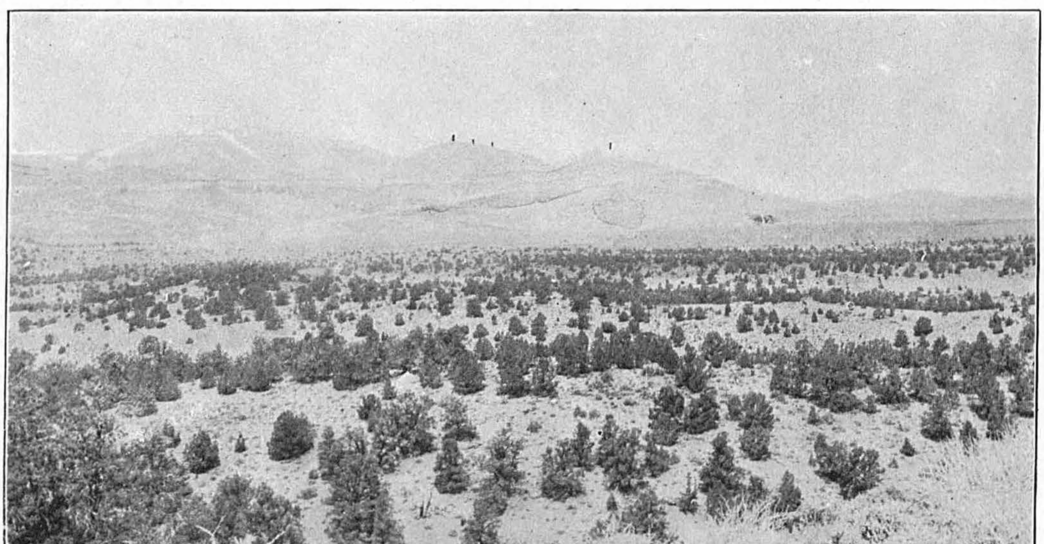
AT NO. 22. LOOKING NORTHWEST.



No. 22.

AT NO. 23. LOOKING NORTHWEST.

No. 38.



West Sister. Middle Sister. No. 32. East Sister.

AT T. 34. LOOKING NORTHWEST.

From No. 32 the line descends rapidly, crosses a ravine, then rises over a rough ridge about a mile southeast, then strikes the northeast slope of a bold spur, from which it descends into the Sweetwater Valley and follows across it through sagebrush to No. 33, at an altitude of 6 986 feet and 5·26 miles distant. This station is at a fence corner. Two miles northwest of this, or 54·3 miles from the intersection of 120° and 39° in Lake Tahoe, is the crossing of the Von Schmidt line of 1873, which runs on the northeast side for 277 miles before the second crossing in Mesquite Valley southeast of Sandy post-office.

About 1¼ miles southeast of No. 33 is a faint road along a fence, running to the old Clinton mines. Nearly one-half mile beyond it crosses Sweetwater Creek, and soon afterwards begins to rise to No. 34, which is on the ridge with a few scattered pines 3·3 miles distant; altitude, 6 530 feet.

From No. 34 the line ascends to No. 35, on a wooded ridge 0·38 mile distant, and 6 444 feet altitude. This point is less than half a mile distant from the Bridgeport road running on the southwest side of the East Walker River. Crossing this stream the line rises over a broken country to No. 36, 3·46 miles distant, altitude 7 259 feet, on a ridge densely covered with a small growth of nut pine. A Von Schmidt cairn is a short distance northeast.

The line next crosses several valleys and ridges to No. 37, 2·6 miles distant, altitude 8 010 feet, nut pine and cedars abounding. Between this and the next point the country is very rough, rising to an altitude of 8 348 feet at No. 38, 1·6 miles distant.

It is 3·07 miles to No. 39 and the country is very rough over the mountains, crossing a creek three-fourths of a mile southeast of No. 39, where the altitude is 8 009 feet. About 200 meters northeast of No. 39 is an old Von Schmidt post marked 278 miles.

From No. 39 the line descends into a valley, crosses a ridge and also Rough Creek 2 miles distant, then rises up over the bold bluff and at No. 40 reaches an altitude of 8 954 feet, 3·5 miles distant, on Beauty Peak, which is bare of trees, but covered with stones and sagebrush. The old triangulation station is north of this point about 200 meters.

From No. 40 the line descends for 1·29 miles over rough ground and stones through sagebrush to No. 41 on the slope.

Seven-eighths of a mile beyond this is the edge of a steep bluff on the northwest side of the road from Bodie to Hawthorne near "Sunshine" or Davidson Ranch, an old stage station. This bluff is a part of the cañyon of Bodie Creek which narrows down rapidly toward Aurora, leaving scarcely enough room for a road and forming highly picturesque scenery. The southeast side is not so precipitous, but rises gradually to the west slope of Mount Brawley, one of the roughest climbs on the line, being a bold uplift of rock very dark and rounding up from the west to the northeast, where the sides are precipitous. This is at an altitude of 9 247 feet at No. 42, and distant 2·31 miles. The line here is about one-eighth of a mile southwest of the Von Scdmidt line of 1873. The highest summit of West Brawley, less than one-fourth of a mile northeast, is 9 506 feet. This station is 2·8 miles southeast of Aurora and 5 miles northeast of Bodie.

The line desends from Mount Brawley over very rough ground and across a faint road about a mile distant, then going over rough hills reaches No. 43 on the northwest side of the road between Bodie and Aurora, 1·65 miles distant.

From No. 43 the line continues to descend to the valley or desert covered with sagebrush, crosses and climbs an isolated mountain, bare except sagebrush, to No. 44 on the east slope nearly 1·79 miles distant, and 8 521 feet altitude. Then the line descends to the valley, passes the edge of a small lake bed and climbs a wooded mountain with double top, crossing a very deep, rocky ravine on the mountain before reaching No. 45, 2·76 miles distant, and 8 179 feet altitude; the timber is piñon and juniper.

From this station the hills covered with scattered nut pine continue for more than 2 miles before reaching the desert; then the line crosses a sandy reach with some nut pine and juniper for about 2 miles and strikes No. 46, 4·57 miles distant, which is about 50 meters southeast of the desert road from Aurora to Adobe Meadows and Benton, in the midst of juniper and nut pine; sandy soil.

There is a gradual rise through the woods and across the hills and hollows to No. 47, altitude 7 878 feet and 2·29 miles distant, on a rocky, wooded ridge. It is on the east slope about 65 meters from the highest part.

The next station, No. 48, 2·74 miles distant, is on a high table-land very stony on the west edge of a lava knoll. To reach it the line crosses some very rough hills and defiles, through sagebrush and a few scattered pines and scrub junipers.

The line continues over very rough and gradually ascending table-land for 0·68 mile to No. 49, which is on the northeast slope of a hump of lava. There are three of these humps close together on the ridge. The station, T 49, on the random line was on the west side of the center hump, and No. 49 is on the east side.

The line descends for nearly 4 miles to the bottom of a ravine draining to the eastward into Hontoun Valley, then ascends for 2 miles over hills, all the way through nut pine and cedar to No. 51, 6·8 miles distant, on a nut-pine covered knoll. The old station, T 50, on the random line was not corrected. It should go northeast 35·69 meters. It is located on a small hill southeast of the ravine in the bottom. At the time of correcting the line it was impracticable to delay the party for the purpose of reaching this place. A dry camp would have been necessary, and the region is almost without value, being nearly inaccessible under present conditions, except for pack animals. The old point, T 50, is 4·18 miles from No. 49 and 2·6 miles from No. 51.

Between 51 and 52 the distance is only 0·5 mile through nut pine. Both of these stations are on the east slope of wooded ridges. From the latter point the line descends into a valley, crosses a wooded ridge into another valley, then up the sides of a densely wooded ridge to No. 53 on the west slope, 2·22 miles distant and 7 942 feet altitude. From this place it crosses hills and hollows through scattered nut pine, stones, and sagebrush to No. 54, 3·8 miles distant and 7 802 feet altitude. This station is on the east slope of a narrow bluff ridge very stony and with a few nut pines.

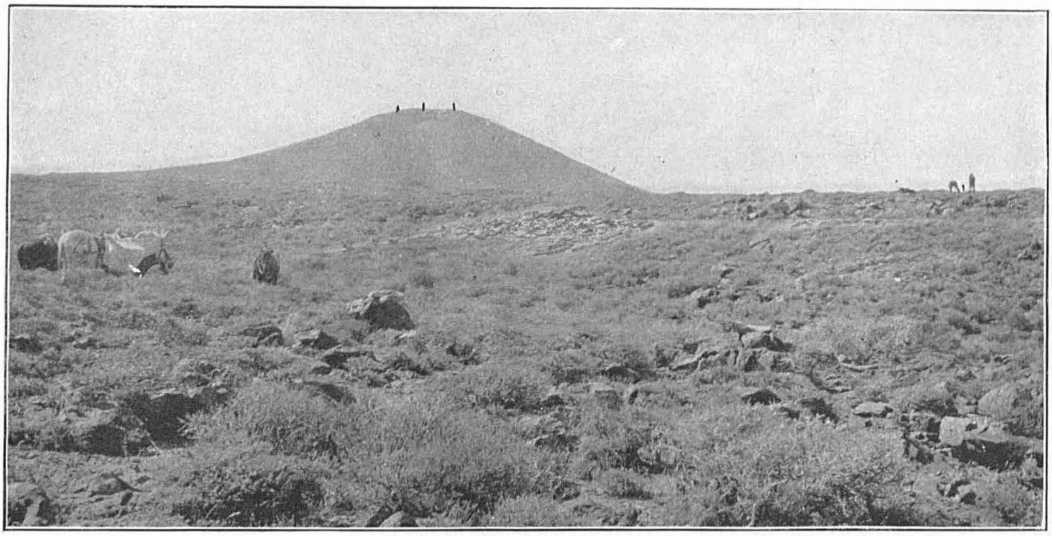
The next point, No. 55, is only 0·46 mile distant and 7 789 feet altitude, on the west slope of a ridge covered with sagebrush.

The next point, No. 56, is 0·66 mile distant, on the east slope of a ridge.

No. 57 is only 0·28 mile distant, also on the east slope of a hill.

The line now ascends to a rough plateau, then rises to No. 58 among large stones and a few scattered nut pines 1·47 miles distant and 7 092 feet altitude.

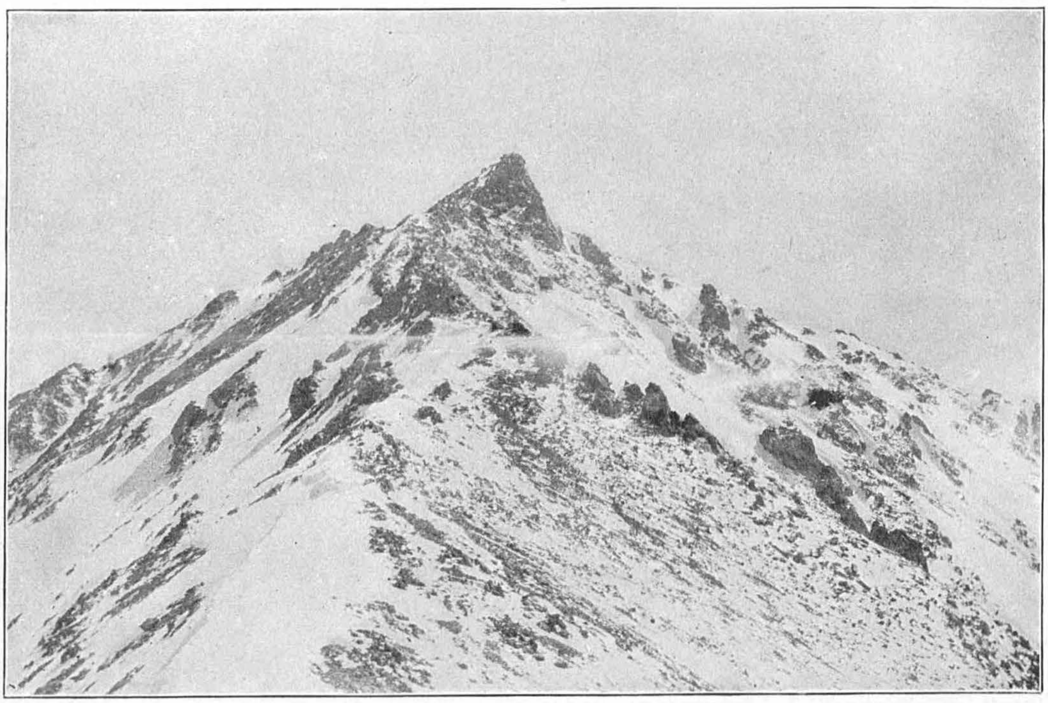
The descent onward from this point is quite precipitous for a mile to the valley, then the line crosses the valley to the Carson and Colorado Railway, 2·98 miles distant, to No. 59, altitude 5 951 feet, which is on the northwest side and 21 meters from the rail-



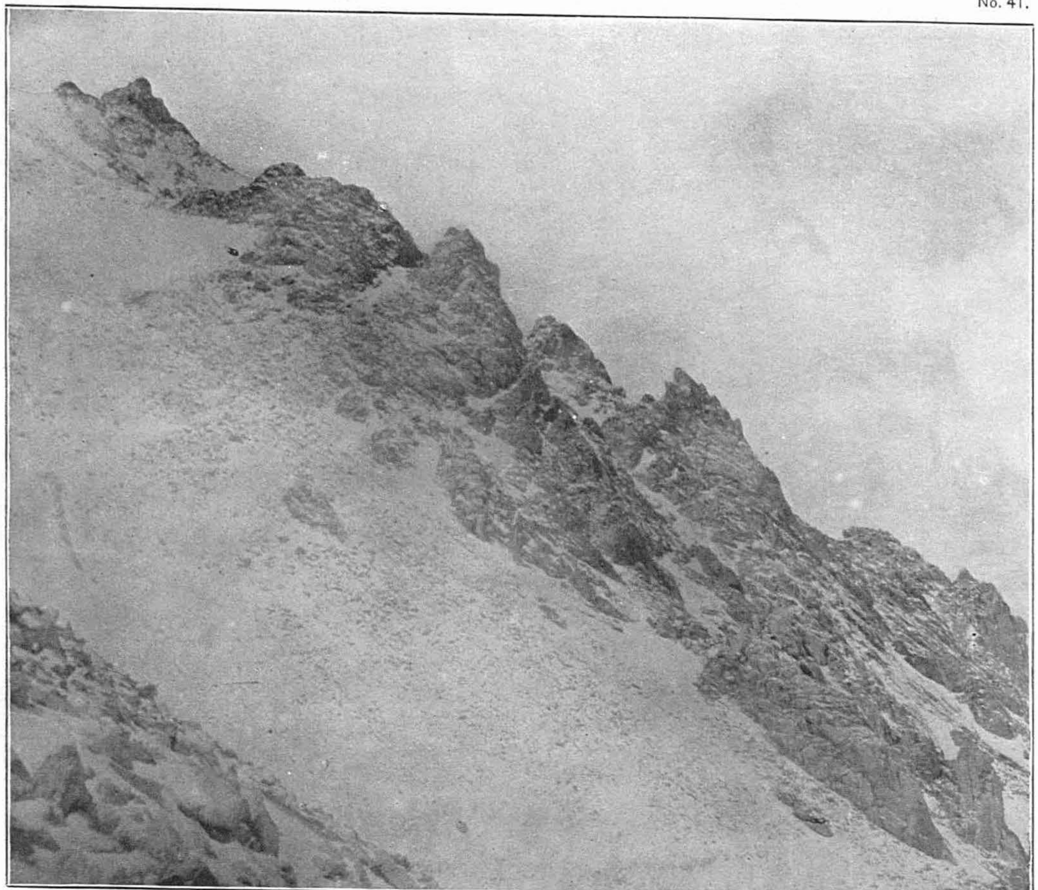
T. 40. No. 40.

BEAUTY PEAK TRIANGULATION STATION FROM NO. 41.

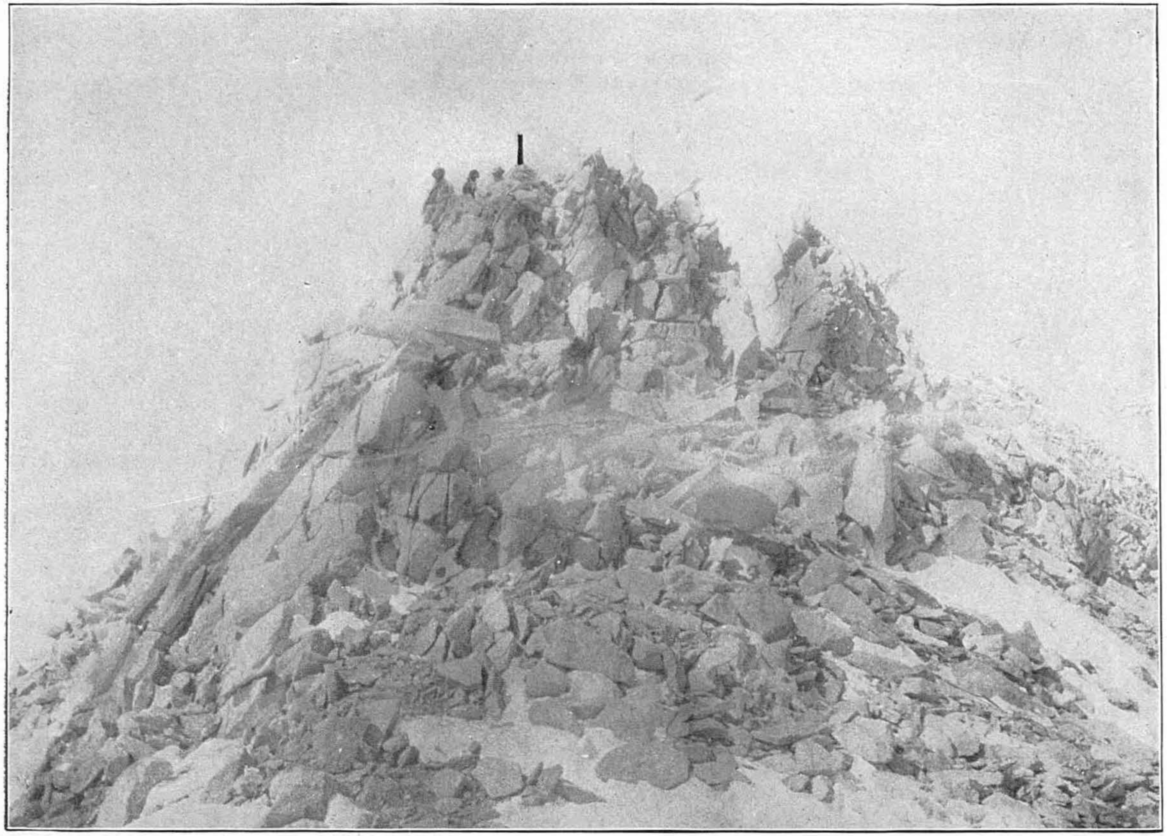
No. 40.



NORTH PEAK (MONTGOMERY PEAK), WHITE MOUNTAINS, FROM NO. 60. ALTITUDE, 13,465 FEET.



ROCKY RIDGE, NORTHWEST SLOPE OF WHITE MOUNTAIN PEAK.



HIGHEST POINT ON THE LINE (NO. 60), WHITE MOUNTAINS—12,937 FEET.

road track. The road from Bertrand's Ranch to Queen Mine is about one-fourth mile to the northwest of this mark. All the stations from No. 47 to 58 are in the Excelsior Mountains.

Rising gradually from No. 59 through sage brush for 1·9 miles, the line goes to No. 59½, 6 618 feet altitude; then, in a little more than a mile, it strikes the steep ascent of the White Mountains, reaching the highest altitude along the line, about 12 930 feet, at No. 60, 4·61 miles distant. Here it crosses in a sag between the two highest summits, a little nearer the northeast summit. The southwest summit, about three-eighths mile from the line, is the highest, being 13 465 feet. The mountain is very difficult of ascent; it is formed of light-colored granite, which is rapidly disintegrating. There is no vegetation on top; only huge masses of rock and sand.

The line descends the steep southeast side of the mountain, then rises to T 61, 3·13 miles distant, and 11 323 feet altitude. This point was not corrected, being snow-covered and very difficult of access. It should go northeast 44·90 meters. It falls on the southeast slope of a very high summit.

The next point is 3·35 miles distant, and 9 653 feet in altitude, falling on the east side of the mountain. T 62 High is only about 250 meters southwest of this point and should not be confounded with it. A Von Schmidt post, marked "333^{m}. 26^{ch}.," is one-half mile northeast of this station.

The line continues on the rough mountain side to No. 63, distant 2·3 miles and 9 077 feet altitude.

No. 64 is on a narrow, rocky ridge nearly a mile southeast and 9 286 feet altitude. There is a deep cañon northwest with running water in it, and another southeast of this station.

There is a deep ravine about halfway to the next point, No. 65, which is 1·36 miles distant and 8 585 feet altitude. This point falls on the southeast slope.

From here there is a descent into a deep ravine with water; then a rise to a ridge on which No. 66 is located, on the northeast slope, distant 2·43 miles and 7 972 feet in altitude.

The line continues obliquely along the northeast slope of the mountain for 4·1 miles to No. 67, on the last spur of the main White Mountain Range, 6 771 feet altitude.

After a sharp descent the sandy soil of Fish Lake Valley, covered with sagebrush, is reached, and the first valley mark is No. 67½, distant 4·4 miles and 4 986 feet altitude. About 1½ miles northwest of this is the McBride post of 1865.

No. 68 is in the valley, 2·1 miles distant and 4 994 feet altitude. About three-fourths of a mile north, at the road crossing, is a Von Schmidt post.

No. 69 is 1·8 miles distant and 5 088 feet altitude.

No. 70 is 0·71 mile distant and 5 056 feet altitude.

No. 71 is 0·71 mile distant and 5 002 feet in altitude. Here was located a bench mark of the United States Geological Survey, marked "5 070 feet." The road to Leidy's ranch crosses just northwest of here.

No. 72 is 2·82 miles distant and 4 982 feet in altitude. Soil still sandy and covered with sagebrush.

No. 73 is 3·36 miles distant. Piper's ranch, Oasis, Cal., is 1½ miles southwest.

No. 74 is 1·74 miles at the road crossing going to Silver Peak, altitude 5 053 feet.

A bench mark of the United States Geological Survey, marked "5 121 feet," was located here. One mile east of this, on the northeast slope of a hill, is a Von Schmidt post, marked "363 miles." Oasis, Cal., is 2 miles west.

The next mark, No. 75, is 2·57 miles distant.

No. 76, 0·73 mile distant and 5 255 feet in altitude, just southwest of the road to Palmetto.

No. 77, distant 1·22 miles, is the last point in Fish Lake Valley. All of the soil is sandy and covered with sagebrush. There are some ranches in the valley which are very productive where water can be procured for irrigation. Grain is grown to a limited extent also, but alfalfa is the principal crop. In 1895 nearly all of our provender was hauled from this valley to the southeast, as far as Oasis, Nev.

The next point, No. 78, is on the first high ridge limiting the southeast end of the valley; the Sylvania Range, 3·36 miles distant and 6 774 feet in altitude; it is on the southwest slope. The line crosses a rough, mountainous region, high hills and deep ravines for a distance of 3·21 miles to No. 79, 7 927 feet in altitude, in a sag of the ridge, with some nut pines growing on it. The old Sylvania mining camp, now abandoned, is a mile north. There are a few springs through this region known to the ranchers and miners.

Less than three-fourths of a mile southeast is a wash or cañon, probably 1 000 feet deep and half a mile wide, which leads up to the northeast about half a mile beyond the line. Crossing this, the line goes over rough country, partly wooded, to No. 80, 4·87 miles distant and 6 894 feet in altitude. The drainage from here is into Death Valley.

The country is still very rough, but descends to No. 81, which is on the west end of a range of hills, 6·83 miles distant and 4 270 feet in altitude.

No. 82 is just southeast of a big wash and the road from Tule Cañon, 2·8 miles distant and 3 763 feet altitude. This country is much cut up by washes from the mountains on the northeast.

No. 83 is just southeast of a large wash, 4·41 miles distant and 4 216 feet in altitude.

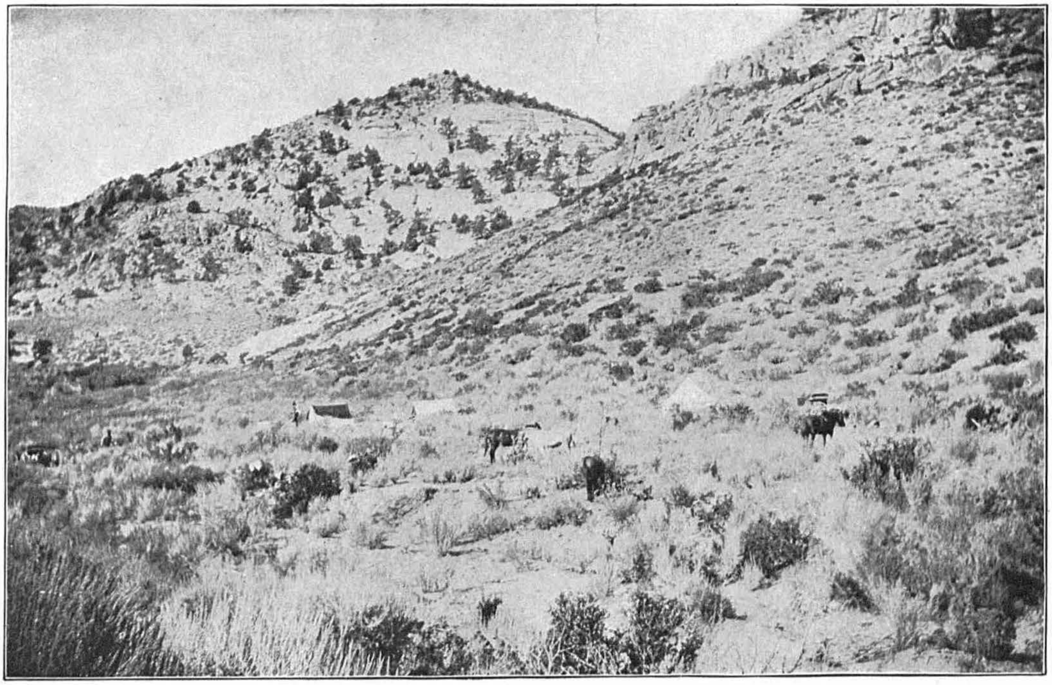
The next point, No. 84, is on a high hill, west slope, 4 766 feet in altitude and 2·14 miles distant. The terrene is extremely rough between the next two points, No. 85 being on a hill, 5 197 feet altitude, 1·23 mile distant. Continuing on the same rough mountains, No. 86 is on the east side of the summit of a symmetrical hill, 5 698 feet altitude and 4·25 miles distant.

Crossing a valley and going up a steep slope, No. 87 is found on the east side of a hill covered with yucca, 1·13 mile distant and 5 444 feet in altitude.

The line goes over rough hills and ravines and washes to No. 88, 5·47 miles distant and 4 260 feet in altitude, on the rocky hill southeast of the road from Staininger's to Thorp's mill.

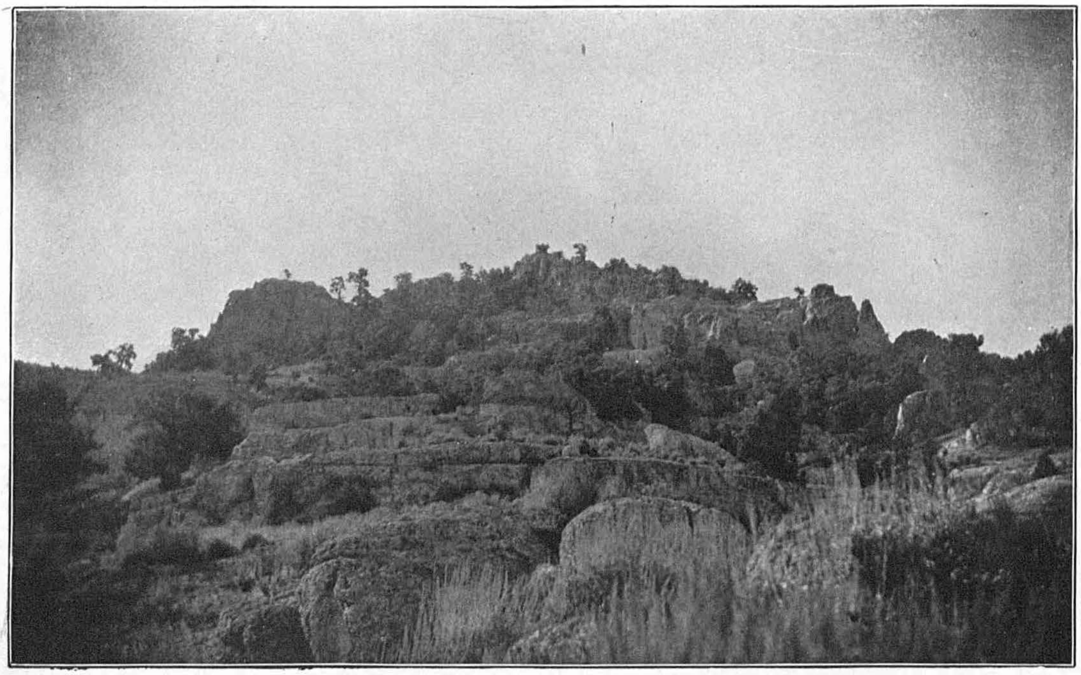
In order to reach the region from No. 81 to No. 84, Sand Spring was used as a water and supply place. The water at Sand Spring, running through grass, has a taste of the roots and is not very wholesome without being boiled. Staininger's ranch, about 20 miles southeast of this place, was the base for reaching all the stations between No. 85 and No. 89, inclusive. There is an abundance of water of good quality, though warm when it emerges from the ground, and a few acres of good ground have been placed under cultivation. Afalfa grows luxuriously, but one can not depend on finding

No. 43.

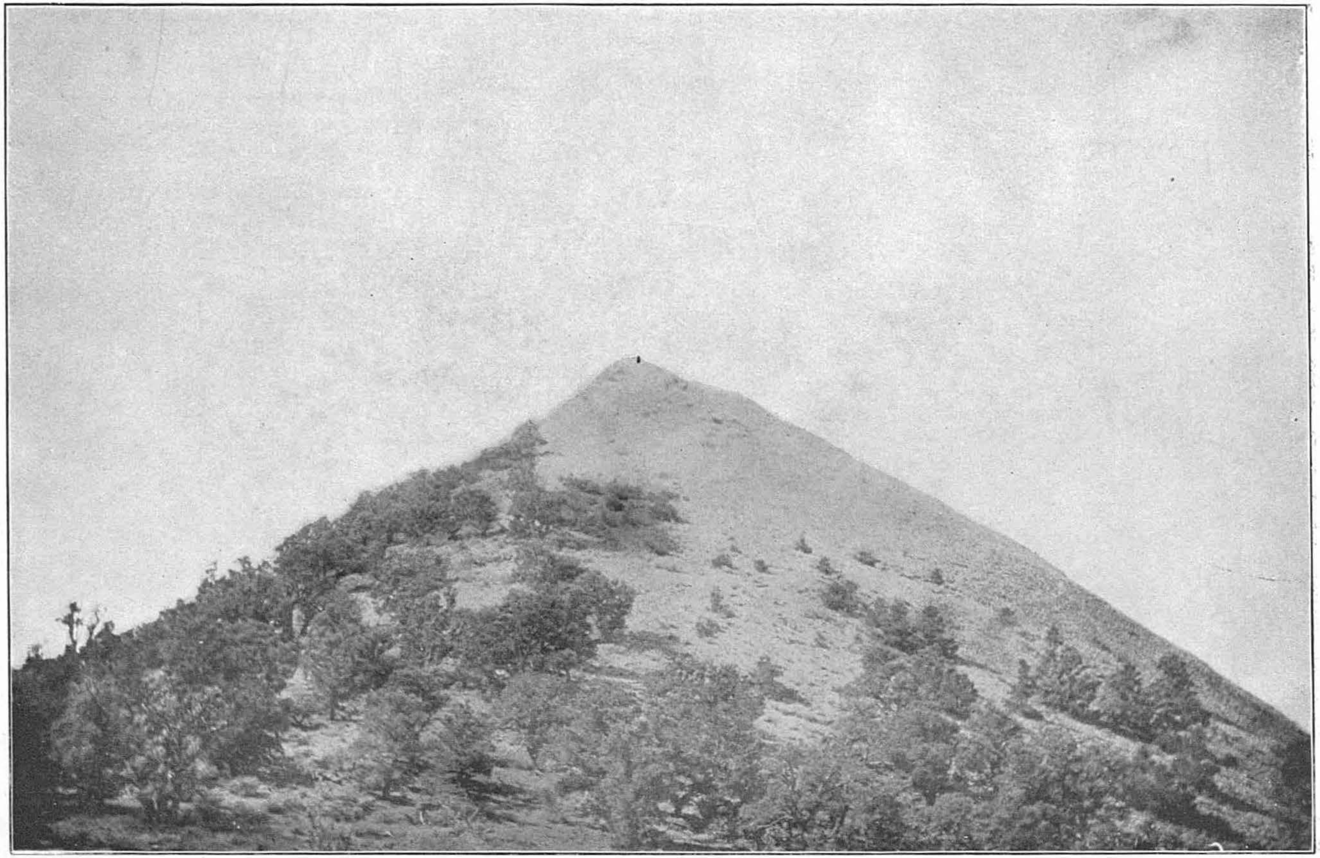


CAMP AT BIG SPRINGS, GRAPE VINE MOUNTAINS.

No. 44.



BIG SPRINGS, GRAPE VINE MOUNTAINS. LOOKING SOUTH.



NYE TRIANGULATION STATION (8,658 FEET), GRAPE VINE MOUNTAINS.

provender at this place except during the summer and early fall when the hay is being harvested. It is not practicable to reach the stations in this region, except No. 82, with teams; only saddle and pack animals can be utilized. The foot of the hill below No. 88 being close to the road, the station is accessible.

Between No. 88 and No. 89 the line crosses a very rough region for 5·64 miles over ravines, washes, and cañons, the foothills of the lofty Grape Vine Mountains. The altitude of No. 89 is approximately 7 000 feet, it is located on a precipice fully 1 000 feet above the gorge to the northeast. The boundary mark is about 300 feet lower than the random line point, T 89.

The point called T 90 on the random line is 4 miles from No. 89. It falls on the west slope of the main peak of the Grape Vines on top of a cliff about 80 feet above the valley or ravine below. It was not changed, but should go northeast 77·70 meters to bring it on the boundary. It will be necessary to go to the northwest a short distance and climb the steep sides of the mountain. The altitude of T 90 is 7 800 feet; that of the main peak is 8 771 feet.

Continuing across narrow valleys, rough hills, and deep gorges for 4·85 miles the line climbs to No. 91, 7 871 feet altitude, on the crest of a ridge running north and south. On the west of this place is a deep cañon extending toward Death Valley. On the north, then extending southeast and south, is a great cañon, one of the roughest on the line; it divides the mountain range and winds around into Death Valley. Beyond this cañon the line crosses a rough mountainous region traversed by gorges before reaching No. 92, on the west slope near the top of a smooth mountain covered with sagebrush, distant 3·4 miles and 7 034 feet altitude. This point commands the Little Amargosa and Great Amargosa deserts for 60 miles.

For Nos. 90, 91, and 92 the Big Springs of the Grape Vine Mountains, at the east foot of the sharpest and next to the highest peak, was used as a base; only pack and saddle animals can be used. The Big Springs are reached from Staininger's by Thorp's mill, where there is a fine well of water, then to Oasis, Nev., and then doubling back west into the mountains about 65 miles from Staininger's.

Between No. 92 and No. 93, 9·52 miles distant, the line crosses to the northeast slope of the Grape Vines, over a region without value, very mountainous, and with no water.

Near No. 93, to the west, up the cañon, are Daylight Springs. The distance from No. 93 to No. 94 is 5·68 miles, and the line descends to 3 853 feet, crossing washes and sagebrush.

From No. 94 the line crosses a rough, rolling country on the east slope of the Funeral Mountains to No. 95, distant 1·89 miles, altitude 3 899 feet. There is a considerable descent from here across a valley covered with sagebrush to No. 96, 3·57 miles distant, altitude 3 614 feet.

Between No. 96 and No. 97 the country is of the same general character and the distance 6·17 miles.

It is about 2·5 miles to No. 98, and nearly a mile farther to No. 98½, both on the northeast slope of the Funeral Mountains. Between these two points and to the southeast on the main slope are T 98, 2 927 feet altitude; and one-half mile southwest, T 98 High, 3 677 feet altitude. To the southeast of No. 98½ is a wash, then a ridge with several summits. There are many washes, some of considerable extent, leading from the mountains on the southwest side of the line. No. 98½ is the last point northwest of the great Amargosa Desert.

The next point, No. 99, is 5·16 miles distant and 2 349 feet in altitude, after passing through a flat sandy region covered with sagebrush and greasewood.

Nearly north of No. 99 about 8 miles distant, rising sheer out of the desert, is a mass of great white sand hills several hundred feet high without vegetation, a marked feature in the landscape.

No. 100 is in a saddle between two low hills, the west one a dark lava formation and the east one light colored. The distance from No. 99 is 5·16 miles, the altitude 2 358 feet. The mountains are several miles to the west of the line. Sand and sagebrush are crossed with a descending slope for 4·45 miles to No. 101, altitude 2 271 feet. About a mile south of this in the old bed of the Amargosa River, among the mesquites, is the water hole, not far from what was called Franklin well. The water is whitish in appearance, but not disagreeable to the taste; it may be found in abundance by digging from 6 to 8 feet.

Still descending, the line crosses sand, gravel, and through sagebrush and greasewood for 4·24 miles to No. 102, altitude 2 176 feet. To the south and 1 464·9 meters distant is the south base, T 102 being the north end of the base. On the northeast, about 2 miles distant, the sand hills, covered with small mesquite, begin. These extend to the west rim of the Ash Meadows.

The line continues to descend to No. 103, which is the lowest monument in the Great Amargosa Desert, being 3·83 miles distant and 2 119 feet altitude, located in a soft bed of brownish red soil, in which the animals sink from 6 to 10 inches. Half a mile to the northwest is an old stream bed covered with coarse grass, and a short distance southeast is another, draining from the eastward.

The region called Ash Meadows, from the ash trees growing along the streams, lies on the southeast side of the Great Amargosa Desert. There are a number of warm springs in the meadows, of great volume, sufficient to irrigate a large area, but the amount of alkali in the soil is prejudicial to the cultivation of hay to any great extent. The grass is sufficient to support a goodly number of cattle.

No. 104 is 2·66 miles distant from No. 103, at the west end of the second range of bold hills rising out of the valley.

No. 105 is on the high ridge forming the eastern slope of the Chung Up or waterless mountains, at a distance of 5·11 miles and an altitude of 3 860 feet. The station is on the east side of a sag and not far from the top of the ridge, among large, fast stones. Care must be taken not to confound the three points on this top; T 105 is nearest to the sag, No. 105 up the slope to the northeast, and T 105 High still farther to the northeast and at an altitude of 3 937 feet. It is very rough, rising from the valley to No. 105. The main summit is one-half mile west.

The line runs over the rough mountains for 3 miles to No. 106, 3 358 feet altitude, located on the east slope of a very precipitous black, rocky ridge, rising in sheer cliffs nearly 900 feet above Stewart Valley.

Beyond No. 106 the line descends rapidly to Stewart Valley and traverses sandy soil covered with sagebrush to the old bed of a lake covered with soft, brownish soil, then along sandy soil to No. 107, 4·18 miles distant and 2 423 feet in altitude.

The next mark is No. 108, 3 miles distant. The monument is on the southwest end of a small range of mountains that bound Stewart Valley on the east. It stands up boldly on a rocky point at least 50 feet higher and 200 meters north of T 108, which is 2 484 feet in altitude. A short distance southeast the line crosses two roads running from Resting Springs to Pahrump and Manse ranches, not much used now. The line is now in Pahrump Valley, traversing sand and sagebrush for 5 miles to No. 109, 2 494 feet altitude. Pahrump Valley is lowest on the southwest side near the western mountains. It rises gradually toward the eastward in the direction of Charleston Peak, a very high summit, about 11 000 feet in altitude, covered with some pine and with large timber pines in the ravines. A sawmill supplies lumber to the mines and the ranches in the valley. There are two ranches near the northeast end of Pahrump Valley, the one farthest north giving name to the region, and 6 miles southeast is Manse. The water supply comes from warm springs, the quantity at Pahrump ranch being sufficient to irrigate about 500 acres of land and the two large springs at Manse a like quantity. These springs have a uniform temperature of 72° and an unvarying flow the year round. There are no other important springs to the northwest until Ash Meadows are reached, 24 miles. Fourteen miles south of Manse there is a small quantity of water at Stump Spring of good quality, but no more until Sandy is reached, 30 miles south of Manse. Stump Spring is on the old immigrant route from Las Vegas to California.

Leaving No. 109 the line traverses sand and sagebrush to No. 110, 3·54 miles distant, and 2 516 feet altitude. The same character of country is found to No. 111, 3·93 miles distant, and 2 527 feet altitude.

No. 112 is 3·41 miles distant, with an altitude of 2 586 feet, and from here the line runs a short mile to No. 113, altitude 2 610 feet.

No. 114 is 2·17 miles distant, altitude 2 647 feet, and No. 115, 2·0 miles distant, with an altitude of 2 689 feet. The character of the country is the same—sand and sagebrush. Stump Spring is 2 miles north and a little east; an old adobe hut without a roof is still standing just northeast of the spring.

Leaving No. 115 there is a gradual descent, partly through sagebrush and some bunch grass, a few sand hills and washes, to the foot of the ridge on which No. 116 is located, then a rise through thick bunch grass up the stone and gravel slope to No. 116, 3·3 miles distant, altitude 3 089 feet. This last point is on the northeast slope of a low ridge running across the valley, dividing it from Mesquite Valley. The low hills near No. 116 turn nearly parallel to the line and extend for nearly 4 miles to the southeast, until they connect with the high, rocky butte near the center of the valley, almost 6 miles from No. 116. A little over one-half mile east of this is the Von Schmidt 521 milepost.

Crossing over the ridge into Mesquite Valley the line traverses sandy and gravelly soil covered with sagebrush and Spanish bayonet. No. 117 is on the west end of a black, rocky ridge about 3·75 miles from No. 116, and about 0·8 mile northwest of T 117 and T 117 High, which are on a brown hill covered with a mass of loose stone. The altitudes of these latter are 2 921 and 2 924 feet, respectively. No. 117 is somewhat higher, from 50 to 60 feet. Half a mile north of this is Von Schmidt 524 milepost.

Leaving No. 117 the line crosses a depression for over half a mile, then a narrow ridge, and near by the stony hill on which the random line points were located, then descends again into Mesquite Valley and continues through gravel, sand, sagebrush, and Spanish bayonet to No. 118, 5·49 miles distant and 2 631 feet altitude, and one-fourth mile southwest of the main road between Pahrump and Sandy. On the northeast side of this road is a region of sand hills, a few of them covered with mesquite. There are a few sand hills about a mile north of the station also; Von Schmidt 531 milepost is one-half mile east.

Southeast of No. 118 the line traverses sandy soil and sagebrush to No. 119, 2·66 miles distant, altitude 2 591 feet. Von Schmidt 533 milepost is one-fourth mile north, and Von Schmidt 534 milepost is a little more than three-fourths mile southeast.

The line continues through sand and sagebrush to No. 120, distant 2·13 miles, altitude 2 556 feet, on the northeast side of the road running southwest from Sandy to the mountains. Sandy post-office is 1⅜ miles northeast among the sand hills. A large quartz mill, the Keystone, was erected there years ago, which is not in use now; but there are copper mines in operation a few miles northeast of Sandy. The water here is good, being raised from a well by means of a windmill, though the quantity is limited. Von Schmidt's 535 milepost is one-fourth mile north of No. 120. The road to Manvel is about 200 meters northeast.

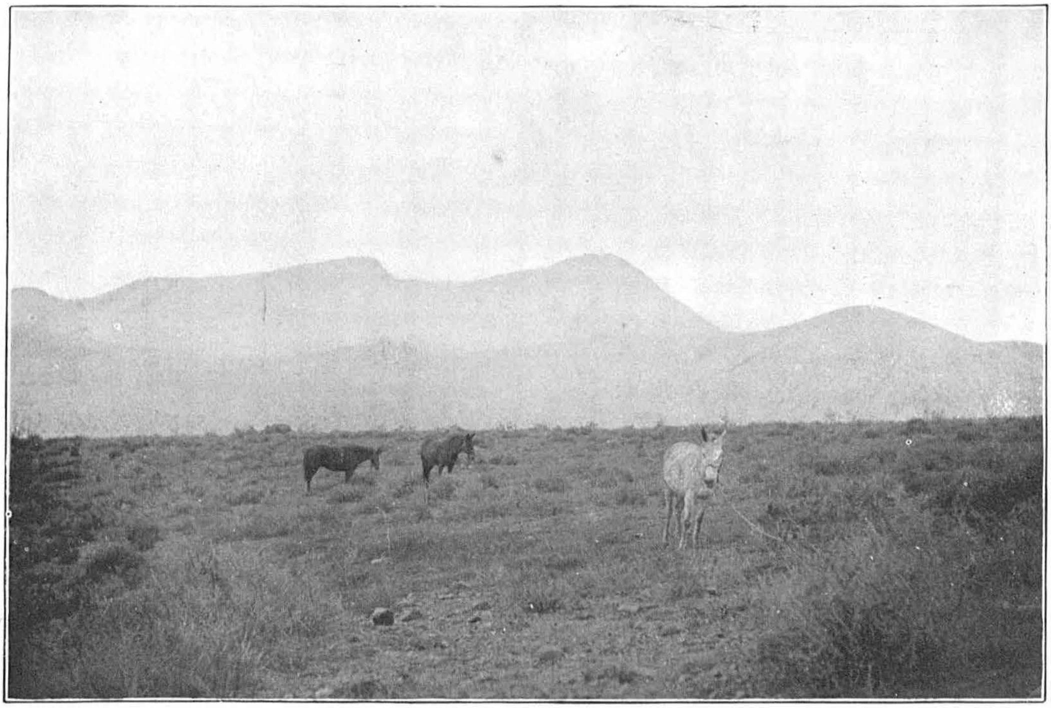
About 1⅛ miles southeast the line crosses the Manvel road and about three-fourths of a mile farther a road branching from it to Sandy. A mass of sand hills is encountered about one-half of a mile northeast of No. 121, which is 3·32 miles distant and 2 584 feet altitude on a sand hill. About 1·25 miles southeast of No. 121 the Von Schmidt line is crossed a second time. The second crossing is 331·31 miles from the intersection of 120° of longitude and 39° of latitude in Lake Tahoe, and 277 miles from the first crossing in the Sweetwater Valley between No. 32 and No. 33.

The line crosses the west slope of high ground on the northeast, full of washes and stones, and also across the upper road between Sandy and Bullock's well, less than a mile northwest of No. 122, about 3·33 miles distant and 2 551 feet altitude. Bullock's well, with alkali water fit only for stock, is 1½ miles south of No. 122. There is no shelter at this place, but a good growth of mesquite, which may be used for firewood, covers the numerous sand hills. The well is at the southeast end of the sand hills.

The line continues on the west slope of the mountains across washes and stony ground covered with sagebrush, greasewood, and some Spanish bayonet, rising over the foothills, and finally crosses the main ridge of the State Line Mountains on the northeast side of the pass, above the precipitous ledges, on the southwest slope of the main ridge in a very commanding position, to No. 123; distant from No. 122, 3·91 miles. The random-line point T 123 has an altitude of 4 342 feet. The boundary monument No. 123 is about 150 feet higher. The State Line Mountains are very striking in appearance. Some of the mass is unstratified, but most of the mountain is formed of horizontal strata from 1 foot to 50 feet thick, greatly eroded by weathering. Some of the strata are fossil bearing; a few of the summits pyramidal in shape, with irregular, receding steps.

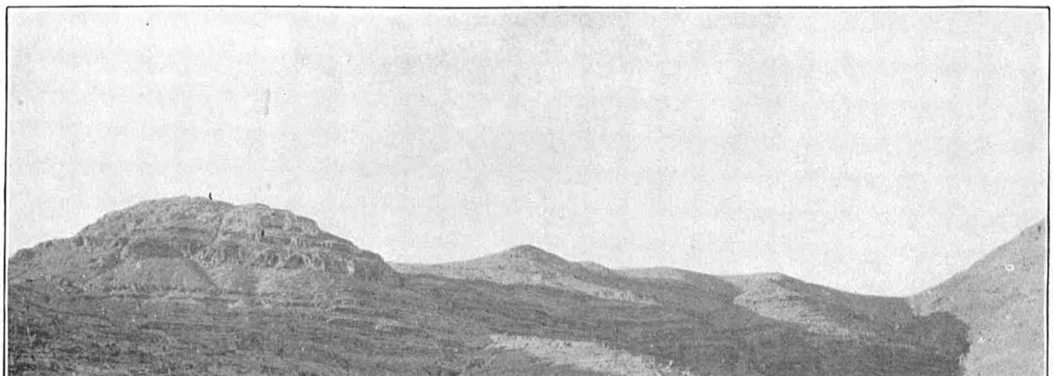
The line continues well on the edge of the mountain down the southeast side, striking the southwest edge of the terminal hills in Dry Lake, until it reaches No. 125, 5·75 miles distant and 2 588 feet in altitude. On the corrected line No. 124 was not necessary, and was therefore omitted. No. 125 is on the alkali flat, forming the north end of Dry Lake about a mile east of the old well (no water) where the road to Sandy, going over the divide, strikes the sagebrush at the foot of the ascent. The road crossing the State Line pass is in very good condition, but the grade on the northwest side is steep

No. 46.



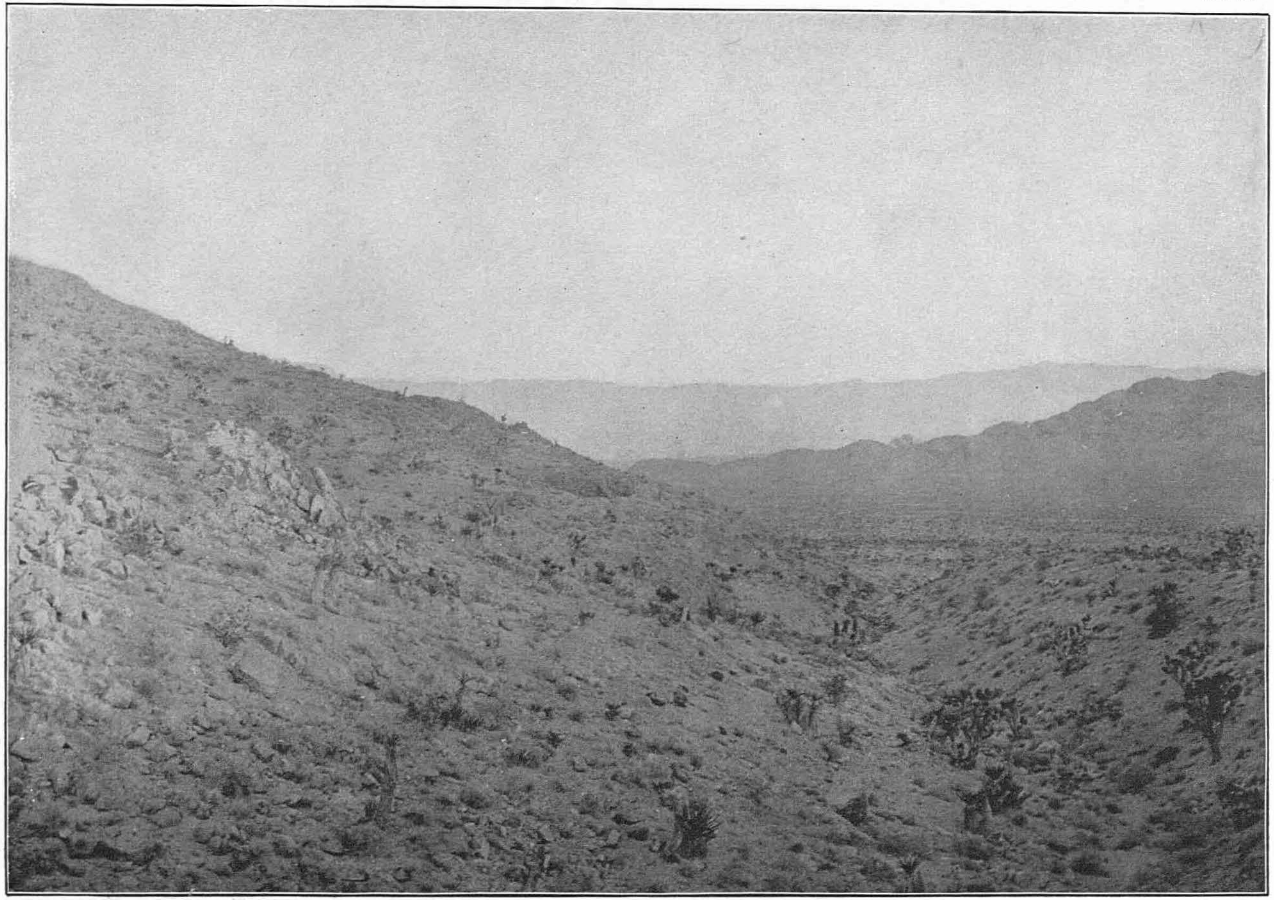
DRY CAMP, LITTLE AMARGOSA DESERT.

No. 47.



No. 123.

FROM ROAD ON STATE LINE PASS. LOOKING NORTHEAST.



IVANPAH VALLEY FROM STATE LINE PASS.

in places. It is about 10 miles across from foot to foot. About one-fourth mile southeast of No. 125 the line crosses the road from Manvel to Good Springs, a mining camp in active operation at this time (1899). The ground is sandy for a short distance and then is covered with stone and large bowlders, sloping upward to No. 126, 3·6 miles and 2 981 feet altitude. The land rises up to the northeastward.

The line continues on the slope through stones and sagebrush for 4·46 miles to No. 127, which is on the southwest side of a high rocky ridge above the general level. The ridge is of black lava and very precipitous. The point on the random line T 127 has an altitude of 3 387 feet, and No. 127 is about 100 feet higher and north one-eighth mile.

For a mile the line continues in the mountains on the west slope, then strikes the sloping mesa, rocky and covered with sagebrush, crossing washes and sandy soil to No. 128, 6·42 miles distant, on the west slope of the mountains. This point is nearly one-fourth mile due east of T 128 on the random, 4 075 feet altitude. T 128 High is just southwest of this, and 4 092 feet altitude. The line crosses the west slope of the mountains over washes, stony and sandy soil, with sagebrush, for 1·72 miles to No. 129, on the northeast slope of a ridge. The random line point T 129, a short distance west, is somewhat higher, being 4 483 feet in altitude.

The line continues on the west slope of the mesa over stones and sand through Spanish bayonet and a forest of yucca to the New York Mountains until No. 130 is reached, 4 miles distant and 5 182 feet altitude. The water for operating from No. 125 to No. 129 may be procured at Dry Lake well, of good quality, on the road from Manvel. To reach No. 130 it is advisable to go to Manvel, then to Malpais Springs, nearly two days' drive from Dry Lake well.

There are three other points near No. 130, T 130 and T 131 on the random line, and T 130 High about one-fourth mile northeast. Malpais Springs are 2·5 miles south of No. 130, in a cañon, with a large stock corral and watering troughs.

The line descends through the large yucca forest, Spanish bayonet, and sagebrush, across the sloping mesa for 5·13 miles to No. 132 on a conspicuous flat-top summit in the Castle Mountains, 4 983 feet altitude. There are two of these summits close together, the line falling on the north one. The Castle Mountains have a number of peculiar rock-capped peaks like cauliflower blooms, the boldest and highest being southwest of the line. The road from Manvel to Searchlight Mines passes about a mile north. The gorge at Malpais Springs drains into the Great Piute Wash that runs into the Colorado River a few miles north of Needles via Ibex Station on the Atlantic and Pacific Railroad.

The line traverses a rough region, hills and valleys, for 4 miles, to No. 133, on the northeast slope of a high rocky mountain. The random line point T 133 is 4 096 feet in altitude, and the line point is about 100 feet lower. For 3·5 miles beyond this the line is in the hills and then comes down into the desert, traversing it to No. 134, 9 miles distant and 2 303 feet in altitude. This point is about a mile northeast of four small buttes in the valley. Von Schmidt's 592 milepost is about 1 mile west, alongside the road to Piute Springs.

Between No. 134 and No. 135 the line rises on the southwest slope, through sand and sagebrush. No. 135 is 5·88 miles distant on the south end of a mass of small summits. The old station on the random line is 2 631 feet in altitude; No. 135 is lower, in a sag among the hillocks. Correcting the line threw T 136 off of the hillside into the lowlands, and it was omitted. The line rises obliquely across the slope and ridges through sagebrush, stones, and sand to No. 137, distant 4 miles from No. 135, altitude 2 671 feet.

No. 138 is only one-fourth mile from No. 137, owing to a rolling table-land. It is in a ledge of large rocks, falling in the space between two of them. The crossing of the road from Piute Springs to Fort Mohave is one-fourth mile southeast of this. No. 138½ is 0·80 mile from No. 138. The soil is sandy, covered with granite bowlders, sagebrush, and a variety of cactus.

The line crosses a number of small granite hills for nearly three-fourths mile to No. 139 on a rocky granite ridge running east and west. T 140 on the random line, altitude 2 168 feet, falls on lower ground in the corrected line and was omitted, as the next, No. 141, is visible, distant 6·25 miles.

Leaving No. 139 the line passes over ground covered with granite bowlders and hills with sagebrush and cactus growth. Three miles to the southeast is a spring in a gorge of the white granite formation. The vertical cliff is covered with Indian hieroglyphics near the spring; the quantity of water is small, and it runs dry some seasons. Just below the spring a broad wash is reached and then a low mesa sloping off toward the river. A quarter of a mile northwest of No. 141, altitude 821 feet, a higher mesa land is reached, formed of sand and gravel. The line from No. 141 crosses the granite hills, covered with sagebrush, to a lower mesa of stone, gravel, and sand, to No. 142, the terminal monument (distant 1·45 miles and altitude 517 feet), which is about 100 meters from the edge of the trees in the river bottom.

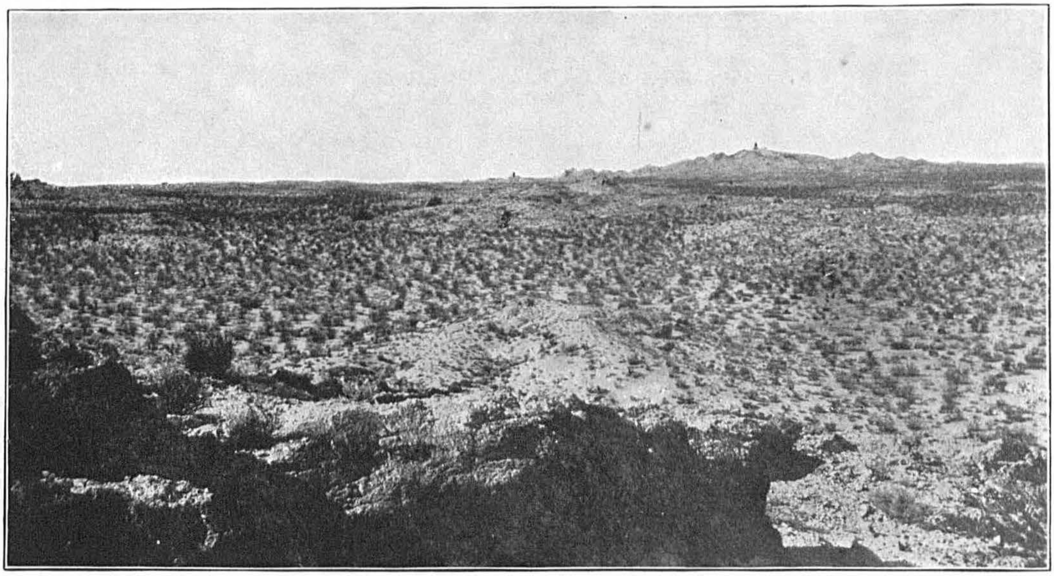
When tracing the line Malpais Springs was used as a base for Nos. 130, 132, 133; then Piute Springs for Nos. 134, 135, 136. From the Colorado River by hauling water and making a dry camp the rest of the points, Nos. 137, 138, 139, 140, 141, and 142 were placed in position.

The line descends from an altitude of about 2 670 feet at the summit of the divide leading up from the Colorado River to 517 feet at No. 142 on the Colorado River in a distance of 9½ miles. The old Government road between Fort Mohave and Piute Springs is very badly washed between Piute Springs and Manvel; crossing the pass it is very steep and rough. Manvel is the best supply point for Piute Springs, and the Needles for the Colorado River camp near the thirty-fifth degree of latitude. In reality the food supplies for the men were brought from Manvel as far northwest as Pahrump Valley, 75 miles distant. To the southeast of No. 142 the line enters the bottom land of the Colorado River, passing through mesquites, willows, and some cottonwoods over a sandy loam for 2·67 miles to the central point between the bluff banks at the crossing of the thirty-fifth degree of latitude, the terminus of the oblique boundary between California and Nevada.

From Fort Mohave to the Needles the Colorado River has bottom lands from 1 to 3 miles wide, edged by bold bluffs of sand and gravel. which may be considered permanent, so little are they subject to change, except superficially through the agency of cloudbursts in the mountains, that send down the water in torrents, tearing gulches and gorges through the mesa.

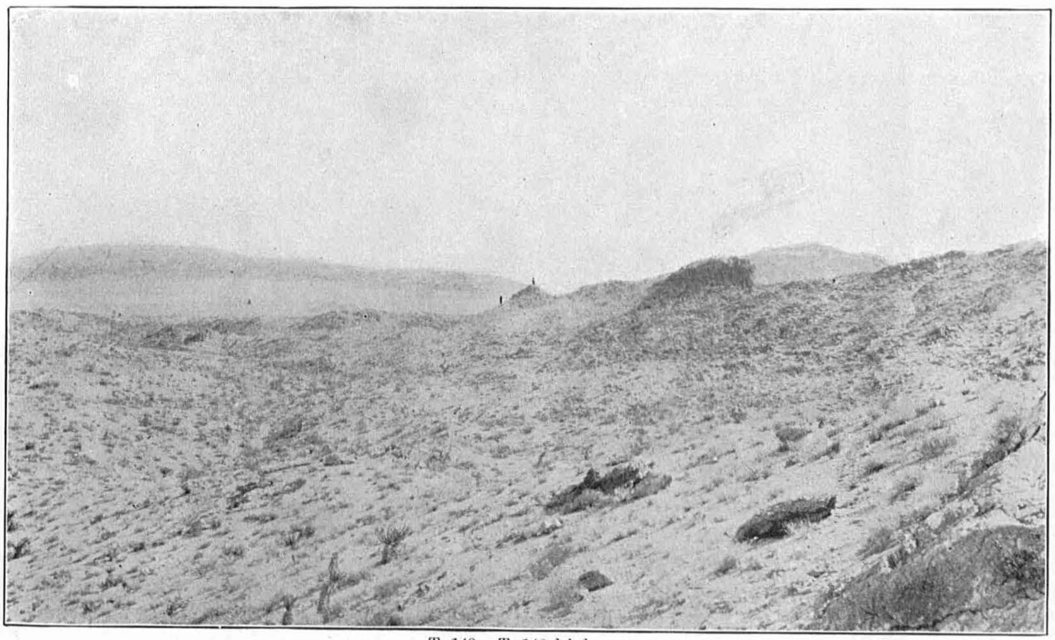
The river wanders from side to side through its alluvial bottom in the most capricious manner during high water, at which time most of the low land is submerged and receives a rich deposit of fertilizing material. There are a number of Mohave Indians

No. 49.



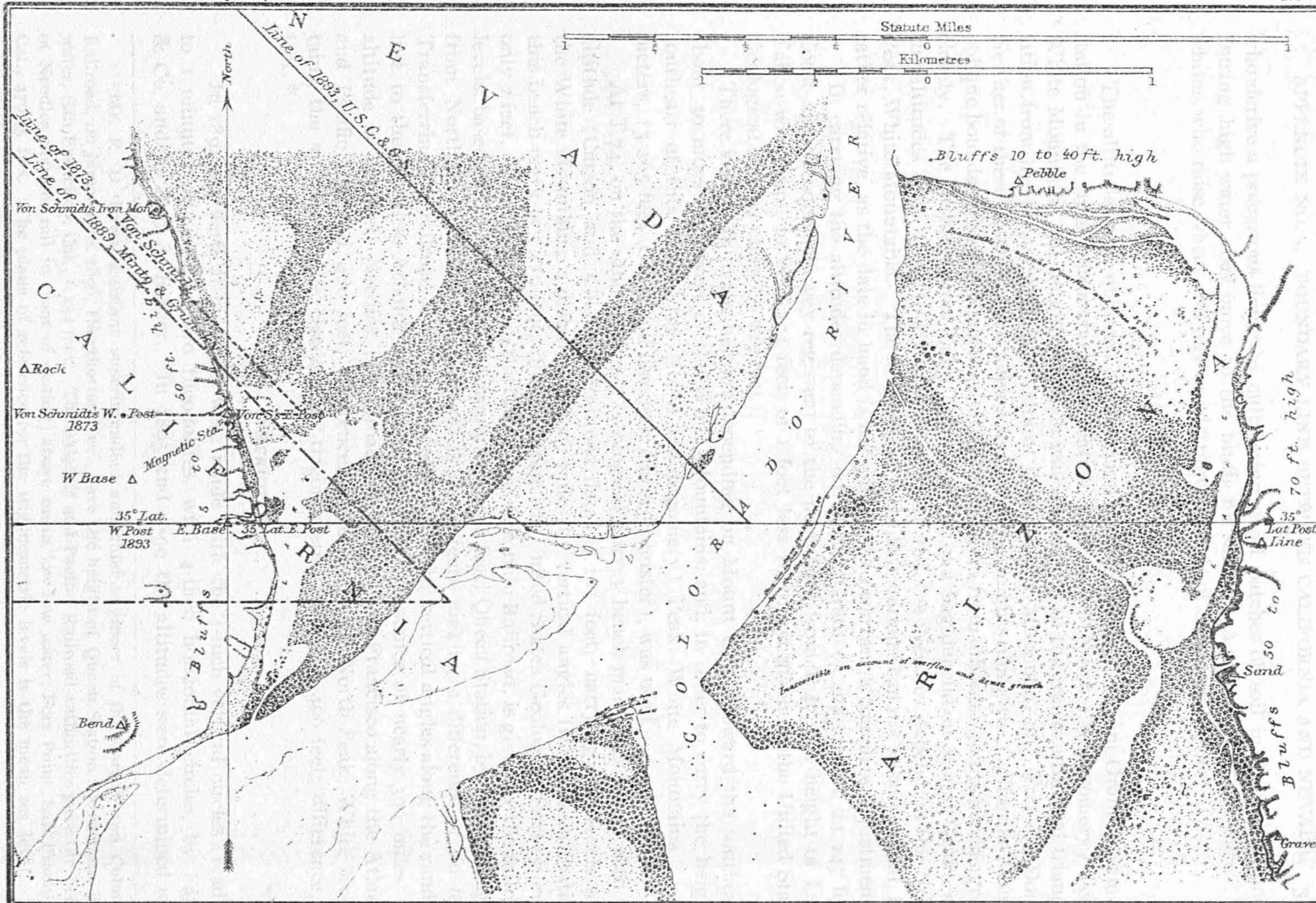
AT T. 139. LOOKING NORTHWEST.

No. 50.



T. 140. T. 140 high.

AT T. 139. LOOKING SOUTHEAST.



CALIFORNIA AND NEVADA BOUNDARY SURVEY

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

who derive a precarious living by cultivating small patches of soil in the low grounds. During high water they move to the bluffs for safety. A few ranches are owned by whites, who raise wheat and hay in addition to herds of cattle and horses.

M. ALTITUDES.

The altitudes were obtained by observing vertical angles on Mount Grant, a primary station in the transcontinental triangulation, and on the North (Montgomery) Peak, White Mountains, the height of which was determined in the transcontinental triangulation from the primary stations—Mount Grant, Lone Mountain, and Toiyabe Dome. Neither of these stations was occupied to determine heights along the California-Nevada oblique boundary, but verticals were observed on them from different points which agreed closely. The altitudes from Lake Tahoe to T 47 and Sag depend on Mount Grant, and the altitudes from T 53 to the Colorado River and the Needles depend on the North Peak, White Mountains. The altitudes of these two stations can not be called final, but rather relative, as the data in hand is not sufficient to warrant a complete adjustment.

In carrying the altitudes depending on Mount Grant (3 428 meters, 11 247 feet, Coast and Geodetic Survey register) to the northwest from T 47, the height of Lake Tahoe was found to be 6 224 feet, or 1 foot less than that given on the United States Geological Survey chart (6 225 feet).

There is a break in the heights depending on Mount Grant toward the southeast, about 30 miles northwest of the White Mountains, and, in order to carry the heights southeast of this break, the North (Montgomery) Peak, White Mountains (4 104 meters, 13 465 feet, Coast and Geodetic Survey register), was used.

At T 74, on the random line, a Geological Survey bench mark was found with the altitude (Carson and Colorado Railroad data) 5 121 feet; carrying the levels over the White Mountains, a distance of 41·7 miles by vertical angles from Queen Station, this bench mark is 5 119 feet; differing from the United States Geological Survey levels only 2 feet. Queen Station, on the Carson and Colorado Railroad, is given by the railroad levels, based on the San Francisco datum, as 6 254 feet; Queen Station, by vertical angles from North Peak, White Mountains, is 6 188 feet; making a difference of 66 feet. Transferring the railroad levels from Queen Station by vertical angles along the random line to the Needles, Atlantic and Pacific Railroad, a distance of nearly 300 miles, the altitude is 532 feet; Needles, by railroad levels from San Francisco along the Atlantic and Pacific Railroad, 480 feet; difference, 52 feet. Using North Peak, White Mountains, the altitude of the Needles (by trigonometric levels) is 466 feet; difference, 14 feet.*

INSTRUMENTS.

In 1894 the vertical measures were made with the 4-inch vertical circles (reading to 1 minute) attached to two theodolites, with 4-inch horizontal circles, by Fauth & Co. and by Buff & Berger. In 1895 and 1899 the altitudes were determined with

*Mr. R. D. Laws, assistant superintendent and chief engineer of the Carson and Colorado Railroad, on January 28, 1896, Hawthorne, Nev., gave the height of Queen Station above mean high water, San Francisco, Cal., 6 254 feet. The Atlantic and Pacific Railroad authorities gave the height of Needles Station (rail in front of station) above mean low low water, Fort Point, San Francisco, Cal., 479·85 feet. The plane of reference for the trigonometric levels is the mean sea level. The

the 5-inch vertical circles (reading to 1 minute) attached to the 7-inch Buff & Berger theodolites. Five of these theodolites were used on the boundary triangulation. (See illustration, No. 58.)

On the random line the stations are designated by T 1, T 2, T 3, etc., counting from Lake Tahoe, while on the corrected line the boundary marks are designated by No. 1, No. 2, No. 3, etc.

IV. TABLES, ETC., SHOWING THE RESULTS IN DETAIL.

A. DISTANCE AND ALTITUDES ON THE RANDOM LINE.

Stations.	Distance between stations.	Total distance from T 1.	Offset to corrected line.	Altitude.	Remarks.
	Meters.	*Meters.*	*Meters.*	*Feet.*	
T 1	0·0	0·0	0·00	6 249·3	T 1 was the azimuth station of 1894.
T 2	377·9	377·9	·09	....	On road, southwest side.
T 3	3 107·8	3 485·7	·82	9 019·4	West side of the mountain top.
T 4	263·4	3 749·1	·88	9 160·7	Do.
T 5	988·6	4 737·7	1·11	9 517·2	Not corrected on account of deep snow.
T 6	652·0	5 389·7	1·26	9 475·3	Do.
T 7	604·1	5 993·8	1·41	9 340·0	East side of the mountain top.
T 8	7 438·1	13 431·9	3·15	5 213·6	Carson Valley, west side.
T 9	1 777·2	15 209·1	3·57	4 833·8	Do.
T 10	1 448·9	16 658·0	3·91	4 865·6	Do.
T 11	1 395·9	18 053·9	4·23	4 800·6	Carson Valley, fork of roads.
T 12	2 276·6	20 330·5	4·77	4 847·1	Carson Valley, in road.
T 13	564·8	20 895·3	4·90	4 848·4	Carson Valley, West Fork Carson River.
T 14	1 040·0	21 935·3	5·14	4 980·2	Carson Valley.
T 15	2 639·5	24 574·8	5·76	5 459·8	Carson Valley, rolling hills.
T 16	727·7	25 302·5	5·94	....	Middle Fork of Carson River.
T 17	1 700·4	27 002·9	6·33	5 815·3	Rolling hills.
T 18	1 940·1	28 943·0	6·79	5 103·9	East Fork Carson River, Kelly's ranch.
T 19	1 256·3	30 199·3	7·08	6 027·4	Wooded mountain, southeast of Kelly's ranch.
T 20	1 141·2	31 340·5	7·35	....	West slope of cliff.
T 21	2 853·1	34 193·6	8·02	6 322·7	West slope, half way to top.

Footnote—Continued.

plane of mean high water is 1·845 feet above mean sea level; and the plane of mean low low water, or, as usually designated, mean lower low water, is 3·182 feet below mean sea level; so that the difference between the above reference planes at Fort Point is 5·027 feet.

The following letter is authority for this statement:

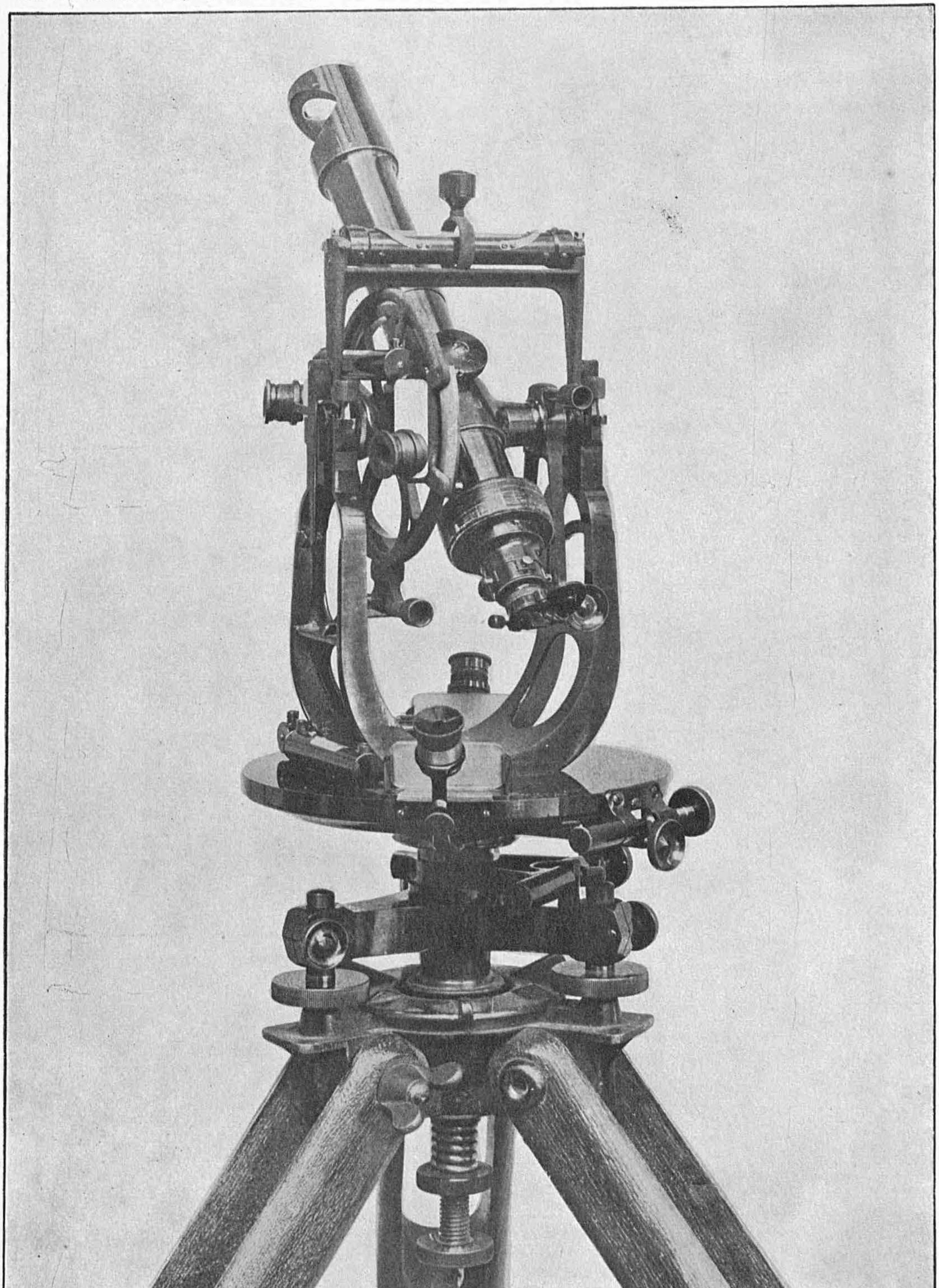
TREASURY DEPARTMENT,
OFFICE OF THE COAST AND GEODETIC SURVEY,
Washington, D. C., January 10, 1901.

Mr. C. H. SINCLAIR,
Assistant, Coast and Geodetic Survey, Washington, D. C.

SIR: In reply to your inquiry of the 9th instant in relation to the difference between mean high water and mean low water at Fort Point, San Francisco Bay, California, I have to state that the difference is 5·027 feet. The plane of mean high water is 1·845 feet above mean sea level; and the plane of mean low low water, or, as usually designated, mean lower low water, is 3·182 feet below mean sea level.

Respectfully, yours,

ANDREW BRAID,
Assistant in charge of the Office.



BUFF & BERGER 7-INCH THEODOLITE.

A. DISTANCE AND ALTITUDES ON THE RANDOM LINE—Continued.

Stations.	Distance between stations.	Total distance from T 1.	Offset to corrected line.	Altitude.	Remarks.
	Meters.	*Meters.*	*Meters.*	*Feet.*	
T 22	4 597·3	38 790·9	9·10	7 612·6	Highest ridge, west slope.
T 23	4 179·1	42 970·0	10·07	7 522·9	Southeast slope.
T 24	3 040·0	46 010·0	10·79	....	Carson & Coleville road, north side.
T 25	2 336·9	48 346·9	11·34	5 303·9	Southeast of Alkali Lake, high hill.
T 26	....	....	....	....	Temporary station.
T 27	3 735·4	52 082·3	12·21	4 936·4	Northwest side of W. Walker River.
T 28	3 737·9	55 820·2	13·09	5 111·9	Antelope Valley.
T 29	7 996·7	63 816·9	14·97	7 480·1	Wooded hill.
T 30	3 733·8	67 550·7	15·84	7 962·8	Bare ridge.
T 31	2 010·5	69 561·2	16·31	8 643·4	Bare ridge.
T 32	6 195·4	75 756·6	17·77	10 556·2	Summit of Sweetwater Mountains.
T 33	8 457·7	84 214·3	19·75	6 985·9	Sweetwater Valley.
T 34	5 307·4	89 521·7	20·99	6 529·6	Do.
T 35	621·9	90 143·6	21·14	6 444·0	Do.
T 36	5 573·3	95 716·9	22·45	7 258·8	On Red Hill.
T 37	4 169·9	99 886·8	23·43	8 009·6	Do.
T 38	2 588·4	102 475·2	24·03	8 347·6	On Rocky Knob.
T 39	4 941·7	107 416·9	25·19	8 009·2	On table-land.
T 40	5 677·3	113 094·2	26·52	8 954·0	On Beauty Peak.
T 41	2 167·8	115 262·0	27·03	....	North of Aurora and Bodie Road.
T 42	3 714·2	118 976·2	27·90	9 246·8	Summit of West Brawley Mountain.
T 43	2 661·3	121 637·5	28·53	....	North of Aurora and Bodie (old) road.
T 44	2 877·1	124 514·6	29·20	8 521·2	Round bare hill—isolated mountain.
T 45	4 449·9	128 964·5	30·24	8 178·7	Wooded peak—double-top mountain, southeast one.
T 46	7 347·0	136 311·5	31·97	....	Aurora and Benton road; desert.
T 47	3 681·5	139 993·0	32·83	7 878·2	On wooded hill.
T 48	4 403·5	144 396·5	33·86	....	On table-land.
T 49	1 043·7	145 440·2	34·11	....	Lava ridge, east side of small knob.
T 50	6 730·2	152 170·4	35·69	....	Hontoun Valley, bottom of defile.
T 51	4 203·3	156 373·7	36·67	....	Excelsior Mountains, east slope wooded mountain.
T 52	812·1	157 185·8	36·86	....	Do.
T 53	3 581·9	160 767·7	37·70	7 942·0	Excelsior Mountains, west slope wooded mountain.
T 54	6 102·7	166 870·4	39·13	7 802·0	Excelsior Mountains, east slope bare ridge.
T 55	746·3	167 616·7	39·31	7 789·0	Excelsior Mountains.
T 56	1 057·0	168 673·7	39·55	....	Do.
T 57	452·7	169 126·4	39·66	....	Do.
T 58	2 365·4	171 491·8	40·22	7 092·0	Excelsior Mountains, wooded.
T 59	4 793·6	176 285·4	41·34	5 951·0	Carson and Colorado R. R., northwest side.
T 59½	3 059·6	179 345·0	42·06	6 618·0	Foot of White Mountains, on mesa.
T 60	7 094·9	186 439·9	43·72	12 887·0	Summit of White Mountains.
T 61	5 039·3	191 479·2	44·90	11 323·0	White Mountains, sharp, bare ridge.
T 62	5 390·9	196 870·1	46·17	9 653·0	White Mountains.
T 63	3 693·9	200 564·0	47·03	9 077·0	Do.
T 64	1 519·5	202 083·5	47·39	9 286·0	Do.
T 65	2 194·4	204 277·9	47·91	8 585·0	Do.
T 66	3 915·5	208 193·4	48·82	7 972·0	Do.
T 67	6 568·2	214 761·6	50·36	6 771·0	Do.
T 67½	7 024·1	221 785·7	52·01	4 986·0	Fish Lake Valley.
T 68	3 355·5	225 141·2	52·80	4 994·0	Do.
T 69	2 973·0	228 114·2	53·50	5 038·0	Do.
T 70	1 318·0	229 432·2	53·80	5 056·0	Do.
T 71	1 343·5	230 775·7	54·12	....	Do.
T 72	4 539·7	235 315·4	55·18	....	Do.
T 73	5 409·2	240 724·6	56·45	....	Do.
T 74	2 796·8	243 521·4	57·11	5 053·0	Do.

A. DISTANCE AND ALTITUDES ON THE RANDOM LINE—Continued.

Stations.	Distance between stations.	Total distance from T 1.	Offset to corrected line.	Altitude.	Remarks.
	Meters.	*Meters.*	*Meters.*	*Feet.*	
T 75	4 145·1	247 666·5	58·08	....	Fish Lake Valley.
T 76	1 180·6	248 847·1	58·36	....	Fish Lake Valley, southeast of road.
T 77	1 968·7	250 815·8	58·82	....	Fish Lake Valley.
T 78	5 409·4	256 225·2	60·09	6 774·0	Foothills of Sylvania Mountains, west slope.
T 79	5 165·2	261 390·4	61·29	7 927·0	Summit of Sylvania Mountains.
T 80	7 844·1	269 234·5	63·14	6 894·0	Sylvania Mountains.
T 81	10 996·6	280 231·1	65·72	4 270·0	Wash from Tule Cañon.
T 82	4 499·0	284 730·1	66·77	3 763·0	Head of Death Valley.
T 83	7 101·6	291 831·7	68·44	4 255·0	Do.
T 84	3 446·5	295 278·2	69·25	4 766·0	Head of Death Valley, rolling hills.
T 85	2 975·4	298 253·6	69·94	5 197·0	Do.
T 86	6 840·5	305 094·1	71·55	5 635·0	Round bare hill.
T 87	1 822·9	306 917·0	71·98	5 444·0	Lava ridge.
T 88	8 810·3	315 727·3	74·04	4 260·0	Lava ridge, very stony.
T 89	9 082·4	324 809·7	76·17	7 688·0	North face of precipice, Grape Vine Mountains.
T 90	6 511·1	331 320·8	77·70	7 800·0	Grape Vine Mountains.
T 91	7 801·7	339 122·5	79·53	7 587.0	Do.
T 92	5 463·6	344 586·1	81·00	7 034·0	Bare summit Grape Vine Mountains.
T 93	15 314·2	359 900·3	84·40	4 974·0	Rocky summit, Funeral Mountains.
T 94	9 149·5	369 049·8	86·55	3 903·5	Little Amargosa Desert.
T 95	3 045·3	372 095·1	87·26	3 899·0	Do.
T 96	5 748·7	377 843·8	88·61	3 614·0	Little Amargosa Desert, bare hill east slope.
T 97	9 928·9	387 772·7	90·94	....	Little Amargosa Desert, big wash.
T 98	4 698·5	392 471·2	92·04	2 927·0	Northeast end of Funeral Mountains.
T 99	9 102·5	401 573·7	94·17	2 349·0	Great Amargosa Desert.
T 100	7 589·2	409 162·9	95·95	2 358·0	Do.
T 101	7 162·6	416 325·5	97·63	2 271·0	Do.
T 102	6 822·3	423 147·8	99·23	2 176·0	Do.
T 103	6 157·0	429 304·8	100·68	2 118·9	Do.
T 104	4 277·9	433 582·7	101·68	....	Do.
T 105	8 226·4	441 809·1	103·61	3 859·7	Northeast end of Chung Up Mountains.
T 106	4 859·2	446 668·3	104·40	3 357·5	Northeast end of Chung Up Mountains, precipice.
T 107	6 728·5	453 396·8	105·59	2 423·1	Stewart Valley.
T 108	4 925·5	458 322·3	106·50	2 484·4	Do.
T 109	8 036·0	466 358·3	108·35	2 494·4	Pahrump Valley.
T 110	5 695·0	472 053·3	110·37	2 515·7	Do.
T 111	6 315·3	478 368·6	111·09	2 526·9	Do.
T 112	5 483·3	483 851·9	113·58	2 585·9	Do.
T 113	1 552·8	485 404·7	111·22	2 609·6	Do.
T 114	3 486·4	488 891·1	113·57	2 646·6	Do.
T 115	3 179·7	492 070·8	112·40	2 689·4	Do.
T 116	5 307·2	497 378·0	116·64	3 089·0	On ridge between Mesquite and Pahrump valleys.
T 117	7 417·8	504 795·8	118·38	2 921·1	On round hill, Mesquite Valley.
T 118	7 624·5	512 420·3	120·17	2 630·9	Mesquite Valley.
T 119	4 285·9	516 706·2	121·17	2 590·5	Do.
T 120	3 526·0	520 232·2	122·01	2 555·6	Mesquite Valley, southwest of Sandy Post-Office.
T 121	5 351·5	525 583·7	123·26	2 583·9	Mesquite Valley, on Sand Hill.
T 122	6 328·3	531 912·0	124·74	2 651·1	Mesquite Valley, east side.
T 123	7 759·4	539 671·4	126·56	4 342·3	Summit of State Line Mountains.
T 124	906·2	540 577·6	126·77	4 270·1	Do.
T 125	8 356·0	548 933·6	128·73	2 588·1	Dry Lake, Ivanpah Valley, northeast end.
T 126	5 798·5	554 732·1	130·09	2 920·8	East side Ivanpah Valley.

A. DISTANCE AND ALTITUDES ON THE RANDOM LINE—Continued.

Stations.	Distance between stations.	Total distance from T 1.	Offset to corrected line.	Altitude.	Remarks.
	Meters.	*Meters.*	*Meters.*	*Feet.*	
T 127.....	7 182·8	561 914·9	131·77	3 387·0	East side Ivanpah Valley.
T 128.....	10 325·2	572 240·1	134·19	4 074·8	Do.
T 129.....	2 769·1	575 009·2	134·84	4 483·3	Do.
T 130.....	6 338·8	581 348·0	136·34	5 181·9	New York Mountains.
T 131.....	237·0	581 585·0	136·40	5 193·9	Do.
T 132.....	8 146·6	589 731·6	138·31	4 983·0	Castle Mountains, flat top.
T 133.....	6 470·8	596 202·4	139·82	4 095·7	Lewis Range, east slope.
T 134.....	14 403·0	610 605·4	143·19	2 303·0	Piute Wash, Piute Valley.
T 135.....	9 361·9	619 967·3	145·39	2 630·7	East side Piute Valley.
T 136.....	3 938·8	623 906·1	146·31	2 648·7	Do.
T 137.....	2 640·7	626 546·8	146·93	2 671·3	Do.
T 138.....	798·0	627 344·8	147·12	2 649·9	Divide between Piute Valley and Colorado River.
T 139.....	2 022·6	629 367·4	147·59	....	Southeast slope to the Colorado River.
T 140.....	1 635·8	631 003·2	147·97	2 168·1	Do.
T 141.....	8 421·2	639 424·4	149·93	820·7	Do.
T 142.....	2 334·2	641 758·6	150·48	517·4	West bank of Colorado River, 100 meters from trees.
Center of river, 35° latitude.	3 646·1	645 404·7	....	....	Middle of Colorado River and 35° latitude.

NOTE.—Points on the random line are designated by T 1, T 2, T 3, etc.; points on the corrected line are designated by No. 1, No. 2, No. 3, etc.

B. DISTANCES ON THE CORRECTED LINE.

No.	Distance between monuments.		Total distance from 120° longitude and 39° latitude.		Remarks.
	Meters.	*Miles.*	*Meters.*	*Miles.*	
0........	0·0	0·0	0·0	0·0	At intersection of 120° longitude and 39° latitude.
1........	5 811·0	3·61	5 811·0	3·61	On lake shore, same as "Initial, 1894."
2........	838·6	0·52	6 649·6	4·13	On road, same as T 2 on random line.
3........	3 107·8	1·93	9 757·4	6·06	West side of the mountain top.
4........	263·4	0·16	10 020·8	6·22	Do.
5........	988·6	0·61	11 009·4	6·83	Do.
6........	652·0	0·40	11 661·4	7·23	Summit of the Sierras.
7........	604·1	0·38	12 265·5	7·62	East of summit.
8........	7 438·1	4·62	19 703·6	12·24	Carson Valley, west side.
9........	1 777·2	1·10	21 480·8	13·35	Do.
10........	1 448·9	0·90	22 929·7	14·25	Do.
11........	1 395·9	0·87	24 325·6	15·12	Carson Valley, forks of roads.
12........	2 273·2	1·41	26 598·8	16·53	Carson Valley, in the road.
13........	568·2	0·35	27 167·0	16·88	Carson Valley, Carson River, west bank.
14........	1 040·0	0·65	28 207·0	17·53	Carson Valley.
15........	2 639·5	1·64	30 846·5	19·17	Carson Valley, rolling hills.
16........	727·7	0·45	31 574·2	19·62	Middle fork of Carson River.
17........	1 700·4	1·06	33 274·6	20·68	Wooded hill.
18........	1 940·1	1·21	35 214·7	21·88	East fork of Carson River, Kelly's ranch.
19........	1 256·3	0·78	36 471·0	22·66	Wooded Mountain, southeast side of Kelly's ranch.
20........	1 141·2	0·71	37 612·2	23·37	West slope of cliff.
21........	2 853·1	1·77	40 465·3	25·14	West slope, halfway to top.

B. DISTANCES ON THE CORRECTED LINE—Continued.

No.	Distance between monuments.		Total distance from 120° longitude and 39° latitude.		Remarks.
	Meters.	*Miles.*	*Meters.*	*Miles.*	
22	4 597·3	2·86	45 062·6	28·00	Highest ridge, west slope.
23	4 179·1	2·60	49 241·7	30·60	Southeast slope.
24	3 040·0	1·89	52 281·7	32·49	Carson and Coleville road, north side.
25	2 336·9	1·45	54 618·6	33·94	Southeast of Alkali Lake, high hill.
26	Omitted.				
27	3 696·0	2·30	58 314·6	36·24	Antelope Valley, West Walker River, northwest side.
28	3 777·3	2·35	62 091·9	38·58	Antelope Valley.
28½	494·5	0·31	62 586·4	38·89	Do.
29	7 496·8	4·66	70 083·2	43.54	
30	3 745·5	2·33	73 828·7	45·88	Bare Ridge.
31	2 000·4	1·24	75 829·1	47·12	Do.
32	6 207·0	3·86	82 036·1	50·98	Summit of the Sweetwater Mountains.
33	8 464·3	5·26	90 500·4	56·23	Sweetwater Valley.
34	5 306·7	3·30	95 807·1	59·53	Do.
35	599·6	0·37	96 406·7	59·90	Do.
36	5 593·3	3·48	102 000·0	63·38	On red hill.
37	4 160·5	2·59	106 160·5	65·97	Do.
38	2 593·0	1·61	108 753·5	67·58	On rocky knob.
39	4 935·1	3·07	113 688·6	70·65	On table-land.
40	5 659·3	3·52	119 347·9	74·17	Beauty Peak.
41	2 095·8	1·30	121 443·7	75·47	North of Aurora and Bodie road.
42	3 795·4	2·36	125 239·1	77·83	Summit of the West Brawley Mountains.
43	2 670·1	1·66	127 909·2	79·49	North of Aurora and Bodie (old) road.
44	2 877·1	1·79	130 786·3	81·28	Isolated Mountain, east slope.
45	4 429·5	2·75	135 215·8	84·03	Wooded Mountain, double top, southeast one.
46	7 367·4	4·58	142 583·2	88·61	Aurora and Benton road, Aurora Desert.
47	3 712·5	2·31	146 295·7	90·92	Wooded hill.
48	4 363·9	2·71	150 659·6	93·63	Table-land.
49	1 051·6	0·65	151 711·2	94·28	Lava ridge, east side of small knob.
50	Omitted.				
51	10 934·1	6·79	162 645·3	101·07	East slope wooded hill, Excelsior Mountains.
52	812·1	0·50	163 457·4	101·57	Do.
53	3 576·0	2·22	167 033·4	103·79	West slope wooded hill, Excelsior Mountains.
54	6 097·2	3·79	173 130·6	107·58	East slope bare hill, Excelsior Mountains.
55	757·7	0·47	173 888·3	108·05	Excelsior Mountains.
56	1 057·0	0·66	174 945·3	108·71	Do.
57	523·1	0·33	175 468·4	109·04	Do.
58	2 167·4	1·35	177 635·8	110·39	Do.
59	4 908·3	3·05	182 544·1	113·43	Carson and Colorado Railroad, northwest side.
59½	3 072·5	1·91	185 616·7	115·34	Northwest foot of White Mountains.
60	7 082·4	4·40	192 699·1	119·74	Summit of the White Mountains.
61	Omitted.				
62	10 433·7	6·48	203 132·8	126·22	White Mountains.
63	3 702·9	2·30	206 835·7	128·52	Do.
64	1 501·4	0·93	208 337·1	129·45	Do.
65	2 228·1	1·38	210 565·2	130·84	Do.
66	3 896·6	2·42	214 461·8	133·26	Do.
67	6 558·0	4·08	221 019·8	137·34	Do.
67½	7 037·6	4·37	228 057·4	141·71	Fish Lake Valley.
68	3 357·9	2·09	231 415·3	143·79	Do.
69	2 970·6	1·85	234 385·9	145·64	Do.
70	1 330·3	0·83	235 716·2	146·47	Do.
71	1 331·2	0·83	237 047·4	147·30	Do.

B. DISTANCES ON THE CORRECTED LINE—Continued.

No.	Distance between monuments.		Total distance from 120° longitude and 39° latitude.		Remarks.
	Meters.	*Miles.*	*Meters.*	*Miles.*	
72	4 539·7	2·82	241 587·1	150·12	Fish Lake Valley.
73	5 409·2	3·36	246 996·3	153·48	Do.
74	2 796·8	1·74	249 793·1	155·22	Do.
75	4 145·1	2·58	253 938·2	157·80	Do.
76	1 180·6	0·73	255 118·8	158·53	Do.
77	1 968·7	1·22	257 087·5	159·75	Do.
78	5 409·4	3·36	262 496·9	163·11	Sylvania Mountains, west slope.
79	5 188·4	3·22	267 685·3	166·33	Summit of the Sylvania Mountains.
80	7 899·4	4·91	275 584·7	171·24	Sylvania Mountains.
81	10 899·1	6·79	286 483·8	178·03	
82	4 518·0	2·81	291 001·8	180·84	Head of Death Valley.
83	7 145·6	4·44	298 147·4	185·28	Do.
84	3 414·1	2·12	301 561·5	187·40	Do.
85	2 981·9	1·85	304 543·4	189·24	Do.
86	6 838·6	4·25	311 382·0	193·49	Round bare hill.
87	1 777·5	1·10	313 159·5	194·59	
88	8 839·5	5·49	321 999·0	200·08	
89	9 082·5	5·64	331 081·5	205·72	North face of precipice, Grape Vine Mountains.
90		Omitted.			
91	14 220·1	8·84	345 301·6	214·56	Grape Vine Mountains.
92	5 584·7	3·47	350 886·3	218·03	Bare summit Grape Vine Mountains.
93	15 302·8	9·51	366 189·1	227·54	Rocky summit Funeral Mountains.
94	9 137·4	5·68	375 327·0	233·22	Little Amargosa Desert.
95	3 059·7	1·90	378 386·7	235·12	Do.
96	5 748·2	3·57	384 134·9	238·69	Little Amargosa Desert, bare hill, east slope.
97	9 915·5	6·16	394 050·4	244.85	Little Amargosa Desert, west slope.
98	4 028·6	2·50	398 079.0	247·35	Funeral Mountains, east slope.
98½	1 447·4	0·90	399 526·4	248·25	Do.
99	8 319·0	5·17	407 845·4	253·42	Great Amargosa Desert.
100	7 589·2	4·72	415 434·6	258·14	Do.
101	7 162·6	4·45	422 597·2	262·59	Do.
102	6 822·3	4·24	429 419·5	266·83	Do.
103	6 157·0	3·83	435 576·5	270·66	Do.
104	4 227·5	2·63	439 804·0	273·29	Do.
105	8 279·0	5·14	448 083·0	278·43	Northeast end of Chung Up Mountains.
106	4 904·0	3·05	452 987·0	281·48	Chung Up Mountains, precipice.
107	6 681·5	4·15	459 668·5	285·63	Stewart Valley.
108	4 751·4	2·95	464 419·9	288·58	Do.
109	8 210·1	5·10	472 630·0	293·68	Pahrump Valley.
110	5 695·0	3·54	478 325·0	297·22	Do.
111	6 315·3	3·92	484 640·3	301·14	Do.
112	5 483·3	3·41	490 123·6	304·55	Do.
113	1 552·8	0·96	491 676·4	305·51	Do.
114	3 486·4	2·17	495 162·8	307·68	Do.
115	3 179·7	1·98	498 342·5	309·66	Do.
116	5 370·0	3·34	503 712·5	313·00	Dividing ridge, southeast end Pahrump Valley.
117	6 164·5	3·83	509 877·0	316·83	West slope Rocky ridge.
118	8 815·0	5·48	518 692·0	322·31	Mesquite Valley.
119	4 285·9	2·66	522 977·9	324·97	Do.
120	3 532·0	2·19	526 509·9	327·16	Mesquite Valley, southwest of Sandy post-office.
121	5 185·2	3·22	531 695·1	330·38	Mesquite Valley, on sand hill.
122	6 488·6	4·03	538 183·7	334·41	Mesquite Valley, east side.
123	7 739·4	4·81	545 923·1	339·22	Summit of State Line Mountains, east of bluffs.
124		Omitted.			

B. DISTANCES ON THE CORRECTED LINE—Continued.

No.	Distance between monuments.		Total distance from 120° longitude and 39° latitude.		Remarks.
	Meters.	*Miles.*	*Meters.*	*Miles.*	
125	9 282.2	5.77	555 205.3	344.99	Ivanpah Valley, dry lake, northeast end.
126	5 798.5	3.60	561 003.8	348.59	Ivanpah Valley, east slope.
127	6 964.0	4.33	567 967.8	352.92	Rocky bluff, east side of Ivanpah Valley.
128	10 781.0	6.70	578 748.8	359.62	Mountains, east side of Ivanpah Valley.
129	2 638.2	1.64	581 387.0	361.26	Do.
130	6 104.0	3.79	587 491.0	365.05	New York Mountains.
131	Omitted.				
132	8 310.0	5.16	595 801.0	370.21	Castle Mountains, flat top.
133	6 704.2	4.17	602 505.2	374.38	Lewis Mountains, east slope,
134	14 371.9	8.93	616 877.1	383.31	Piute Valley.
135	9 487.6	5.90	626 364.7	389.21	Piute Valley, southwest butte, near top.
136	Omitted.				
137	6 519.0	4.05	632 883.7	393.25	Piute Valley.
138	412.2	0.26	633 295.9	393.51	Divide between Piute Valley and Colorado River.
138½	1 323.0	0.82	634 618.9	394.33	East slope.
139	1 132.4	0.70	635 751.3	395.03	Rough ridge, on slope.
140	Omitted.				
141	10 018.0	6.23	645 769.3	401.26	Mesa.
142	2 261.0	1.40	648 030.3	402.67	West bank of Colorado River, 100 meters from trees.
Center of River, 35° lat.	3 646.1	2.27	651 676.4	404.94	Middle of Colorado River at 35° latitude.

NOTE.—Points on the random line are designated by T 1, T 2, T 3, etc. Points on the corrected line are designated by No. 1, No. 2, No. 3, etc.

*C.** GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899.*

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
Initial 94	38 57 45.99	119 56 59.31	178 26 41.9	358 26 40.2	Folsom Peak	2 370.9
			303 30 40.5	123 32 15.7	East Peak	4 374.8
No. 1	**45.99**	**59.31**	**311 16 45.3**	**131 16 54.3**	**No 2**	**838.6**
T 1 Azimuth Sta	38 57 36.13	119 56 44.93	131 16 54.3	311 16 45.3	Initial 94	460.7
			171 16 23.0	351 16 12.3	Folsom Peak	2 705.3
T 2	38 57 28.05	119 56 33.13	131 17 14	311 17 07	T 1 Azimuth Sta	377.9
			220 24 31	40 25 46	Castle Rock	4 455.0
No. 2	**28.05**	**33.13**	**311 16 47.7**	**131 18 05.1**	**No. 3**	**3 107.8**
T 3	38 56 21.54	119 54 56.17	131 18 05.1	311 16 47.7	Initial 94	3 946.4
			254 35 09.1	74 35 26.9	East Peak	707.4
No. 3	**21.57**	**56.16**	**311 18 12.1**	**131 18 17.3**	**No. 4**	**263.4**
T 4	38 56 15.90	119 54 47.95	131 18 17.3	311 18 12.1	T 3	263.4
			233 13 03.3	53 13 15.9	East Peak	604.4
No. 4	**15.92**	**47.93**	**311 17 59**	**131 18 43**	**No. 7**	**2 244.7**
T 5	38 55 54.74	119 54 17.12	131 19 00.6	311 18 41.2	T 4	988.6
			165 42 43.6	345 42 36.9	East Peak	1 046.9
No. 5	(*)	(*)	(*)	(*)	(*)	(*)

* Not corrected—deep snow.

** See note, end of table.


SYLVANIA MOUNTAINS
Tule Canyon Road
Tule Canyon
Sand and boulders
Sage brush
Greasewood
To Gold Hill
Sand Spring
To Death Valley
Granite
Cacti
Baldwin
Palmetto
Von Schmidt's line
Sage brush
To Thorps Mill
To Stainingers Ranch
GRAPEVINE MOUNTAINS
Big Spring
LITTLE AMARGOZA DESERT
TELESCOPE MOUNTAINS

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893-1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 6	38 55 40.78	119 53 56.79	131 19 15.4	311 19 02.6	T 5	652.0
			152 38 00.4	332 37 40.9	East Peak	1 627.1
No. 6	(*)	(*)	(*)	(*)	(*)	(*)
T 7	38 55 27.84	119 53 37.96	176 28 17.4	356 28 13.9	Bowlder	2 163.1
			210 25 22.4	30 26 04.5	Ledge	3 183.2
No. 7	27.87	37.92	311 18 52	131 21 18	No. 8	7 438.1
T 8	38 52 48.49	119 49 46.23	131 22 05	311 19 39	T 7	7 438.1
			152 36 44	332 35 00	Ledge	8 626.6
No. 8	48.57	46.15	311 20 55	131 21 30	No. 9	1 777.2
T 9	38 52 10.40	119 48 50.90	131 22 40	311 19 40	T 7	9 215.3
			149 02 18	328 59 59	Ledge	10 303.1
No. 9	10.49	50.80	311 22 28	131 22 56	No. 10	1 448.9
T 10	38 51 39.33	119 48 05.81	131 23 08	311 19 39	T 7	10 664.2
			146 53 31	326 50 44	Ledge	11 692.0
No. 10	39.42	05.70	311 21 56	131 22 23	No. 11	1 395.9
T 11	38 51 09.41	119 47 22.37	131 23 35.2	311 19 39.4	T 7	12 060.1
			145 15 35.2	325 12 21.4	Ledge	13 042.5
No. 11	09.51	22.26	311 22 50	131 23 34	No. 12	2 273.2
T 12	38 50 20.58	119 46 11.56	131 24 20	311 19 40	T 7	14 336.7
			143 13 25	323 09 27	Ledge	15 262.7
No. 12	20.77	11.53	311 24 44	131 24 55	No. 13	568.2
T 13	38 50 08.46	119 45 54.00	131 24 32	311 19 41	T 7	14 901.5
			142 48 28	322 44 18	Ledge	15 815.8
No. 13	08.58	53.87	311 23 32	131 23 52	No. 14	1 040.0
T 14	38 49 46.16	119 45 21.67	131 24 51	311 19 40	T 7	15 941.5
			142 06 49	322 02 20	Ledge	16 836.4
No. 14	46.28	21.53	311 25 05	131 25 56	No. 15	2 639.5
T 15	38 48 49.52	119 43 59.66	131 25 51	311 19 48	T 7	18 581.0
			140 41 07	320 35 46	Ledge	19 436.1
No. 15	49.66	59.50	311 23 51	131 24 05	No. 16	727.7
T 15½	38 48 48.71	119 43 58.47	221 44 20	41 44 21	Northeast base	60.69
			311 26 06	131 26 19	T 16	689.7
No. 15½	(†)	(†)	(†)	(†)	(†)	(†)
T 16	38 48 33.91	119 43 37.04	131 25 49	311 25 34	T 15	727.7
No. 16	34.05	36.88	311 25 35	131 26 08	No. 17	1 700.4
T 17	38 47 57.39	119 42 44.19	131 26 48.6	311 23 54.2	T 11	8 949.0
			197 33 44.6	17 34 21.3	Rock Cliff	4 675.1
No. 17	57.55	44.02	311 26 15	131 26 53	No. 18	1 940.1
T 18	38 47 15.74	119 41 43.94	311 27 49.9	131 28 14.3	T 19	1 256.3
			347 27 41.9	167 28 01.1	Bald	3 416.5
No. 18	15.90	43.76	311 26 57	131 27 21	No. 19	1 256.3
T 19	38 46 48.76	119 41 04.94	4 34 06.8	184 34 01.6	Bald	2 511.1
			84 16 08.8	264 14 01.0	Barber	4 950.6
No. 19	48.93	04.75	311 26 46	131 27 08	No. 20	1 141.2
T 20	38 46 24.26	119 40 29.51	31 07 49	211 07 22	Bald	2 041.4
			131 28 15	311 27 53	T 19	1 141.2
No. 20	24.44	29.31	311 27 20	131 28 15	No. 21	2 853.1

* Not corrected—deep snow. ** See note, end of table. † Omitted.

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893-1899*—Continued.

Stations.	Latitude.			Longitude.			Azimuth.			Back azimuth.			To stations.	Distance.
	°	′	″	°	′	″	°	′	″	°	′	″		*Meters.*
T 21	38	45	22·98	119	39	00·97	11	03	46	191	03	40	Ridge	1 291·7
							131	29	11	311	27	53	T 19	3 994·3
No. 21			**23·17**			**00·75**	**311**	**28**	**43**	**131**	**30**	**04**	**No. 22**	**4 597·3**
T 22	38	43	44·19	119	36	38·40	30	17	40·1	210	17	00·3	High Peak	3 048·3
							115	44	15·1	295	42	39·5	Ridge	4 097·4
No. 22			**44·41**			**38·15**	**311**	**28**	**43**	**131**	**30**	**04**	**No. 23**	**4 179·1**
T 23	38	42	14·38	119	34	28·85	131	30	53·4	311	29	32.4	T 22	4 179·1
							139	36	43·4	319	36	12·8	Knoll	1 826·0
No. 23			**14.62**			**28·58**	**311**	**31**	**27**	**131**	**32**	**26**	**No. 24**	**3 040·0**
T 24	38	41	08·99	119	32	54·70	131	33	13	311	32	14	T 23	3 040·0
							200	08	51	20	09	13	Lake	2 469·2
No. 24			**09·25**			**54·41**	**311**	**32**	**48**	**131**	**33**	**33**	**No. 25**	**2 336·9**
T 25	38	40	18·71	119	31	42·37	131	34	04	311	32	20	T 23	5 376·9
							166	56	23	346	56	00	Lake	3 971·3
No. 25			**18·98**			**42·06**	**311**	**32**	**45**	**131**	**33**	**56**	**No. 27**	**3 696·0**
T 27	38	38	58·33	119	29	46·78	121	26	23	301	22	59	Dome	9 263·4
							149	49	43	329	48	07	Lake	7 342·6
No. 27			**59·46**			**47·66**	**311**	**34**	**32**	**131**	**35**	**45**	**No. 28**	**3 777·3**
T 28	38	37	37·85	119	27	51·21	131	36	22	311	32	13	T 23	12 850·2
							143	43	07	323	40	19	Lake	10 955·2
No. 28			**38·16**			**50·85**	**311**	**27**	**37**	**131**	**27**	**46**	**No. 28½**	**494·5**
No. 28½	**38**	**37**	**27·66**	**119**	**27**	**35·70**	**311**	**35**	**06**	**131**	**37**	**31**	**No. 29**	**7 496·8**
T 29	38	34	45·64	119	23	44·12	311	38	08	131	39	59	T 31	5 744·3
							331	54	51	151	55	32	Mahogany	3 328·7
No. 29			**46·11**			**43·88**	**311**	**37**	**37**	**131**	**38**	**49**	**No. 30**	**3 745·5**
T 30	38	33	25·17	119	21	48·87	251	06	27	71	08	20	Don	4 647·2
							311	39	20	131	39	59	T 31	2 010·5
No. 30			**25·41**			**48·25**	**311**	**38**	**35**	**131**	**39**	**13**	**No. 31**	**2 000·4**
T 31	38	32	41·83	119	20	46.84	130	30	31·8	310	28	41·9	Flat	5 613·5
							166	45	26·8	346	44	43·5	Pine nut	7 330·8
No. 31			**42·30**			**46·52**	**311**	**39**	**15**	**113**	**41**	**14**	**No. 32**	**6 207·0**
T 32	38	30	28·21	119	17	35·83	131	42	02·9	311	40	03·9	T 31	6 195·4
							166	03	03·9	346	02	19·4	Don	7 171·7
No. 32			**28·47**			**35·11**	**311**	**41**	**18**	**131**	**44**	**00**	**No. 33**	**8 464·3**
T 33	38	27	25·66	119	13	15·40	131	44	51	311	42	09	T 32	8 457·7
							237	45	18	57	47	35	Sweetwater Ecc.	6 326·2
No. 33			**25·82**			**14·42**	**311**	**44**	**11**	**131**	**45**	**53**	**No. 34**	**5 306·7**
T 34	38	25	31·01	119	10	32·16	191	24	28	11	25	03	Sweetwater Ecc.	7 047·9
							311	46	34	131	46	46	T 35	621·9
No. 34			**31·22**			**31·17**	**311**	**46**	**00**	**131**	**46**	**11**	**No. 35**	**599·6**
T 35	38	25	17·57	119	10	13·04	131	46	44.5	311	42	09.1	T 32	14 387·0
							187	14	32·5	7	14	56·4	Sweetwater Ecc.	7 381·9
No. 35			**18·26**			**12·73**	**311**	**45**	**54**	**131**	**47**	**41**	**No. 36**	**5 593·3**
T 36	38	23	17·11	119	07	21·79	131	48	36	311	46	50	T 35	5 573·3
							226	56	33	46	56	35	Red	86·2
No. 36			**17·40**			**20·83**	**311**	**47**	**31**	**131**	**48**	**50**	**No. 37**	**4 160·5**
T 37	38	21	16·95	119	05	13·77	133	00	25·5	312	59	07·6	Red	4 162·7
							191	55	29·5	11	55	54·3	West Walker.	4 687·5
No. 37			**47·47**			**13·07**	**311**	**48**	**19**	**131**	**49**	**08**	**No. 38**	**2 593·0**

**See note, end of table.

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893-1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 38	38 20 50.97	119 03 54.33	131 49 54	311 49 05	T 37	2 588.4
			211 29 36	31 30 17	Long	3 084.7
No. 38	**51.40**	**53.47**	**311 50 21**	**131 51 55**	**No. 39**	**4 935.1**
T 39	38 19 04.01	119 01 22.81	131 52 43	311 51 09	T 38	4 941.7
			160 46 48	340 45 55	Long	6 278.3
No. 39	**04.61**	**22.12**	**311 50 37**	**131 52 25**	**No. 40**	**5 659.3**
T 40	38 17 01.11	118 58 28.82	157 39 01	337 38 59	Beauty Peak	183.4
			274 49 44	94 53 58	Aurora Peak	9 988.9
No. 40	**02.13**	**28.65**	**311 53 20**	**131 54 00**	**No. 41**	**2 095.8**
T 41	38 16 14.16	118 57 22.44	265 51 05	85 54 37	Aurora Peak	8 361.7
			307 05 03	127 06 20	West Brawley	3 797.8
No. 41	**16.73**	**24.45**	**311 53 42**	**131 54 54**	**No. 42**	**3 795.4**
T 42	38 14 53.68	118 55 28.76	132 41 01	312 39 08	Beauty Peak	6 047.9
			145 27 53	325 26 10	Bald Peak	7 171.0
No. 42	**54.53**	**28.27**	**311 56 44**	**131 57 35**	**No. 43**	**2 670.1**
T 43	38 13 55.96	118 54 07.39	311 55 25	131 56 20	T 44	2 877.1
			77 26 20	257 25 58	Lake View	883.7
No. 43	**56.64**	**06.61**	**311 54 39**	**131 55 33**	**No. 44**	**2 877.1**
T 44	38 12 53.00	118 52 39.39	135 18 27	315 16 49	West Brawley	5 478.2
			192 08 32	12 09 09	Aurora Peak	6 940.1
No. 44	**54.30**	**38.59**	**311 56 36**	**131 58 00**	**No. 45**	**4 429.5**
T 45	38 11 17.10	118 50 23.42	133 49 43.0	313 46 40.8	West Brawley	9 923.3
			169 17 41.9	349 16 54.9	Aurora Peak	9 933.1
No. 45	**18.26**	**23.22**	**311 58 25**	**132 00 44**	**No. 46**	**7 367.4**
T 46	38 08 37.63	118 46 39.16	132 01 36	311 59 17	T 45	7 347.0
			272 01 30	92 04 04	Sag	6 068.3
No. 46	**38.39**	**38.28**	**312 00 36**	**132 01 46**	**No. 47**	**3 712.5**
T 47	38 07 17.68	118 44 46.89	135 58 23	55 59 48	Sag	4 018.8
			312 02 41	132 04 23	T 49	5 447.2
No. 47	**17.80**	**45.04**	**312 02 08**	**132 03 30**	**No. 48**	**4 363.9**
T 48	38 05 42.01	118 42 32.69	132 04 08	311 59 17	T 45	15 432.0
			146 32 12	326 26 34	Aurora Peak	24 096.9
No. 48	**43.00**	**32.02**	**312 03 28**	**132 03 48**	**No. 49**	**1 051.6**
T 49	38 05 19.32	118 42 00.90	132 04 27.3	311 59 17.0	T 45	16 475.7
			173 07 08.1	353 06 50.1	Sag	5 940.4
No. 49	**20.15**	**41 59.98**	**312 02 57**	**132 06 22**	**No. 51**	**10 934.1**
T 50	38 02 53.03	118 38 35.97	132 05 52	312 03 45	T 49	6 730.2
			281 12 11	101 15 54	Top	9 017.7
No. 50	(*)	(*)	(*)	(*)	(*)	(*)
T 51	38 01 21.63	118 36 28.11	132 07 10	312 03 45	T 49	10 933.5
			259 29 11	79 31 36	Top	5 825.9
No. 51	**22.50**	**27.10**	**312 06 17**	**132 06 32**	**No. 52**	**812.1**
T 52	38 01 03.96	118 36 03.41	132 07 26	312 03 45	T 49	11 745.6
			252 35 06	72 37 16	Top	5 371.7
No. 52	**04.84**	**02.40**	**312 06 43**	**132 07 50**	**No. 53**	**3 576.0**
T 53	37 59 46.03	118 34 14.52	301 52 14	121 55 07	Roach	8 072.6
			312 08 45	132 10 39	T 54	6 102.7
No. 53	**47.05**	**13.66**	**312 07 55**	**132 09 49**	**No. 54**	**6 097.2**

* Not corrected.

** See note, end of table.

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 54	37 57 33·16	118 31 09·15	234 44 16	54 46 03	Cap	5 180·5
			274 08 16	94 09 15	Roach	2 336·8
No. 54	**34·33**	**08·42**	**312 10 30**	**132 10 44**	**No. 55**	**757·7**
T 55	37 57 16·90	118 30 46·50	132 10 49	312 10 35	T 54	746·3
			259 24 38	79 25 23	Roach	1 808·5
No. 55	**17·83**	**45·42**	**312 09 59**	**132 10 19**	**No. 56**	**1 057·0**
T 56	37 56 53·88	118 30 14·42	132 11 09	312 10 35	T 54	1 803·3
			223 39 58	43 40 23	Roach	1 440·4
No. 56	**54·82**	**13·33**	**312 06 57**	**132 07 07**	**No. 57**	**523·1**
T 57	37 56 44·02	118 30 00·68	206 05 29	26 05 46	Roach	1 498·7
			312 11 22	132 12 06	T 58	2 365·4
No. 57	**43·45**	**29 57·45**	**312 12 39**	**132 13 19**	**No. 58**	**2 167·4**
T 58	37 55 52·49	118 28 48·91	159 34 32·2	339 34 04·7	Roach	3 131·6
			260 00 00·6	80 01 24·0	Lava	3 364·3
No. 58	**56·19**	**51·68**	**312 11 20**	**132 12 51**	**No. 59**	**4 908·3**
T 59	37 54 08·03	118 26 23·56	132 13 32·6	312 12 03·3	T 58	4 793·6
			176 26 47·1	356 26 41·2	Lava	3 811·7
No. 59	**09·29**	**22·81**	**312 12 23**	**132 13 20**	**No. 59½**	**3 072·5**
T 59½	37 53 01·33	118 24 50·84	132 14 26	312 13 29	T 59	3 059·6
			151 34 52	331 34 13	N. base	3 259·3
No. 59½	**02·33**	**49.68**	**312 13 36**	**132 15 48**	**No. 60**	**7 082·4**
T 60	37 50 26·58	118 21 16·02	132 16 34·4	312 11 56·3	T 58	14 948·1
			143 55 56·3	323 52 41·5	Lava	13 157·4
No. 60	**27·88**	**15·19**	**312 14 46**	**132 17 59**	**No. 62**	**10 433·7**
T 61	37 48 36·62	118 18 43·55	132 17 23	312 15 50	T 60	5 039·3
			297 07 06	117 09 50	Indian	7 337·9
No. 61	(*)	(*)	(*)	(*)	(*)	(*)
T 62	37 46 38·95	118 16 00·57	132 18 47	312 15 34	T 60	10 430·2
			263 42 09	83 43 13	Indian	2 558·7
No. 62	**40·24**	**15 59·57**	**312 18 44**	**132 19 53**	**No. 63**	**3 702·9**
T 63	37 45 18·26	118 14 09·01	132 20 06	312 15 44	T 60	14 124·1
			163 41 26	343 40 30	Black	7 995·0
No. 63	**19.37**	**07·71**	**312 20 01**	**132 20 29**	**No. 64**	**1 501·4**
T 64	37 44 45·07	118 13 23·14	132 20 37·6	312 15 47·8	T 60	15 643·6
			158 50 12·7	338 48 48·3	Black	9 326·0
No. 64	**46·58**	**22·38**	**312 19 11**	**132 19 52**	**No. 65**	**2 228·1**
T 65	37 43 57·12	118 12 16·90	248 52 52	68 56 50	Sand	10 207·2
			312 21 26	132 22 38	T 66	3 915·5
No. 65	**57·92**	**15·10**	**312 24 43**	**132 25 55**	**No. 66**	**3 896·6**
T 66	37 42 31·54	118 10 18·78	135 27 44·8	315 25 56·5	T 64 High	6 178·2
			226 24 10·6	46 26 56·4	Sand	9 155·4
No. 66	**32·57**	**17·53**	**312 20 14**	**132 22 15**	**No. 67**	**6 558.0**
T 67	37 40 07·89	118 07 00·80	132 24 45.8	312 22 44·8	T 66	6 568·2
			189 26 07·9	9 26 52·5	Sand	10 886·8
No. 67	**09·37**	**06 59·82**	**312 23 43**	**132 25 52**	**No. 67½**	**7 037·6**
T 67½	37 37 34·18	118 03 29·31	132 26 41	312 24 32	T 67	7 024·1
			216 50 31	36 52 18	Slate	7 121·7
No. 67½	**35·41**	**27·87**	**312 25 42**	**132 26 44**	**No. 68**	**3 357·9**

*Omitted.

** See note, end of table.

*C.*** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893-1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 68	37 36 20.72	118 01 48.36	132 27 43	312 24 32	T 67	10 379.6
			192 42 44	12 43 29	Slate	8 163.6
No. 68	21.92	46.83	312 27 02	132 27 57	No. 69	2 970.6
T 69	37 35 15.60	118 00 18.96	132 28 37	312 24 32	T 67	13 352.6
			177 44 09	357 43 59	Slate	9 978.4
No. 69	16.86	16.48	312 25 08	132 25 32	No. 70	1 330.3
T 70	37 34 46.73	117 59 39.35	132 29 01.3	312 24 31.8	T 67	14 670.6
			172 50 12.0	352 49 38.0	Slate	10 946.3
No. 70	47.75	37.45	312 31 23	132 31 47	No. 71	1 331.2
T 71	37 34 17.30	117 58 58.98	132 29 40	312 29 15	T 70	1 343.5
			212 28 53	32 29 43	Esmeralda	3 706.2
No. 71	18.58	57.48	312 28 53	132 30 16	No. 72	4 539.7
T 72	37 32 37.80	117 56 42.62	132 31 02.7	312 29 15.0	T 70	5 883.2
			167 39 50.2	347 39 16.5	Esmeralda	6 339.9
No. 72	39.11	41.09	312 30 39	132 32 18	No. 73	5 409.2
T 73	37 30 39.18	117 54 00.30	132 33 02	312 31 23	T 72	5 409.2
			163 31 59	343 31 22	Luck	5 236.3
No. 73	40.51	53 58.73	312 30 33	132 31 24	No. 74	2 796.8
T 74	37 29 37.86	117 52 36.39	132 33 20.3	312 30 50.3	T 72	8 206.0
			152 51 28.7	332 50 00.8	Luck	7 768.2
No. 74	39.20	34.81	312 32 44	132 34 00	No. 75	4 145.1
T 75	37 28 06.90	117 50 32.14	132 34 48	312 33 32	T 74	4 145.1
			169 12 60	349 12 35	Pike	5 449.1
No. 75	08.27	30.53	312 33 58	132 34 20	No. 76	1 180.6
T 76	37 27 40.99	117 49 56.77	132 35 09.3	312 33 32.2	T 74	5 325.7
			162 56 14.2	342 55 27.4	Pike	6 435.2
No. 76	42.36	55.15	312 34 30	132 35 06	No. 77	1 968.7
T 77	37 26 57.77	117 48 57.80	132 36 03	312 35 27	T 76	1 968.7
			235 24 55	55 26 00	Cab	3 187.3
No. 77	59.16	56.17	312 35 22	132 37 00	No. 78	5 409.4
T 78	37 24 58.97	117 46 15.88	132 37 43.0	312 35 28.7	T 76	7 378.0
			194 28 18.5	14 28 29.8	Dab	1 832.2
No. 78	25 00.38	14.21	312 36 49	132 38 23	No. 79	5 188.4
T 79	37 23 05.47	117 43 41.41	132 39 20.1	312 37 46.3	T 78	5 165.2
			147 39 09.6	327 37 47.1	Dab	6 242.4
No. 79	06.41	39.00	312 38 14	132 40 37	No. 80	7 899.4
T 80	37 20 13.00	117 39 47.06	53 38 45	233 38 28	T 80 High	856.0
			132 41 39	312 39 17	T 79	7 844.1
No. 80	12.78	42.94	312 36 22	132 39 39	No. 81	10 899.1
T 81	37 16 11.36	117 34 18.60	282 15 37	102 18 21	Nig	6 821.0
			312 56 30	132 57 51	T 82	4 499.0
No. 81	13.31	17.33	312 55 36	132 56 57	No. 82	4 518.0
T 82	37 14 31.92	117 32 04.98	163 40 18.6	343 39 31.7	Sclav	6 786.1
			244 24 32.1	64 25 54.9	Nig	3 739.4
No. 82	33.49	03.12	312 45 18	132 47 27	No. 83	7 145.6
T 83	37 11 55.44	117 28 33.62	132 48 17	312 46 09	T 82	7 101.6
			244 09 02	64 10 45	Cone	4 641.7
No. 83	56.09	30.39	312 46 28	132 47 29	No. 84	3 414.1

**See note, end of table.

*C.*** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 84	37 10 39·51	117 26 51·10	260 39 29	80 40 44	Crystal	3 099·1
			317 10 29	137 11 09	T 85 High	2 408·9
No. 84	**40·88**	**48·82**	**312 49 22**	**132 50 16**	**No. 85**	**2 981·9**
T 85	37 09 33·88	117 25 22·68	115 14 12	295 13 59	T 85 High	601·6
			199 08 22	19 08 44	Crystal	2 673·9
No. 85	**35·13**	**20·19**	**312 49 26**	**132 51 29**	**No. 86**	**6 838·6**
T 86	37 07 02·96	117 21 59·50	250 48 33	70 48 34	T 86 High	60·0
			312 52 28	132 53 01	T 87	1 822·9
No. 86	**04·29**	**57·02**	**312 53 02**	**132 53 34**	**No. 87**	**1 777·5**
T 87	37 06 22·72	117 21 05·40	134 34 36	314 34 05	T 86 High	1 795·6
			178 22 46	358 22 42	Baldwin	5 717·4
No. 87	**25·04**	**04·27**	**312 52 17**	**132 54 55**	**No. 88**	**8 839·5**
T 88	37 03 08·16	117 16 44·17	133 12 59·3	313 09 50·5	T 86 High	10 604·4
			187 32 23·9	7 32 47·1	Queer	7 240·4
No. 88	**09·89**	**42·10**	**312 55 06**	**132 57 48**	**No. 89**	**9 082·5**
T 89	36 59 47·39	117 12 15·24	132 58 35·7	312 55 53·8	T 88	9 082·4
			192 17 49·2	12 18 13·8	Helmet	4 745·6
No. 89	**49·18**	**13·11**	**312 59 10**	**133 03 23**	**No. 91**	**14 220·1**
T 90	36 57 23·36	117 09 02·68	297 07 44	117 09 21	Nye	4 494·9
			313 00 27	133 02 46	T 91	7 801·7
No. 90	(*)	(*)	(*)	(*)	(*)	(*)
T 91	36 54 30·67	117 05 12·23	137 05 58	317 03 40	Grape	8 340·5
			152 31 06	332 30 25	Nye	3 689·2
No. 91	**34·65**	**12·91**	**313 01 10**	**133 02 49**	**No. 92**	**5 584·7**
T 92	36 52 29·66	117 02 31·01	140 54 17	320 51 59	Nye	9 026·0
			166 53 07	346 52 51	Shale	2 916·4
No. 92	**31·03**	**28·03**	**313 04 01**	**133 08 31**	**No. 93**	**15 302·8**
T 93	36 46 50·14	116 54 59·87	241 43 18	61 43 19	T 93 high	58·3
			313 08 57	133 12 31	T 95	12 194·7
No. 93	**51·80**	**57·18**	**313 08 23**	**133 11 04**	**No. 94**	**9 137·9**
T 94	36 43 27·08	116 50 30·90	182 18 09	2 18 16	Dune	7 008·2
			281 35 31	101 37 43	Green	5 600·9
No. 94	**29·10**	**28·47**	**313 10 29**	**133 11 23**	**No. 95**	**3 059·7**
T 95	36 42 19·44	116 49 01·43	133 28 07·6	313 24 34·4	T 93 high	12 176·3
			167 58 06·6	347 57 19·9	Dune	9 292·1
No. 95	**21·16**	**48 58·55**	**313 11 38**	**133 13 19**	**No. 96**	**5 748·2**
T 96	36 40 11·72	116 46 12·69	169 20 10·3	349 19 48·1	Green	4 980·8
			217 31 49·5	37 33 27·7	Bleak	6 692·5
No. 96	**13·48**	**09·79**	**313 14 06**	**133 16 59**	**No. 97**	**9 915·5**
T 97	36 36 30·92	116 41 21·67	133 17 47	313 14 53	T 96	9 929·2
			165 26 40	345 25 24	Bleak	12 514·8
No. 97	**33·04**	**19·11**	**313 06 43**	**133 07 54**	**No. 98**	**4 028·6**
T 98	36 34 46·42	116 39 04·08	190 59 19	10 59 41	Funeral	4 844·0
			313 18 00	133 20 39	T 99	9 102·5
No. 98	**35 03·70**	**20·81**	**313 23 44**	**133 24 09**	**No. 98½**	**1 447·4**
No. 98½	**36 34 31·44**	**116 38 38·50**	**313 20 33**	**133 22 58**	**No. 99**	**8 319·0**

*Not corrected. **See note, end of table.

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.			Longitude.			Azimuth.			Back azimuth.			To stations.	Distance.
	°	′	″	°	′	″	°	′	″	°	′	″		Meters.
T 99	36	31	23.81	116	34	37.81	128	38	09.9	308	35	20.1	T 98 high	9 074.0
							152	38	31.7	332	36	15.2	Funeral	12 387.8
No. 99			**26.00**			**35.16**	**313**	**21**	**30**	**133**	**23**	**42**	**No. 100**	**7 589.2**
T 100	36	28	34.68	116	30	56.21	108	44	30.9	288	41	35.4	Sexton	7 756.5
							133	24	26.8	313	22	15.0	T 99	7 589.2
No. 100			**36.91**			**53.50**	**313**	**20**	**18**	**133**	**22**	**22**	**No. 101**	**7 162.6**
T 101 east	36	25	55.06	116	27	27.17	94	14	15.4	274	11	38.0	Butte	6 618.0
							133	24	11.5	313	22	07.3	T 100	7 162.6
No. 101			**57.38**			**24.36**	**313**	**26**	**41**	**133**	**28**	**39**	**No. 102**	**6 822.3**
T 102	36	23	22.82	116	24	08.40	222	02	43.6	42	03	25.0	King	2 594.2
							353	07	10.4	173	07	14.6	S. Base	1 464.8
No. 102			**25.12**			**05.61**	**313**	**25**	**38**	**133**	**27**	**24**	**No. 103**	**6 157.0**
T 103	36	21	05.42	116	21	09.13	122	56	36.9	302	54	54.8	S. Base	5 115.7
							156	06	29.9	336	05	24.9	King	6 739.4
No. 103			**07.75**			**06.29**	**313**	**28**	**39**	**133**	**29**	**52**	**No. 104**	**4 227.5**
T 104	36	19	29.90	116	19	04.68	182	55	42.9	2	55	50.7	Shoshone	6 420.2
							133	29	55.8	313	28	42.1	T 103	4 278.0
No. 104			**33.36**			**03.30**	**313**	**28**	**53**	**133**	**31**	**15**	**No. 105**	**8 279.0**
T 105	36	16	26.11	116	15	05.60	293	09	22.3	113	13	19.9	Rump	10 914.0
							313	32	19.5	133	33	42.9	T 106	4 859.3
No. 105			**28.39**			**02.70**	**313**	**30**	**53**	**133**	**32**	**17**	**T 106**	**4 904.0**
T 106	36	14	37.49	116	12	44.52	278	16	35.2	98	19	09.4	Rump	6 580.4
							168	44	50.5	348	44	17.9	Pah	7 058.3
No. 106			**38.36**			**39.70**	**313**	**33**	**47**	**133**	**35**	**42**	**No. 107**	**6 681.5**
T 107	36	12	07.01	116	09	29.35	203	56	45.3	23	57	24.2	Rump	4 036.2
							133	35	38.4	313	33	43.1	T 106	6 728.5
No. 107			**09.45**			**26.37**	**313**	**35**	**33**	**133**	**36**	**54**	**No. 108**	**4 751.4**
T 108	36	10	16.79	116	07	06.62	263	36	30.2	83	37	00.5	End	1 290.7
							340	42	00.8	160	43	17.6	Hard	9 852.2
No. 108			**23.14**			**08.67**	**313**	**36**	**07**	**133**	**38**	**27**	**No. 109**	**8 210.1**
T 109	36	07	16.86	116	03	13.99	133	39	30.9	313	37	13.7	T 108	8 036.0
							141	28	20.7	321	26	33.8	End	7 274.0
No. 109			**19.37**			**10.92**	**313**	**39**	**55**	**133**	**41**	**32**	**No. 110**	**5 695.0**
T 110	36	05	09.25	116	00	29.33	313	40	43.8	133	42	31.3	T 111	6 315.3
							39	54	44.4	219	53	27.4	Dell	5 101.3
No. 110			**11.80**			**26.31**	**313**	**39**	**22**	**133**	**41**	**09**	**No. 111**	**6 315.3**
T 111	36	02	47.70	115	57	26.86	93	18	14.6	273	15	10.3	Dell	7 853.3
							133	14	14.3	313	12	26.0	Manse	6 319.7
No. 111			**50.27**			**23.72**	**313**	**42**	**10**	**133**	**43**	**43**	**No. 112**	**5 483.3**
T 112	36	00	44.70	115	54	48.63	48	17	59.6	228	16	23.2	Gap	5 501.5
							133	45	16.9	313	43	43.8	T 111	5 483.3
No. 112			**47.32**			**45.41**	**313**	**43**	**37**	**133**	**44**	**05**	**No. 113**	**1 552.8**
T 113	36	00	09.92	115	54	03.77	63	41	02.4	243	38	59.7	Gap	5 836.5
							86	50	19.2	266	46	04.0	Blow	10 889.9
No. 113			**12.50**			**00.61**	**313**	**44**	**06**	**133**	**45**	**05**	**No. 114**	**3 486.4**
T 114	35	58	51.66	115	52	23.28	48	10	32.4	228	08	51.3	Ring	5 787.3
							88	43	07.9	268	40	06.2	Gap	7 751.1
No. 114			**54.28**			**20.06**	**313**	**45**	**10**	**133**	**46**	**04**	**No. 115**	**3 179.7**

** See note, end of table.

C.** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.			Longitude.			Azimuth.			Back azimuth.			To stations.	Distance.
	°	′	″	°	′	″	°	′	″	°	′	″		*Meters.*
T 115	35	57	40.33	115	50	51.59	313	48	45.5	133	50	15.2	T 116	5 307.2
							75	54	30.3	255	51	55.4	Ring	6 815.8
No. 115			42.93			48.40	313	47	04	133	48	35	No. 116	5 370.0
T 116	35	55	41.10	115	48	18.82	100	56	49.8	280	52	45.3	Ring	10 633.1
							133	48	44.8	313	46	21.3	T 114	8 487.0
No. 116			42.33			13.74	313	47	04	133	48	48	No. 117	6 164.5
T 117	35	52	54.45	115	44	45.39	26	01	17.1	206	00	44.6	Mag	3 176.7
							133	50	24.1	313	48	18.9	T 116	7 417.8
No. 117		53	23.90		45	16.29	313	48	18	133	50	46	No. 118	8 815.0
T 118	35	50	03.08	115	41	06.23	69	02	36.7	249	01	22.2	Jumbo	3 420.3
							109	24	58.4	289	22	17.5	Mag	7 308.5
No. 118			05.85			02.81	313	51	32	133	52	44	No. 119	4 285.9
T 119	35	48	26.68	115	39	03.17	59	34	02.7	239	31	19.8	Move	8 115.5
							103	55	26.4	283	54	05.9	Snow	3 558.1
No. 119			29.48		38	59.72	313	51	53	133	52	52	No. 120	3 532.0
T 120	35	47	07.37	115	37	21.97	41	11	16.6	221	09	46.5	Martin	5 881.4
							133	53	47.5	313	52	48.3	T 119	3 526.0
No. 120			10.05			18.32	313	50	00	133	51	27	No. 121	5 185.2
T 121	35	45	06.93	115	34	48.50	61	17	05.0	241	16	07.2	Taylor	2 835.4
							84	44	23.8	264	41	24.1	Martin	7 761.7
No. 121			13.36			49.61	313	54	33	133	56	45	No. 122	6 488.6
T 122	35	42	44.44	115	31	47.19	113	17	21.3	293	14	37.6	Taylor	7 667.6
							133	57	26.6	313	55	40.7	T 121	6 328.3
No. 122			47.32			43.64	313	56	12	133	58	21	No. 123	7 739.4
T 123	35	39	49.62	115	28	05.10	33	15	08.0	213	14	41.1	Spanish	2 117.1
							133	59	39.6	313	57	30.1	T 122	7 759.5
No. 123			53.02			02.06	313	59	17	134	01	52	No. 125	9 282.2
T 124	35	39	29.21	115	27	39.20	313	59	54.0	134	02	13.1	T 125	8 356.0
							57	48	57.3	237	48	15.3	Spanish	2 142.0
No. 124		(*)			(*)			(*)			(*)		(*)	(*)
T 125	35	36	20.80	115	23	40.39	63	42	11.5	243	41	20.9	Well	2 439.6
							120	50	06.5	300	47	05.5	Spanish	9 105.6
No. 125			23.77			36.72	314	01	23	134	02	59	No. 126	5 798.5
T 126	35	34	09.99	115	20	54.85	85	14	03.0	265	12	38.7	Skit	3 662.6
							114	55	14.0	294	52	47.1	Well	7 007.2
No. 126			12.98			51.15	314	19	00	134	20	55	No. 127	6 964.0
T 127	35	31	27.88	115	17	29.97	93	39	24.1	273	36	45.7	Patch	6 883.5
							112	26	20.5	292	24	02.1	Link	6 491.6
No. 127			39.81			33.19	313	55	04	133	58	03	No. 128	10 781.0
T 128	35	27	34.67	115	12	35.89	118	09	14.4	298	05	48.1	Storm	10 158.5
							134	08	17.2	314	05	26.5	T 127	10 325.2
No. 128			32.20			25.25	314	06	48	134	07	32	No. 129	2 638.2
T 129	35	26	31.76	115	11	16.76	309	32	07.8	129	33	56.8	T 130 high	6 155.0
							332	48	53.4	152	50	07.7	Vanderbilt	7 086.8
No. 129			32.60			10.15	314	02	49	134	04	30	No. 130	6 104.0

* Omitted.

** See note, end of table.

*C.** GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
T 130	35 24 08·44	115 08 16·54	134 11 15·5	314 09 31·1	T 129	6 338·8
			201 51 25·8	21 51 30·4	T 130 high	536·3
No. 130	14·85	16·26	314 14 04	134 16 21	No. 132	8 310·0
T 131	35 24 03·09	115 08 09·83	288 22 08·0	108 24 53·1	Searchlight	7 580·6
			314 10 58·6	134 13 12·5	T 132	8 146·6
No. 131	(*)	(*)	(*)	(*)	(*)	(*)
T 132	35 20 58·79	115 04 18·44	118 24 50·5	298 22 02·6	Vanderbilt	8 322·6
			137 31 38·5	317 29 25·3	T 130 high	8 601·5
No. 132	21 04·89	22·72	314 12 09	134 13 59	No. 133	6 704·2
T 133	35 18 32·31	115 01 14·89	134 15 07·5	314 13 21·3	T 132	6 470·7
			208 17 11·3	28 18 01·1	Setter	4 586·6
No. 133	34·90	10·11	314 14 20	134 18 15	No. 134	14 371·9
T 134	35 13 05·96	114 54 26·96	134 19 04·6	314 15 09·0	T 133	14 403·0
			150 02 19·2	329 59 13·3	Setter	16 274·9
No. 134	09·24	22·84	314 20 58	134 23 32	No. 135	9 487·6
T 135	35 09 33·72	114 50 02·33	36 13 36·3	216 13 04·1	Piute	2 391·8
			148 56 42·4	328 56 09·3	House	2 822·7
No. 135	33·92	49 54·74	314 17 18	134 19 04	No. 137	6 519·0
T 136	35 08 04·35	114 48 11·08	46 47 29·6	226 47 29·0	T 136 high	38·4
			134 22 30·7	314 21 26·7	T 135	3 938·8
No. 136	(*)	(*)	(*)	(*)	(*)	(*)
T 137	35 07 04·42	114 46 56·55	105 57 53·1	285 56 18·1	Gus	4 348·5
			134 23 13·6	314 21 26·7	T 135	6 579·5
No. 137	16·16	50·44	314 19 47	134 19 54	No. 138	412·2
T 138	35 06 46·28	114 46 34·03	170 23 21·4	350 23 16·5	Newberry	1 282·2
			327 05 15·1	147 05 36·4	Vex	1 725·6
No. 138	56·81	38·80	314 21 33	134 21 55	No. 138½	1 323·0
No. 138½	35 06 26·79	114 46 01·44	314 22 18	134 22 36	No. 139	1 132·4
T 139	35 06 00·39	114 45 36·95	85 57 08·9	265 56 57·4	Vex	508·1
			148 13 37·5	328 12 59·8	Newberry	3 151·3
No. 139	01·08	29·47	314 22 06	134 24 48	No. 141	10 018·0
T 140	35 05 23·24	114 44 50·81	228 04 55·0	48 05 34·9	Beatty	2 359·5
			314 23 35·6	134 25 52·0	T 141	8 421·2
No. 140	(*)	(*)	(*)	(*)	(*)	(*)
T 141	35 02 12·02	114 40 53·43	133 58 41·7	313 56 24·2	T 140 high	8 425·8
			150 19 40·9	330 18 04·4	Beatty	8 597·3
No. 141	13·59	46·84	314 24 37	134 25 14	No. 142	2 261·0
T 142	35 01 18·98	114 39 47·68	134 26 38·4	314 26 00·7	T 141	2 334·2
			163 14 55·0	343 14 28·7	Quail	4 042·7
No. 142	22·24	43·12				
Fort Mohave, Ariz., flagstaff.	35 02 31·65	114 37 13·92	37 52 39	217 51 25	Von Schmidt E. post	5 333·5
			57 23 24	237 20 58	Peak	7 661·6

* Omitted. ** See note, end of table.

*C.*** *GEOGRAPHIC POSITIONS OF POINTS ON RANDOM AND CORRECTED LINES, 1893–1899*—Continued.

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
Iron monument, Von Schmidt, north shore Lake Tahoe.	39 13 19·18	120 00 21·94	339 05 53	159 07 58	Deadman Point....	13 329·4
			62 16 03	242 12 39	Observatory Point..	8 767·5
Stone monument, Von Schmidt, north shore Lake Tahoe.	39 13 17·25	120 00 21·96	339 00 17	159 02 22	Deadman Point ...	13 273·7
			62 36 47	242 33 23	Observatory Point..	8 739·5

NOTE.—Points on the random line are designated by T 1, T 2, T 3, etc. Points on the corrected line are designated by No. 1, No. 2, No. 3, etc.

** NOTE.—The geographic positions in the tables C, D, and F depend on the following positions on the Yolo Base Datum for Mount Lola and Round Top.

Round Top: Latitude, 38° 39′ 43″·636; longitude, 120° 00′ 04″·997.

Mount Lola: Latitude, 39° 25′ 53″·342; longitude, 120° 21′ 55″·496.

Round Top to Mount Lola: Azimuth, forward, 159° 51′ 41″·60; back, 339° 37′ 56″·02. Distance, 91 038·53 meters; Log., 4·959 225 2.

This was the best available information at the time the work was done and the computation completed.

On March 13, 1901, the necessary connections between triangulation in widely separated localities having been made and the computations being sufficiently advanced to afford the basis for such a decision, the Coast and Geodetic Survey adopted a standard datum, to be known as the "U. S. Standard Datum," to which all geographic positions throughout the United States will be reduced, wherever possible, as rapidly as practicable, so as to make such positions strictly comparable in all portions of the country. On the U. S. Standard Datum the positions of Round Top and Mount Lola are as follows:.

Round Top: Latitude, 38° 39′ 50″·316; longitude, 120° 00′ 01″·126.

Mount Lola: Latitude, 39° 26′ 00″·061; longitude, 120° 21′ 51″·594.

Round Top to Mount Lola: Azimuth, forward, 159° 51′ 45″·92; back, 339° 37′ 60″·33. Distance, 91 039·14 meters; Log., 4·959 228 2.

The corrections to reduce the positions here published to the U. S. Standard Datum will be of the same order of magnitude as the corrections at Round Top and Mount Lola indicated above, and will not be constant from one end of the line to the other.

The exact values of these corrections are not now available, and this note is inserted to prevent the use of the uncorrected positions for geographic purposes.

July 30, 1901. EDITOR.

*D.** GEOGRAPHIC POSITIONS OF RECOVERED POINTS ON THE VON SCHMIDT LINE.*

Stations.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.
	° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*
Lake shore stone	38 57 25.05	119 57 05.99	310 51 35	130 51 35	V. S. 211 M. P.	80.46
V. S. 211 M. P.	38 57 23.50	119 57 03.50	310 56 53	130 57 05	V. S. 211m. 30ch. P.	605
V. S. 211m. 30ch. P.	38 57 10.64	119 56 44.52	311 18 29	131 18 49	V. S. 212 M. P.	1 003
V. S. 212 M. P.	38 56 49.16	119 56 13.22	310 36 03	130 36 27	V. S. 212m. 53ch. 21l. P.	1 074
V. S. 212m. 53ch. 21l. P.	38 56 26.50	119 55 39.37	310 52 21	130 57 05	V. S. 221m. 76ch. P.	14 408
V. S. 221m. 76ch. P.	38 51 20.50	119 48 07.53	310 57 48	131 00 27	V. S. 227 M. P.	8 117
V. S. 227 M. P.	38 48 27.86	119 43 53.51	311 00 29	131 07 23	V. S. 239m. 64ch. P.	21 164
V. S. 239m. 64ch. P.	38 40 56.97	119 32 52.75	311 54 07	131 55 13	V. S. 242 M. P.	3 448
V. S. 242 M. P.	38 39 42.29	119 31 06.62	311 02 37	131 09 03	V. S. 254m. 49ch. P.	19 869
V. S. 254m. 49ch. P.	38 32 38.73	119 20 47.84	311 16 56	131 18 54	V. S. Mid. sister P.	6 122
V. S. Mid. sister P.	38 30 27.70	119 17 37.97	311 19 10	131 23 05	V. S. 266 M. P.	12 198
V. S. 266 M. P.	38 26 06.33	119 11 20.24	311 23 53	131 26 23	V. S. 270m. 61ch. P.	7 798
V. S. 270m. 61ch. P.	38 23 19.01	119 07 19.20	311 25 24	131 29 08	V. S. 278 M. P.	11 716
V. S. 278 M. P.	38 19 07.46	119 01 17.57	311 29 32	131 31 05	V. S. 281 M. P.	4 871
V. S. 281 M. P.	38 17 22.77	118 58 47.44	311 29 03	131 30 04	V. S. 283 M. P.	3 214
V. S. 283 M. P.	38 16 13.71	118 57 08.39	311 32 33	131 33 41	Brawley Mountain, 285m. 14ch. 67l.	3 560
V. S. 285m. 14ch. 67l.	38 14 57.13	118 55 18.81	311 32 54	131 38 14	V. S. 295m. 49ch. P.	16 812
V. S. 295m. 49ch. P.	38 08 55.17	118 46 42.08	311 36 11	131 48 53	Stone monument, Carson and Colorado Railroad.	40 385
Stone monument, V. S. 320m. 25ch. P.	37 54 23.66	118 26 05.94	311 49 34	131 56 00	V. S. 333m. 23ch. P.	20 634
V. S. 333m. 23ch. P.	37 46 56.87	118 15 37.58	311 52 18	131 53 03	V. S. 334m. 61ch. P.	2 393
V. S. 334m. 61ch. P.	37 46 05.05	118 14 24.77	311 58 39	132 06 20	Fish Lake Valley, V. S. 350 M. P.	24 894
V. S. 350 M. P.	37 37 04.99	118 01 50.15	312 03 34	132 09 54	V. S. 363 M. P.	20 623
V. S. 363 M. P.	37 29 36.40	117 51 26.84	312 36 45	132 48 15	V. S. 387 M. P.	38 084
V. S. 387 M. P.	37 15 38.49	117 32 29.42	312 18 19	132 18 49	V. S. 388 M. P.	1 660
V. S. 388 M. P.	37 15 02.25	117 31 39.61	312 11 56	132 27 19	V. S. 420m. 70ch. P.	51 116
V. S. 420m. 70ch. P.	36 56 25.67	117 06 09.29	312 47 46	132 59 41	V. S. 446 M. P.	40 384
V. S. 446 M. P.	36 41 33.93	116 46 15.63	313 01 00	133 14 13	V. S. 474 M. P.	45 386
V. S. 474 M. P.	36 24 47.34	116 24 03.71	313 16 32	133 17 00	V. S. 475 M. P.	1 611
V. S. 475 M. P.	36 24 11.52	116 23 16.65	314 00 47	134 14 41	V. S. 505 M. P.	49 035
V. S. 505 M. P.	36 05 43.81	115 59 46.95	315 25 35	135 28 39	V. S. 512 M. P.	11 139
V. S. 512 M. P.	36 01 26.25	115 54 34.72	315 31 32	135 35 37	V. S. 521 M. P.	14 903
V. S. 521 M. P.	35 55 41.03	115 47 38.24	314 56 40	134 58 00	V. S. 524 M. P.	4 833
V. S. 524 M. P.	35 53 50.23	115 45 21.83	314 55 51	134 57 21	V. S. 528 M. P.	5 462
V. S. 528 M. P.	35 51 45.05	115 42 47.72	314 53 21	134 53 48	V. S. 529 M. P.	1 615
V. S. 529 M. P.	35 51 08.06	115 42 02.12	314 57 15	134 58 08	V. S. 531 M. P.	3 229
V. S. 531 M. P.	35 49 54.02	115 40 31.07	314 50 48	134 51 15	V. S. 532 M. P.	1 614
V. S. 532 M. P.	35 49 17.07	115 39 45.46	315 03 07	135 03 34	V. S. 533 M. P.	1 615
V. S. 533 M. P.	35 48 39.98	115 39 00.01	315 00 55	135 01 22	V S. 534 M. P.	1 616
V. S. 534 M. P.	35 48 02.90	115 38 14.52	314 58 32	134 58 59	V. S. 535 M. P.	1 616
V. S. 535 M. P.	35 47 25.85	115 37 29.01	314 56 16	134 56 43	V. S. 536 M. P.	1 616
V. S. 536 M. P.	35 46 48.82	115 36 43.47	314 55 31	134 55 58	V. S. 537 M. P.	1 614
V. S. 537 M. P.	35 46 11.85	115 35 57.99	315 00 41	135 01 08	V. S. 538 M. P.	1 615
V. S. 538 M. P.	35 45 34.78	115 35 12.53	314 33 01	134 56 04	V. S. 592 M. P.	84 562
V. S. 592 M. P.	35 13 23.21	114 55 29.64	314 36 15	134 44 01	V. S. 610 M. P.	28 845
V. S. 610 M. P.	35 02 25.16	114 41 59.36	314 34 36	134 35 02	V. S. 611 M. P.	1 596
V. S. 611 M. P.	35 01 48.80	114 41 14.50	313 14 56	133 15 22	V. S. 612 M. P.	1 599
V. S. 612 M. P.	35 01 13.24	114 40 28.55				
V. S. West lat. post	35 00 15.02	114 39 41.31				
V. S. East lat. post	35 00 15.02	114 39 23.06				
V. S. iron monument.	35 00 44.22	114 39 35.52				

NOTE.—m. = miles, ch. = chains, and l. = links, M. P. = mile post, P. = post, V. S. = Von Schmidt.

**See note, end of Table C.

E. DISTANCES AND DESCRIPTION OF RECOVERED POINTS ON THE VON SCHMIDT LINE.

Nos.	Distance between Von Schmidt points.		Remarks.
	Meters.	*Miles.*	
$210^m\ 76^{ch}$	0·0	0·00	A granite monument 6 feet long, 4 feet above ground, 8½ inches at top, 10⅛ inches at bottom, terminating in a flat pyramid. Marked O, 210^m 76^{ch}, 1873 (changed from 1863), NEV., Califor. Stands about 100 feet from the water on southeast shore of Lake Tahoe. It is 590 meters southwest of the corrected line, United States Coast and Geodetic Survey. The distances on the Von Schmidt line posts, miles and chains, are reckoned from Oregon. This stone being the first on the shore of Lake Tahoe to mark the oblique boundary, was used by Grunsky and Minto in 1889 as the starting point from which to fix their initial mark on the shore of the lake..
211^m	80·46	0·05	In the marsh or meadow land, a post said to be cottonwood, about 8 feet long, 10 inches square, in good state of preservation, 585 meters southwest of corrected line.
$211^m\ 30^{ch}$	605	0·38	A cut granite monument in road on southeast side fronting Lake Side Tavern, old house of Lapham, 580 meters southwest of corrected line. This monument was used as the starting point of the United States Coast and Geodetic Survey in 1893, for the determination of latitude and longitude (telegraphic) on account of its convenience to the telephone wire running to Carson City, which was utilized for the exchange of telegraphic longitude signals. The first point on the lake shore was established by measurement, with reference to this stone.
212^m	1 003	0·63	Pine post 6 inches by 6 inches by 7 feet on foot hills, west slope, 570 meters southwest of corrected line.
$212^m\ 53^{ch}\ 21^l$	1 074	0·67	Site for Von Schmidt's iron monument, which was never set. A pine tree, 8 inches diameter, marked "CAL.," "NEV. 1873," and the distance was found in place; 543 meters southwest of corrected line.
$221^m\ 76^{ch}$	14 408	8·95	Cut granite monument, cairn built around it, in Carson Valley, ¾ mile west of Baldwin's house, nearly due south of No. 10 and 576 meters distant; 460 meters southwest of corrected line.

E. DISTANCES AND DESCRIPTION OF RECOVERED POINTS ON THE VON SCHMIDT LINE—Continued.

Nos.	Distance between Von Schmidt points.		Remarks.
	Meters.	*Miles.*	
227m	8 117	5·04	Pine post northwest of road to middle fork of Carson River in Carson Valley, near Galliner's house; 440 meters southwest of corrected line.
239m 64ch	21 164	13·15	Pine post on west side of road from Holbrook to Coleville, northwest side of Alkali Lake; 250 meters southwest of corrected line.
242m	3 448	2·14	On northwest side of Rickey's meadow in Antelope Valley, in fence line, post found lying on the ground; about 240 meters southwest of corrected line.
254m 49ch	19 869	12·33	No post; pile of stones due south of No. 31, 120 meters distant; 92 meters southwest of corrected line.
Middle Sister	6 122	3·80	A small flag pole 80 meters southwest of No. 32, 64 meters southwest of corrected line; elevation 10 942 feet by aneroid barometer.
266m	12 198	7·58	Pine post in Sweetwater Valley, about 1 mile northwest of No. 34; very close to and northeast of corrected line.
270m 61ch	7 798	4·85	Post and pile of rocks on same hill and only 3 feet southeast of Red △ and 70 meters northeast of No. 36 and the corrected line.
278m	11 716	7·28	Cedar post, 120 meters northeast of No. 39 and the corrected line.
281m	4 871	3·03	Mountain mahogany post one-half mile northeast of No. 40 on northeast slope of Beauty Peak, 160 meters northeast of the corrected line.
283m	3 214	2·00	Pine post 400 meters east of No. 41, on top of steep bluff northwest of Bodie Creek, 168 meters northeast of corrected line.
Brawley, 285m 14ch 67l.	3 560	2·21	A small pole in cairn on southeast side of West Brawley summit, 220 meters east of No. 42 and 175 meters northeast of the corrected line.
295m 49ch	16 812	10·45	Juniper post east of road across desert from Aurora to Adobe Meadows, 500 meters north of No. 46 and 310 meters northeast of the corrected line.
Stone monument	40 385	25·09	Von Schmidt, 32 0m 25ch P. Cut granite monument at crossing of Carson and Colorado R. R., west side, and 600 meters northeast of No. 59 and the corrected line; in first valley northwest of the White Mountains.

E. DISTANCES AND DESCRIPTION OF RECOVERED POINTS ON THE VON SCHMIDT LINE—Continued.

Nos.	Distance between Von Schmidt points.		Remarks.
	Meters.	*Miles.*	
333^m 23^{ch}	20 634	12·82	725 meters northeast of No. 62 and the corrected line.
334^m 61^{ch}	2 393	1·49	Pine post 0·9 mile north of No. 63 and 760 meters northeast of the corrected line.
350^m	24 894	15·47	In Fish Lake Valley, 0·82 mile north of No. 68 and 900 meters northeast of the corrected line; cottonwood post.
363^m	20 623	12·81	Cottonwood post in Fish Lake Valley, 1·02 miles east of No. 74, one-fourth mile southeast of the road to Silver Peak, on northwest slope of first hill in valley east of Piper's upper ranch, 1 020 meters northeast of the corrected line.
387^m	38 084	23·66	Pine post, 1·29 miles nearly north of No. 82 and seven-eighths mile northwest of road from Tule Cañon to Sand Springs; 1 000 meters northeast of the corrected line.
388^m	1 660	1·03	Pine post, 1 020 meters northeast of No. 82, on bluff bank southeast of wash and road; 1 000 meters northeast of the corrected line.
420^m 70^{ch}	51 116	31·76	Nut pine post, 400 meters northeast of Nye △ and 1 536 meters northeast of the corrected line.
446^m	40 384	25·09	Pine post, 1½ miles north of No. 96 and 1 672 meters northeast of corrected line.
474^m	45 386	28·20	Mesquite post in Amargosa Desert, 1½ miles north of No. 102 and 1 860 meters northeast of corrected line; near Franklin Well.
475^m	1 611	1·00	Mesquite post, 1·15 miles northeast of No. 102; three-eighths mile southwest of King △ (Sand Hill), and 1 850 meters northeast of corrected line.
505^m	49 035	30·47	Mesquite post in Pahrump Valley; 1 384 meters northeast of corrected line.
512^m	11 139	6·92	Mesquite post in Pahrump Valley, three-fourths mile and a little east of west from No. 112; 1 040 meters northeast of corrected line.
521^m	14 903	9·26	Willow post in Pahrump Valley, one-half mile east of No. 116. Not on line with other posts. The line (not the 521 M. P.) is 640 meters northeast of corrected line, while the 521 M. P. is only 576 meters northeast of the corrected line.

E. DISTANCES AND DESCRIPTION OF RECOVERED POINTS ON THE VON SCHMIDT LINE—Continued.

Nos.	Distance between Von Schmidt points.		Remarks.
	Meters.	*Miles.*	
524^m	4 833	3·00	Willow post in Pahrump Valley, one-half mile north of No. 117; on line, but the distance does not agree with other mileposts; 496 meters northeast of corrected line.
528^m	5 462	3·39	Willow post in Mesquite Valley, 2½ miles northwest of No. 118; 360 meters northeast of corrected line.
529^m	1 615	1·00	Willow post in Mesquite Valley, 1½ miles northwest of No. 118; 320 meters northeast of corrected line.
531^m	3 229	2·01	Willow post in Mesquite Valley, one-half mile east of No. 118; 290 meters northeast of corrected line.
532^m	1 614	1·00	Willow post in Mesquite Valley, 1½ miles southeast of No. 118; 270 meters northeast of corrected line.
533^m	1 615	1·00	Willow post in Mesquite Valley, one-fourth mile north of No. 119; 225 meters northeast of corrected line.
534^m	1 616	1·00	Mesquite post in Mesquite Valley, seven-eighths mile southeast of No. 119; 190 meters northeast of corrected line.
535^m	1 616	1·00	Mesquite post in Mesquite Valley, three-eighths mile north and a little east of No. 120, one-fourth mile northeast of crossroads southwest of Sandy Post-Office; 160 meters northeast of corrected line.
536^m	1 616	1·00	Mesquite post in Mesquite Valley, three-fourths mile southeast of No. 120; 120 meters northeast of corrected line.
537^m	1 614	1·00	Mesquite post in Mesquite Valley, 1¾ miles southeast of No. 120; 82 meters northeast of corrected line.
538^m	1 615	1·00	Mesquite post in Mesquite Valley, five-eighths mile northwest of No. 121; 60 meters northeast of corrected line.
592^m	84 562	52·54	Cottonwood post 1⅛ miles west and a little north of No. 134, 1 mile northeast of four buttes in the valley (Piute Valley); 870 meters southwest of the corrected line.

E. DISTANCES AND DESCRIPTION OF RECOVERED POINTS ON THE VON SCHMIDT LINE—Continued.

Nos.	Distance between Von Schmidt points.		Remarks.
	Meters.	*Miles.*	
610m	28 845	17·92	Cottonwood post 1⅛ miles west of No. 141, on south side of ravine one-fourth mile east of foot of bald hill; 990 meters southwest of corrected line
611m	1 596	·99	Cottonwood post two-thirds mile southwest of No. 141; 990 meters southwest of corrected line.
612m	1 599	·99	Cottonwood post two-thirds mile southwest of No. 142; 990 meters southwest of corrected line.
Iron monument			611m 59ch iron monument, Colorado River. This monument was not on prolongation of line through 610m, 611m, and 612m posts, but was 150 meters northeast and 960 meters north of Von Schmidt's east latitude post.

*F.** GEOGRAPHIC POSITIONS AND HEIGHTS OF TRIANGULATION STATIONS.*

Stations.	Latitude.			Longitude.			Height above sea level.	Remarks.
	°	′	″	°	′	″	*Feet.*	
Lake Tahoe (surface)							6 224	Deduced from Mt. Grant.
Rubicon	38	59	52·20	120	05	47·53	6 232	
Folsom	38	59	02·85	119	57	01·98	6 717	
Castle Rock	38	59	18·03	119	54	33·14	7 922	
Lake Shore Stone	38	57	25·05	119	57	05·99	6 229	
Ledge	38	56	56·85	119	52	31·02	8 058	
Bowlder	38	56	37·85	119	53	43·49	9 080	
East Peak	38	56	27·64	119	54	27·85	9 590	
Rock Cliff	38	50	21·93	119	41	45·70	5 569	
Barber	38	46	32·68	119	44	29·00	6 090	
Bald	38	45	27·59	119	41	13·22	6 464	
Ridge	38	44	41·86	119	39	11·24	7 115	
Cold Hill	38	44	23·24	119	32	44·60	6 301	
High Peak	38	42	18·83	119	37	42·04	8 468	
Knoll	38	42	59·48	119	35	17·83		
Dome	38	41	34·91	119	35	13·83	8 260	
Lake	38	42	24·17	119	32	19·50		
Pine Nut	38	36	33·25	119	21	56·25		
Flat	38	34	40·04	119	23	43·16		

** See note, end of Table C, p. 346.

F. GEOGRAPHIC POSITIONS AND HEIGHTS OF TRIANGULATION STATIONS—Continued.

Stations.	Latitude.			Longitude.			Height above sea level.	Remarks.
	°	′	″	°	′	″	*Feet.*	
Don	38	34	13·93	119	18	47·25	....	
Mahogany	38	33	10·40	119	22	39·41	....	
East Sister	38	31	18·24	119	17	25·89	....	
Sweetwater Ecc	38	29	15·06	119	09	34·64	7 782	
West Walker	38	24	15·69	119	04	33·85	7 097	
Red	38	23	19·01	119	07	19·20	....	
Long	38	22	16·27	119	02	47·94	8 052	
Sugar Loaf	38	20	06·13	118	58	41·14	7 643	
Bald Peak	38	18	05·23	118	58	16·07	7 911	
Beauty Peak	38	17	06·62	118	58	31·69	8 977	From Mt. Grant (direct).
Aurora Peak	38	16	33·65	118	51	39·33	8 712	
Lake View	38	13	49·72	118	54	42·85	....	
Cedar	38	12	24·87	118	47	29·42	....	
Spring Peak	38	15	12·50	118	50	25·84	....	
Sag	38	08	30·61	118	42	30·12	8 606	
Top	38	01	56·05	118	32	33·25	....	
Sounding Rock	38	01	07·08	118	33	13·79	....	
Trail	37	59	50·78	118	34	10·19	....	
Queen	37	59	48·32	118	32	24·78	....	
T 38	38	20	50·97	119	03	54·33	8 348	From Mount Grant (direct).
Roach	37	57	27·68	118	29	33·68	8 114	From North Peak, White Mountains.
Cap	37	59	10·13	118	28	15·82	8 526	
Mine	37	53	16·17	118	18	32·38	10 252	
Lava	37	56	11·42	118	26	33·24	7 078	
White, East Peak, White Mountains.	37	50	40·05	118	21	05·73	13 145	
Hogback	37	50	49·53	118	13	09·81	6 989	
Black	37	49	27·14	118	15	40·81	9 720	
Davis	37	47	51·76	118	13	21·54	8 847	
McNett	37	48	00·17	118	08	01·59	5 221	
T 62 High	37	46	35·90	118	16	07·08	9 976	
T 64 High	37	44	54·34	118	13	15·78	9 346	
Sand	37	45	56·23	118	05	47·89	4 926	
Leidy	37	42	52·37	118	02	59·15	4 861	
Slate	37	40	39·01	118	00	35·05	5 353	
Esmeralda	37	35	58·70	117	57	37·84	4 947	

F. GEOGRAPHIC POSITIONS AND HEIGHTS OF TRIANGULATION STATIONS—Continued.

Stations.	Latitude.			Longitude.			Height above sea level.	Remarks.
	°	′	″	°	′	″	*Feet.*	
Luck	37	33	22·06	117	55	00·77	5 240	
Pike	37	31	00·53	117	51	13·66	6 456	
Bab	37	28	50·48	117	49	21·59	5 936	
Cab	37	27	56·44	117	47	11·02	6 143	
Dab	37	25	56·51	117	45	57·26	6 886	
Fab	37	24	16·29	117	43	21·69	7 851	
Gab	37	23	43.92	117	42	09·82	....	
Hab	37	22	30·10	117	41	51·89	8 197	
Jab	37	23	03·30	117	40	20·46	....	
Mab	37	21	33·69	117	37	37·11	7 624	
T 80 high	37	19	56·54	117	40	15·06	7 467	
Sclav	37	18	03·16	117	33	22·44	5 534	
Granite	37	16	27·53	117	36	23·75	5 240	
Nig	37	15	24·29	117	29	48·12	4 872	
Cone	37	13	01·06	117	25	44·22	6 575	
Wash	37	11	55·76	117	28	38·77	4 216	
Crystal	37	10	55·82	117	24	47·13	6 182	
T 85 high	37	09	42·20	117	25	44·74	5 167	
Palmetto	37	09	42·65	117	24	05·17	6 167	
Baldwin	37	09	28·11	117	21	11·95	....	
T 86 high	37	07	03·60	117	21	57·21	5 698	
Oucer	37	07	01·00	117	16	05·69	5 793	
Helmet	37	02	17·81	117	11	34·34	7 044	
T 89 high	36	59	30·78	117	12	15·88	8 410	
Coyote	36	59	50·67	117	07	56·24	8 600	
Vine	36	59	34·45	117	03	48·56	6 446	
Grape	36	57	48·81	117	09	01·74	8 771	
Nye	36	56	16·81	117	06	21·02	8 658	
Sage	36	55	58·20	116	58	32·09	5 522	
Shale	36	54	01·80	117	02	57·74	7 440	
Sharp	36	53	02·10	116	54	24·75	4 820	
T 93 high	36	46	51·04	116	54	57·80	5 072	
Dune	36	47	14·25	116	50	19·55	3 560	
Jock	36	44	24·04	116	46	42·49	3 327	
Green	36	42	50·51	116	46	49·83	4 016	
Bleak	36	43	03·87	116	43	28·41	2 744	
Funeral	36	37	20·69	116	38	26·92	3 552	
T 98 High	36	34	27·52	116	39	22·89	3 677	
Sexton	36	29	55·43	116	35	51·34	2 680	

F. GEOGRAPHIC POSITIONS AND HEIGHTS OF TRIANGULATION STATIONS—Continued.

Stations.	Latitude.			Longitude.			Height above sea level.	Remarks.
	°	′	″	°	′	″	*Feet.*	
Butte	36	26	10·84	116	31	52·15	....	
Rose	36	23	35·24	116	28	34·60	....	
King	36	24	25·32	116	22	58·68	....	
South Base, Amargosa	36	22	35·64	116	24	01·36	2 160	
Watkins	36	22	55·63	116	21	48·53	....	
Shoshone	36	22	57·92	116	18	51·53	2 157	
Hunch	36	19	23·07	116	17	12·88	2 793	
Pah	36	18	22·08	116	13	39·72	2 779	
T 105 High	36	16	33·77	116	15	01·44	3 937	
Rump	36	14	06·68	116	08	23·76	3 291	
Low	36	11	06·52	116	04	16·80	2 504	
End	36	10	21·45	116	06	15·30	2 766	
Crown	36	07	35·49	116	02	46·40	2 592	
Hard	36	05	15·09	116	04	56·47	2 820	
Manse	36	05	08·12	116	00	30·89	2 515	
Dell	36	03	02·27	116	02	40·10	2 780	
Blow	35	59	50·22	116	01	17·89	3 221	
Gap	35	58	45·93	115	57	32·59	2 541	
Ring	35	56	46·41	115	55	15·35	2 617	
Belle	35	52	35·93	115	47	35·90	2 984	
T 117 High	35	52	54·07	115	44	46·08	2 924	
Mag	35	51	21·82	115	45	40·94	2 870	
Jumbo	35	49	23·37	115	43	13·47	2 643	
Snow	35	48	54·44	115	41	20·74	2 645	
Move	35	46	13·22	115	43	41·74	2 893	
Martin	35	44	43·73	115	39	56·11	2 835	
Taylor	35	44	22·72	115	36	27·47	2 537	
Bullock	35	40	55·26	115	33	19·31	2 561	
Spanish	35	38	52·17	115	28	51·25	4 547	
T 123 High	35	40	05·23	115	27	49·58	4 723	
Well	35	35	45·72	115	25	07·29	2 592	
Skit	35	34	00·09	115	23	19·79	2 595	
Link	35	32	48·21	115	21	28·19	2 693	
Patch	35	31	42·03	115	22	02·64	2 592	
Storm	35	30	10·05	115	18	31·28	2 846	
T 128 High	35	27	33·91	115	12	37·06	4 092	
Palisade	35	26	31·77	115	13	52·92	3 564	
T 129 High	35	26	22·42	115	11	33·76	4 528	
Quartz Ledge	35	25	43·34	115	13	34·33	3 784	

F. GEOGRAPHIC POSITIONS AND HEIGHTS OF TRIANGULATION STATIONS—Continued.

Stations.	Latitude.			Longitude.			Height above sea level.	Remarks.
	°	′	″	°	′	″	*Feet.*	
T 130 High	35	24	24·59	115	08	08·63	5 212	
Vanderbilt	35	23	07·19	115	09	08·48	5 417	
Searchlight	35	22	45·48	115	03	24·80	4 371	
Setter	35	20	43·36	114	59	48·82	3 459	
Collie	35	13	56·02	114	53	19·77	2 382	
Pointer	35	12	23·07	114	54	58·27	2 429	
House	35	10	52·19	114	50	59·88	2 588	
Piute	35	08	31·11	114	50	58·17	2 324	
T 136 High	35	08	03·50	114	48	12·18	2 692	
Gus	35	07	43·20	114	49	41·68	2 383	
Newberry	35	07	27·30	114	46	42·49	2 950	
Vex	35	05	59·23	114	45	56·96	2 685	
Beatty	35	06	14·38	114	43	41·47	2 048	
T 140 High	35	05	21·80	114	44	52·79	2 300	
Quail	35	03	24·60	114	40	33·66	838	
Zona	35	02	44·02	114	39	51·71	618	
Nellie	35	00	40·14	114	40	48·97	827	
Peak	35	00	17·20	114	41	37·08	993	
V. Schmidt's E. Lat. Post.	35	00	14·64	114	39	31·71	514	Lake Tahoe data.
Do			15·02			23·06	....	Needles data.
Bluff	34	54	52·34	114	37	57·58	539	Do.
Bend	34	59	31·01	114	39	41·88	570	Do.
Hill	34	54	04·88	114	40	11·29	789	Do.
West Base, Needles	34	50	53·57	114	36	57·33	475	Do.
East Base, Needles	34	50	38·68	114	35	52·52	452	Do.
Knoll	34	50	03·06	114	37	33·81	664	Do.
Railroad station, Needles, Cal., rail in front of station.	.....			.....			466	From North Peak, White Mountains.
							480	Southern Pacific R. R. datum.
Mount Grant	38	34	07·84	118	47	30·60	11 247	
White Mountains, North Peak.	37	50	13·77	118	21	26·34	13 465	
White Mountains, South Peak.	37	37	57·60	118	15	22·10	14 272	
Freels Peak	.....			.....			10 837	

G. VALUES OF THE MAGNETIC DECLINATION ALONG THE CALIFORNIA AND NEVADA BOUNDARY LINE FROM LAKE TAHOE TO THE COLORADO RIVER.

[Observed in 1894, 1895, and 1899, under the direction of C. H. Sinclair, assistant, Coast and Geodetic Survey, and reduced to January 1, 1900.]

Station.	Latitude.		Longitude west of Greenwich.		Date.	Magnetic declination (east). At date of observation.		Magnetic declination (east). On January 1, 1900.		Observer.
	°	′	°	′	1894.	°	′	°	′	
Initial 1894	38	57·8	119	57·0	Aug. 18	16	29	....		J. H. Mather.
T 1	38	57·6	119	56·7	Sept. 1	16	43	....		Do.
T 3	38	56·4	119	54·9	Aug. 24	17	08	....		Do.
T 4	38	56·3	119	54·8	....do ...	16	26	....		Do.
T 5	38	55·9	119	54·3	Aug. 23	16	35	....		Do.
T 6	38	55·7	119	53·9	....do ...	16	14	....		Do.
T 7	38	55·5	119	53·6	Aug. 24	15	42	....		Do.
Mean	38	56·5	119	55·0	....	16	28	16	28	
T 8	38	52·8	119	49·8	Sept. 4	16	52	....		Do.
T 9	38	52·2	119	48·8	Sept. 8	17	10	....		Do.
T 10	38	51·7	119	48·1	Sept. 5	17	06	....		Do.
T 11	38	51·2	119	47·4	....do ...	17	11	....		Do.
T 12	38	50·3	119	46·2	Sept. 6	17	16	....		Do.
T 13	38	50·1	119	45·9	Sept. 8	15	48	....		Do.
T 14	38	49·8	119	45·4	Sept. 12	16	49	....		Do.
Mean	38	51·2	119	47·4	....	16	53	16	53	
T 15	38	48·8	119	44·0	Sept. 15	16	34	....		Do.
T 16	38	48·6	119	43·6	....do ...	16	48	....		Do.
T 17	38	48·0	119	42·7	Sept. 19	15	52	....		Do.
T 18	38	47·3	119	41·7	....do ...	16	06	....		Do.
T 19	38	46·8	119	41·1	....do ...	16	20	....		Do.
T 20	38	46·4	119	40·5	....do ...	16	18	....		Do.
Mean	38	47·6	119	42·3	....	16	20	16	20	
T 22	38	43·7	119	36·6	Oct. 4	18	56	....		Do.
T 23	38	42·2	119	34·5	Oct. 3	16	39	....		Do.
T 24	38	41·1	119	32·9	Oct. 5	17	08	....		Do.
T 25	38	40·3	119	31·7	....do ...	17	07	....		Do.
T 27	38	39·0	119	29·8	....do ...	16	23	....		Do.
Mean	38	41·3	119	33·1	....	17	05	17	15	
T 28	38	37·6	119	27·9	Oct. 5	16	48	....		Do.
T 29	38	34·8	119	23·7	Oct. 9	16	57	....		Do.
T 30	38	33·4	119	21·8	Oct. 10	16	27	....		Do.
T 31	38	32·7	119	20·8	....do ...	16	45	....		Do
T 32	38	30·5	119	17·6	Oct. 15	15	52	....		Do.
Mean	38	33·8	119	22·4	....	16	23	16	33	

G. VALUES OF THE MAGNETIC DECLINATION ALONG THE CALIFORNIA AND NEVADA BOUNDARY LINE, ETC.—Continued.

Station.	Latitude.	Longitude west of Greenwich.	Date.	Magnetic declination (east). At date of observation.	Magnetic declination (east). On January 1, 1900.	Observer.
	° ′	° ′	1894.	° ′	° ′	
T 33	38 27·4	119 13·3	Oct. 16	17 30	....	J. H. Mather.
T 34	38 25·5	119 10·5	Oct. 21	16 33	....	Do.
T 35	38 25·3	119 10·2	Oct. 16	16 39	....	Do.
T 36	38 23·3	119 07·4	Oct. 23	16 37	....	Do.
T 37	38 21·8	119 05·2	Oct. 30	15 18	....	Do.
T 38	38 20·8	119 03·9	Oct. 29	16 24	....	Do.
Mean	38 24·0	119 08·4	....	16 30	16 30	
T 42	38 14·9	118 55·5	Nov. 7	*20 27	*20 27	Do.
T 39	38 19·1	119 01·4	Oct. 29	16 27	....	Do.
T 40	38 17·0	118 58·5	Nov. 1	14 59	....	Do.
T 43	38 13·9	118 54·1	Nov. 7	16 09	....	Do.
T 44	38 12·9	118 52.7	....do...	16 55	....	Do.
T 45	38 11·3	118 50·4	Nov. 8	15 17	....	Do.
Mean	38 14·8	118 55·4	....	15 57	15 57	
T 46	38 08·6	118 46·7	Nov. 8	16 16	....	Do.
T 48	38 05·7	118 42·5	Nov. 9	17 35	....	Do.
T 49	38 05·3	118 42·0	....do...	15 57	....	Do.
T 50	38 02·9	118 38·6	Nov. 11	15 54	....	Do.
T 53	37 59·8	118 34·2	Nov. 10	16 20	....	Do.
Mean	38 04·5	118 40·8	....	16 24	16 24	
T 58	37 55·9	118 28·8	Nov. 10	*13 42	13 42	Do.
			1895.			
T 59	37 54·1	118 26·4	July 2	16 22	....	A. W. Cuddeback.
T 60	37 50·4	118 21·3	June 30	16 18	....	Do.
T 61	37 48·6	118 18·7	June 26	17 35	....	Do.
T 62	37 46·6	118 16·0	June 25	17 02	....	Do.
T 63	37 45·3	118 14·2	July 9	16 18	....	Do.
Mean	37 49·0	118 19·3	....	16 43	16 43	
T 64	37 44·8	118 13·4	June 24	16 26	....	Do.
T 65	37 44·0	118 12·3	July 30	16 19	....	Do.
T 66	37 42·5	118 10·3	July 4	15 55	....	Do.
T 67	37 40·1	118 07·0	Aug. 3	16 16	....	Do.
T 67½	37 37·6	118 03·5	July 26	16 08	....	Do.
Mean	37 41·8	118 09·3	....	16 13	16 13	

* Local disturbance.

G. *VALUES OF THE MAGNETIC DECLINATION ALONG THE CALIFORNIA AND NEVADA BOUNDARY LINE, ETC.*—Continued.

Station.	Latitude.		Longitude west of Greenwich.		Date.		Magnetic declination (east). At date of observation.		Magnetic declination (east). On January 1, 1900.		Observer.
	°	′	°	′	1895.		°	′	°	′	
T 68	37	36·3	118	01·8	July	26	16	20			A. W. Cuddeback.
T 69	37	35·3	118	00·3	Aug.	6	16	18			Do.
T 70	37	34·8	117	59·7	do		17	24			Do.
T 71	37	34·3	117	59·0	do		16	08			Do.
T 72	37	32·6	117	56·7	do		16	13			Do.
Mean	37	34·7	117	59·5			16	29	16	29	
T 73	37	30·7	117	54·0	Aug.	7	16	37			Do.
T 74	37	29·6	117	52·6	do		16	26			Do.
T 75	37	28·1	117	50·5	do		16	14			Do.
T 76	37	27·7	117	49·9	do		16	02			Do.
T 77	37	27·0	117	49·0	do		16	15			Do.
Mean	37	28·6	117	51·2			16	19	16	19	
T 78	37	25·0	117	46·3	Aug.	12	16	10			Do.
T 79	37	23·1	117	43·7	do		16	34			Do.
T 80	37	20·2	117	39·8	Aug.	16	15	53			Do.
T 82	37	14·5	117	32·1	Aug.	22	15	57			Do.
T 83	37	11·9	117	28·6	Aug.	28	17	07			Do.
Mean	37	18·9	117	38·1			16	20	16	20	
T 86	37	07·0	117	22·0	Oct.	18	*20	58	20	58	Do.
T 84	37	10·7	117	26·9	Aug.	26	15	55			Do.
T 85	37	09·6	117	25·4	Aug.	29	16	10			Do.
T 88	37	03·1	117	16·7	Oct.	17	16	33			Do.
T 89	36	59·8	117	12·3	Oct.	18	15	56			Do.
Mean	37	05·8	117	20·3			16	08	16	08	
T 90	36	57·4	117	09·0	Sept.	6	16	08			Do.
T 91	36	54·5	117	05·2	Sept.	7	16	12			Do.
T 92	36	52·5	117	02·5	Sept.	20	16	09			Do.
Mean	36	54·8	117	05·6			16	10	16	10	
T 94	36	43·5	116	50·5	Oct.	9	15	52			Do.
T 95	36	42·3	116	49·0	do		15	37			Do.

* Local disturbance.

G. *VALUES OF THE MAGNETIC DECLINATION ALONG THE CALIFORNIA AND NEVADA BOUNDARY LINE, ETC.*—Continued.

Station.	Latitude.	Longitude west of Greenwich.	Date.	Magnetic declination (east). At date of observation.	Magnetic declination (east). On January 1, 1900.	Observer.
	° ′	° ′	1895.	° ′	° ′	
T 96	36 40·2	116 46·2	Oct. 8	15 47	....	A. W. Cuddeback.
T 97	36 36·5	116 41·4	Oct. 10	15 36	....	Do.
T 98	36 34·8	116 39·1	...do ...	15 30	....	Do.
Mean	36 39·5	116 45·2	....	15 40	15 40	
			1899.			
T 98	36 34·8	116 39·1	Mar. 18	15 35	....	F. W. Edmonds.
T 99	36 31·4	116 34·6	Mar. 17	15 18	....	Do.
T 100	36 28·6	116 30·9	...do ...	15 18	....	Do.
T 101	36 25·9	116 27·5	Mar. 16	15 22	....	Do.
Mean	36 30·2	116 33·0	....	15 23	15 23	
T 102	36 23·4	116 24·1	Mar. 16	15 19	....	Do.
T 103	36 21·1	116 21·2	Mar. 15	15 12	....	Do.
T 104	36 19·5	116 19·1	...do ...	15 02	....	Do.
T 106	36 14·6	116 12·7	Mar. 14	15 05	....	Do.
Mean	36 19·6	116 19·3	....	15 10	15 10	
T 107	36 12·1	116 09·5	Mar. 13	15 19	....	Do.
T 108	36 10·3	116 07·1	Mar. 11	15 08	....	Do.
T 109	36 07·3	116 03·2	...do ...	15 02	....	Do.
T 110	36 05·2	116 00·5	...do ...	15 22	....	Do.
Mean	36 08·7	116 05·1	....	15 13	15 13	
T 111	36 02·8	115 57·4	Mar. 10	15 07	....	Do.
T 112	36 00·7	115 54·8	Mar. 12	15 12	....	Do.
T 113	36 00·2	115 54·1	Mar. 10	14 56	....	Do.
T 114	35 58·9	115 52·4	...do ...	15 16	....	Do.
T 115	35 57·7	115 50·9	...do ...	14 59	....	Do.
Mean	36 00·1	115 53·9	....	15 06	15 06	
T 116	35 55·7	115 48·3	Mar. 7	15 19	....	o.
T 117 (high)	35 52·9	115 44·8	...do ...	15 04	....	Do.
T 119	35 48·4	115 39·1	Mar. 6	14 56	....	Do.
T 120	35 47·1	115 37·4	...do ...	14 52	....	Do.
Mean	35 51·0	115 42·4	....	15 03	15 03	

G. VALUES OF THE MAGNETIC DECLINATION ALONG THE CALIFORNIA AND NEVADA BOUNDARY LINE, ETC.—Continued.

Station.	Latitude.		Longitude west of Greenwich.		Date.		Magnetic declination (east). At date of observation.		Magnetic declination (east). On January 1, 1900.		Observer.
	°	′	°	′	1895.		°	′	°	′	
T 121..........	35	45·1	115	34·8	Mar.	8	14	51	....		F. W. Edmonds.
T 122..........	35	42·7	115	31·8	Mar.	6	14	57	....		Do.
T 124..........	35	39·5	115	27·7	Mar.	5	15	02	....		Do.
T 125..........	35	36·3	115	23·7	Mar.	3	14	52	....		Do.
Mean	35	40·9	115	29·5	....		14	56	14	56	
T 127..........	35	31·5	115	17·5	Mar.	4	*11	39	*11	39	Do.
T 130 (high)....	35	24·1	115	08·5	Feb.	27	14	37	....		Do.
T 132..........	35	21·0	115	04·3	....do ...		13	35	....		Do.
T 133..........	35	18·5	115	01·2	Feb.	25	15	39	....		Do.
Mean	35	21·2	115	04·6	....		14	37	14	37	
On line between T 134 and T 135.	35	11·5	114	52·4	Feb.	21	15	11	....		Do.
T 135..........	35	09·6	114	50·0	....do ...		14	10	....		Do.
T 138..........	35	06·8	114	46·6	Feb. 18 / Feb. 20		14	52	....		Do.
T 139..........	35	06·0	114	45·6	Feb.	18	14	37	....		Do.
Mean	35	08·5	114	48·6	....		14	42	14	42	
T 141..........	35	02·2	114	40·9	Feb.	17	14	10	....		Do.
T 142..........	35	01·3	114	39·8	....do ...		14	19	....		Do.
Von Schmidt 35° E. latitude post.	35	00·3	114	39·4	Feb.	16	14	06	....		Do.
Mean	35	01·3	114	40·0	....		14	12	14	12	

* Local disturbance.

The above observations were made with Coast and Geodetic Survey Compass Declinometer No. 741; they have all been referred to the mean value per day (24 hours).

RECAPITULATION OF MEAN VALUES OF MAGNETIC DECLINATIONS ALONG BOUNDARY LINE.

Stations.	Latitude.		Longitude west of Greenwich.		Magnetic declination east Jan. 1, 1900.	
	°	′	°	′	°	′
Initial 1894, T 1, T 3, T 4, T 5, T 6, T 7	38	56·5	119	55·0	16	28
T 8, T 9, T 10, T 11, T 12, T 13, T 14	38	51·2	119	47·4	16	53
T 15, T 16, T 17, T 18, T 19, T 20	38	47·6	119	42·3	16	20
T 22, T 23, T 24, T 25, T 27	38	41·3	119	33·1	17	15
T 28, T 29, T 30, T 31, T 32	38	33·8	119	22·4	16	33
T 33, T 34, T 35, T 36, T 37, T 38	38	24·0	119	08·4	16	30
T 39, T 40, T 43, T 44, T 45	38	14·8	118	55·4	15	57
T 46, T 48, T 49, T 50, T 53	38	04·5	118	40·8	16	24
T 59, T 60, T 61, T 62, T 63	37	49·0	118	19·3	16	43
T 64, T 65, T 66, T 67, T 67½	37	41·8	118	09·3	16	13
T 68, T 69, T 70, T 71, T 72	37	34·7	117	59·5	16	29
T 73, T 74, T 75, T 76, T 77	37	28·6	117	51·2	16	19
T 78, T 79, T 80, T 82, T 83	37	18·9	117	38·1	16	20
T 84, T 85, T 88, T 89	37	05·8	117	20·3	16	08
T 90, T 91, T 92	36	54·8	117	05·6	16	10
T 94, T 95, T 96, T 97, T 98	36	39·5	116	45·2	15	40
T 98, T 99, T 100, T 101	36	30·2	116	33·0	15	23
T 102, T 103, T 104, T 106	36	19·6	116	19·3	15	10
T 107, T 108, T 109, T 110	36	08·7	116	05·1	15	13
T 111, T 112, T 113, T 114, T 115	36	00·1	115	53·9	15	06
T 116, T 117, T 119, T 120	35	51·0	115	42·4	15	03
T 121, T 122, T 124, T 125	35	40·9	115	29·5	14	58
T 130, T 132, T 133	35	21·2	115	04·6	14	37
(T 134, T 135), T 135, T 138, T 139	35	08·5	114	48·6	14	42
T 141, T 142, Von Schmidt, 35° E. latitude post	35	01·3	114	40·0	14	12
Carson City, Nev., pavilion grounds	39	10	119	46	16	36
Lake Tahoe, southeast end California Astronomic Station	38	57	119	57	17	00

The last two results were obtained by theodolite magnetometer on three days at each station.

H. RESULTS FOR LATITUDE OF STATION NEEDLES, CAL., 1889.

[Observer, C. H. Sinclair. Date, June, 1889. Instrument, meridian instrument No. 2. Level, 1 division = 0″·91. Micrometer, 1 revolution = 65″·818. Number pairs, 21. Number observations, 69.]

Pairs of stars. C. and G. S. Catalogue.		n'.	w.	Latitude.			Extremes.
				°	′	″	
1162	1191	1	2	34	50	17·24	
1183	1191	2	5			17·49	
1197	1201	3	5			18·26	
1201	1215	3	6			17·75	
1232	1236	3	8			16·87	
1237	1254	3	5			17·98	
1237	1260	3	5			18·41	
1265	1276	3	8			17·54	
1296	1300	4	9			18·91	
1303	1315	4	10			17·36	
1325	1328	4	9			18·27	
1333	1335	4	10			18·10	
1347	1350	4	10			16·02	Minimum.
1359	1362	3	8			18·41	
1369	1371	3	7			20·48	Maximum.
1383	1396	3	7			18·36	
1410	1418	4	10			17·49	
1432	1443	4	5			17·15	
1437	1443	4	5			18·10	
1443	1449	4	5			18·14	
1460	1464	3	8			17·98	
Mean				34	50	17·92	

Weighted mean, 34° 50′ 17″·90 ± 0″·14.
Reduction to longitude pier + 00″·27.
Latitude of longitude station, 34° 50′ 18″·17 ± 0″·14.

I. RESULTS FOR LATITUDE, VON SCHMIDT'S EAST POST, COLORADO RIVER, 1893.

[Observer, C. H. Sinclair. Date, May, 1893. Instrument, zenith telescope, No. 6. Number of pairs, 18. Number of observations, 87.]

Pairs of stars, C. and G. S. Catalogue.		n'.	w.	Latitude.			Δ
				°	′	″	″
1056	1067	3	9	35	00	14·74	+0·28
1073	1084	5	9			15·74	− ·72
1097	1100	5	13			15·25	− ·23
1121	1131	5	11			15·22	− ·20
1129	1133	5	13			16·11	−1·09
1142	1150	5	13			14·38	+ ·64
1154	1175	5	4			14·90	+ ·12
1182	1184	5	13			14·99	+ ·03
1191	1203	5	13			15·09	− ·07
1208	1216	5	11			14·95	+ ·07
1232	1236	5	13			14·32	+ ·70
1241	1254	5	12			15·51	− ·49
1260	1265	5	12			14·97	+ ·05
1276	1291	5	13			14·71	+ ·31
1308	1313	5	11			14·70	+ ·32
1320	1326	5	9			15·20	− ·18
1324	1326	5	9			15·11	− ·09
1335	1341	4	10			14·54	+ ·48
Mean				50	00	15·02	

Weighted mean, 35° 00′ 15″.02 ± 0″.08.

Station on a bluff of sand and gravel on the west bank of the Colorado River, about 15 meters above the water and about 40 meters from its edge. It is also in the latitude of Von Schmidt's east post of 1873, which is supposed to have been intended for the parallel of 35° N. latitude. A concrete pier was built in 1893, 18 inches by 18 inches by 5 feet long (3 feet above ground), 5·87 meters due west of this post for zenith-telescope No. 6. The station (post) is connected by triangulation with the astronomic station at Needles, Cal., occupied in 1889 by Assistant C. H. Sinclair.

J. RESULTS FOR LATITUDE, SOUTHEAST END OF LAKE TAHOE, CALIFORNIA, 1893.

[Date, August, 1893. Observer, C. H. Sinclair. Instrument, zenith telescope, No. 6, focal length 66 cm., aperture 5 cm. 1 division latitude level = 2″·172. Value 1 turn micrometer, 76″·172 from observations on δ Ursa Minoris U. C., August 21, 1893. Number of pairs, 22. Number of observations, 108.]

Pairs of stars. B. A. C. Catalogue.		n′.	w.	Latitude.			Δ
				°	′	″	″
5940	5972	4	15	38	57	19·88	− ·10
6005	(1484)	5	14			20·75	− ·93
6069	6114	5	13			19·92	− ·14
6109	(1521)	5	14			19·31	+ ·47
(1533)	(1536)	5	10			19·35	− ·43
6246	18083 P.	5	12			19·82	− ·04
6246	18084 P.	5	12			19·77	+ ·01
6355	G. 2644	5	11			19·46	− ·32
6355	6391	5	14			19·76	+ ·02
1590	3461	5	6			20·76	− ·98
6478	6471	5	16			20·07	− ·29
6563	6597	5	15			19·41	+ ·37
6615	6662	5	17			19·97	− ·19
6670	6702	5	13			19·97	− ·19
G. 2900	6715	4	14			19·80	− ·02
6731	6784	5	16			19·10	+ ·68
6834	6868	5	14			19·38	+ ·40
6926	(1768)	5	15			19·78	·00
(1776)	6976	5	13			19·61	+ ·17
G. 3133	7008	5	9			19·44	+ ·34
7022	7061	5	16			20·20	− ·42
7098	7149	5	18			19·59	+ ·19
Mean				38	57	19·78	

Weighted mean, 38° 57′ 19″·76 ± 0″·06.

The station was 50 inches due west of the longitude pier, which is 61½ feet south and 33 feet west of the second granite monument of Von Schmidt, 1873, which is therefore in latitude 38° 57′ 20″·37, longitude 119° 59′ 47″·020 ($0^s·028$ east of the longitude pier southeast side of Lake Tahoe).

K. DIFFERENCE OF LONGITUDE BETWEEN LOS ANGELES, CAL., AND NEEDLES, CAL.

Date.	Observer at— Los Angeles.	Observer at— Needles.	From western or Los Angeles signals.	From eastern or Needles signals.	W.-E.	Mean of W. and E. signals.	Personal equation.	Difference of longitude Δλ.	*p*.	*v*.
1889.			*m.* *s.*	*m.* *s.*	*s.*	*m.* *s.*	*s.*	*m.* *s.*		
May 22	R. A. Marr.	C. H. Sinclair.	14 37·052	14 37·005	0·047	14 37·028	−0·282	14 36·746	6	−0·010
23	.....do.....	.....do.....	36·996	36·956	·040	36·976	....	·694	8	− ·062
24	.....do.....	.....do.....	37·030	36·988	·042	37·009	....	·727	6	− ·029
June 1	.....do.....	.....do.....	37·014	36·976	·038	36·995	....	·713	6	− ·043
5	.....do.....	.....do.....	37·229	37·174	·055	37·202	....	·920	6	+ ·164
Mean	....	....	....	....	·044	14 37·042	....	....	...	....
June 7	C. H. Sinclair.	R. A. Marr.	14 36·439	14 36·396	·043	14 36·418	+0·282	·700	6	− ·056
8	.....do.....	.....do.....	·532	·491	·041	·511	....	·793	6	+ ·037
12	.....do.....	.....do.....	·504	·474	·030	·489	....	·771	4	+ ·015
13	.....do.....	.....do.....	·507	·459	·048	·483	....	·765	2	+ ·009
15	.....do.....	.....do.....	·549	·497	·052	·523	....	·805	3	+ ·049
16	.....do.....	.....do.....	·466	·432	·032	·449	....	·731	4	− ·025
Mean	....	....	....	....	·041	14 36·479	....	14 36·760	...	....

Weighted mean, $14^{m}\ 36^{s}\cdot756 \pm 0^{s}\cdot013$.
Transmission time, $0^{s}\cdot021 \pm 0^{s}\cdot001$.
Personal equation, S.–M. $= +\,0^{s}\cdot282 \pm 0^{s}\cdot018$.

At Los Angeles transit No. 19 was placed over the station in the grounds of the normal school. At Needles transit No. 18 was mounted over a station in the inclosure of the Catholic church.

Adjusted longitude of Needles, Cal., $7^{h}\ 38^{m}\ 24^{s}\cdot836$ west from Greenwich.

L. DIFFERENCE OF LONGITUDE BETWEEN LAKE TAHOE, CALIFORNIA, AND CARSON CITY, NEV.

Date.	Observations at— Lake Tahoe.	Observations at— Carson City.	From western or Lake Tahoe signals.	From eastern or Carson City signals.	W.-E.	Mean of W. and E. signals.	Personal equation.	Difference of longitude Δλ.	*p*.	*v*.
1893.			*m.* *s.*	*m.* *s.*	*s.*	*m.* *s.*	*s.*	*m.* *s.*		*s.*
Aug. 3	C. H. Sinclair.	G. Davidson.	0 44·432	0 44·431	0·001	0 44·432	−0·358	0 44·074	3	−0·035
4	.....do.....	.....do.....	·496	·493	·003	·494	....	·136	3	+ ·027
6	.....do.....	.....do.....	·482	·473	·009	·478	....	·120	7	+ ·011
7	.....do.....	.....do.....	·476	·476	·000	·476	....	·118	4	+ ·009
8	.....do.....	.....do.....	·447	·436	·011	·441	....	·083	3	− ·026
Mean	....	....	....	....	·005	0 44·464	....	....	...	....
Aug. 9	G. Davidson.	C. H. Sinclair.	0 43·794	0 43·785	·009	0 43·789	+0·358	0 44·147	4	+ ·038
11	.....do.....	.....do.....	·739	·732	·007	·735	....	·093	6	− ·016
12	.....do.....	.....do.....	·748	·741	·007	·744	....	·102	9	− ·007
Mean	....	....	....	....	·008	0 43·756	....	0 44·109	...	....

Weighted mean, $0^{m}\ 44^{s}\cdot109 \pm 0^{s}\cdot006$.
Reduction to transit, Friend's Observatory $-\,0^{s}\cdot022$.

$\Delta\lambda$ Lake Tahoe, southeast end T_{1893} — Carson City, Friend's Observatory $T_{1889} = 0^m\ 44^s{\cdot}087 \pm 0^s{\cdot}006$.
Transmission time $= 0^s{\cdot}003 \pm 0^s{\cdot}0005$.

Personal equation, $D\text{-}S = -0^s{\cdot}354 \pm 0^s{\cdot}006$; same from weighted means $= -0^s.358$. A large but reliable value.

At Lake Tahoe transit No. 18 was mounted upon a brick and cement pier on the east side of the road from Bijou post-office to Glenbrook, near Lake Side Tavern. The pier is 61½ feet south and 33 feet west of the granite monument of Von Schmidt, marked 211 miles 30 chains, counting from Oregon.

At Carson City the station was a brick pier 0·803 meters north and 8·015 meters ($= 0^s{\cdot}022$) east of the transit pier in Friend's Observatory. Transit No. 19 was mounted on this pier.

Longitude of transit pier southeast end Lake Tahoe (observed), $7^h\ 59^m\ 47^s{\cdot}048$.

Longitude of transit, Friend's Observatory, Carson City (observed), $7^h\ 59^m\ 02^s{\cdot}961$.

Latitude of transit, Friend's Observatory, Carson City (observed), $39°\ 09'\ 47''{\cdot}50 \pm 0''{\cdot}06$.

V. DESCRIPTION OF ASTRONOMIC TRANSITS NO. 18 AND NO. 19.

[See illustration No. 12.]

These instruments were constructed at the Office of the United States Coast and Geodetic Survey in Washington, D. C., in 1887–88. They were made as nearly alike as possible; aperture, 3 inches; focal length, 37 inches; magnifying power about 104; glass diaphragm with 2 horizontal and 13 vertical lines, of which 11 were used for time observations, arranged in 3 tallies of 3, 5, and 3 lines each, and 2 outside lines for eye and ear observations, the star being confined between the horizontal lines while transiting; equatorial intervals about 2·5 seconds; diameter of pivots 1¼ inches; the pivots rest along their entire length in the Ys; the azimuth and level adjustments are made at the base of the iron stand supporting the Ys; the iron stand rests upon an iron sub-base to which it is attached by 3 holding-down screws, of which 2 are in slots to permit adjustment in azimuth; the sub-base is fastened to the pier with plaster of paris or cement. Striding level of No. 18 one division equals 1·674, of No. 19 equals 1·85 seconds of arc.

For longitude work the observations are recorded on a Fauth cylinder chronograph (see illustration No. 13) by means of an observing key held in the hand of the observer, who breaks the electric circuit as the star crosses each line of the diaphragm of the transit. During the exchange of longitude signals the chronograph is made to revolve at double speed so that the signals may be read to $0^s{\cdot}01$.

A sidereal break-circuit chronometer is used to make the chronographic record at regular intervals of one or two seconds, the transits of stars being on the same sheet.

VI. APPENDIX.

A. LETTER OF THE SUPERINTENDENT TO PROFESSOR DAVIDSON.

UNITED STATES COAST AND GEODETIC SURVEY,
OFFICE OF THE SUPERINTENDENT,
Washington, D. C., March 8, 1893.

DEAR PROFESSOR DAVIDSON: Yours relating to the proposed survey of the Nevada-California boundary line has been under consideration for some time. I submitted it to Mr. Schott; requesting him to make a full memorandum of his views on the best method of doing the work. His reply is extremely interesting, and I send you a copy of it herewith.

I am strongly inclined to the "geodetic method" of locating the line, that is, by means of a system of triangulation connecting the two extremities, provided it does not prove to be too expensive. Local deflection is likely to introduce such errors into the determination of astronomical positions that the result would never be entirely satisfactory. I wish you would read the paper carefully and send me your views at your early convenience. In the meantime the location of the extremities of the line might be gone into. It is only the *oblique* portion of the line that we are required to survey. Undoubtedly the meridian north from Lake Tahoe is in error, but the appropriation does not provide for this. If found to be a serious matter it may be corrected in the future. Within a month Mr. Sinclair and Mr. Walter Fairfield will be available for this work and will be directed to report to you. Mr. Sinclair will be in the "neighborhood" of the southern extremity of the line, and he might receive instructions to look into the matter there, as to the existence and whereabouts of the monument and other matters relating thereto, without reporting to you in person. He might also connect our telegraphic longitude station at Needles with the boundary point and proceed with the determination of the southern point. Mr. Fairfield might also begin operations in the vicinity of Lake Tahoe. Here it will probably be necessary to establish a telegraph line from one of our stations to the shore of the lake, and the latitude and longitude of a point on the shore as near the presumable intersection of the boundary line as possible must be ascertained. All of this work can be done independent of any decision as to how the line itself is to be run.

About $5 000 will be available, and I would like to see it judiciously expended before July 1. If not possible to expend all of it wisely in the field, it might be invested in material, supplies, equipment, camp, etc., which would be required after July 1.

I will be glad to hear from you with reference to these matters at an early date.

Yours, faithfully,

T. C. MENDENHALL, *Superintendent.*

Prof. GEORGE DAVIDSON,

Suboffice Coast and Geodetic Survey, San Francisco, Cal.

B. LETTER OF ASSISTANT C. A. SCHOTT TO THE SUPERINTENDENT ON GEODETIC LINES.

COMPUTING DIVISION,
UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C., February 28, 1893.

Dr. T. C. MENDENHALL,

Superintendent United States Coast and Geodetic Survey.

SIR: The letter submitted to you by Assistant Davidson on the California and Nevada line does not exaggerate the difficulties to be encountered in marking it, yet there are some points, either lightly or not at all touched upon, in that letter which I deem of importance, and beg leave to submit them for consideration.

1. LOCAL DEFLECTION.

The line is to begin at the intersection of the one hundred and twentieth degree of longitude with the thirty-ninth degree of latitude, thence to run in a *straight* line to a point where the channel of the Colorado crosses the thirty-fifth degree of latitude. These termini fall in the water and are inaccessible. The first step to be taken is the fixation of two points on terra firma *nearest to them* and *in* the junction line. To do this we have to decide whether the law contemplates astronomic or geodetic data; in other words, is the line to be run *with* or *without* local deflections, that is, is it to be a wavy and irregular line or a straight and smooth one; the law calls for a "straight line." Let us see, however, what these local deflections amount to:

	$''$
Average local deflection from 59 latitudes, Maine to Georgia. (Appendix 8, Report 1879)	$\pm 2 \cdot 9$
Same, from 48 azimuths	$\pm 4 \cdot 2$
Average local deflection from 31 latitudes, central California to Santa Barbara	$\pm 4 \cdot 8$
Same from 24 azimuths	$\pm 4 \cdot 8$

Taking the value $\pm 4''$, it amounts to 123 meters, or about 400 feet, on the average, and to three times this amount in extreme cases. When the astronomic latitude and longitude is specified for each of two points their relative true position may be out several hundred feet, as found by their geodetic latitude and longitude; in fact, we can not get the real azimuth and distance of the line joining them so long as they are laid down astronomically only, the local deflections being included; this is our case. What sort of a line, then, would we get by starting from an astronomical end point (charged with local deflection in latitude and longitude) with a local deflection azimuth and try to reach, by alternate forward and backward sighting, the opposite end, likewise charged with local deflections, as well as every intermediate point of our line where the instrument was set up, its verticality depending on the local azimuth? The surveyor may find himself several hundred feet out of line and not know whether this was due to defective work or purely difference of local deflections.

Suppose we have placed our two auxiliary end monuments in position (by astronomic or geodetic means) we must connect them by triangulation if we require to know their distance apart and *direction;* the mere computing based upon *disconnected* latitudes and longitudes will land us in the above local-deflection uncertainty. Hence to locate the line accurately demands triangulation from one end to the other. Indeed, we have already a triangulation point—White Mountain N., located by Assistant Eimbeck, in or close to the line about 115 miles from Lake Tahoe.

The triangulation being effected, any desired number of points in the line may be located with accuracy, triangulation being independent of local deflection. A surveyor attempting to follow the line by sighting will soon find himself stopped by obstructions ranging above 12 900 feet (White Mountains) of elevation (Lake Tahoe is 6 224 feet above the sea and the Colorado River at Fort Mohave 514 feet) and would have to resort to a local triangulation, as Assistant Davidson has already pointed out; further, should he attempt to take up a new (verification) azimuth it would not be completed without a knowledge of his latitude and longitude. The former he may observe, the latter get from distance run and direction of line. His assigned distance will be too rough (for instance; he has to climb within 4 miles of Lake Tahoe, an altitude of nearly 3 200 feet, and come down again at the other side of the spur; also the incline will have to be allowed for). The number of permanent monuments in the line may be estimated by the consideration that about 20 miles should be their greatest distance apart, so that a surveyor setting up his transit at one end of them may get a sight forward and backward over the line; further monuments are required where a road crosses the line, and in particular where obstructions limit the length of the sight. For 400 miles 20 monuments and for special sights perhaps as many more would be needed.

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2. VARIETY OF LINES BETWEEN THE TERMINALS.

As to the kind of line between two points *not intervisible*, contemplated by the law givers, their term "straight" line may be interpreted to mean any of the following eight theoretical lines, viz:

(*a*) The intersection of the surface by a plane through the normal at one end (A), and through the other end (B). It is a plane elliptic arc.

(*b*) A similar plane curve passing through the normal of B and through A. These two curves will be distant at about the middle of our line, say 202 miles from either end, by only $1^{m}.83$ or 6 feet (see my report of July 17, 1885), and the angles contained between these arcs at A and B will be $2''.45$ and $2''.19$ (see my report of January 6, 1890).

(*c*) A line called "line of alignment" by Clarke, defined by the property that at every point in it the azimuths of A and B are 180° apart, and it is important to observe that no other three points in the line possess this π property. It is a tortuous curve closely approaching—

(*d*) The geodetic or shortest line between A and B; it has no element in common with either (*a*), (*b*), or (*c*).

(*e*) A forward straight line starting in the plane through the normal at A and through B, and in advancing keeping B constantly sighted.

(*f*) A forward sight line starting at B as above; these lines are distinct and tortuous.

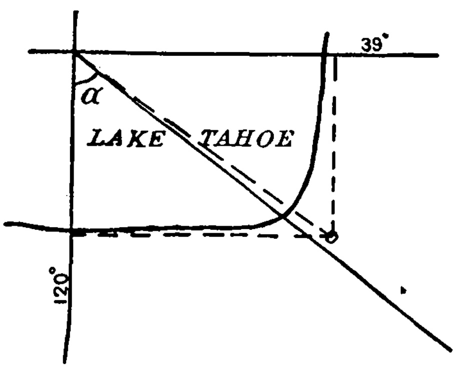
(*g*) A forward and backward sight line over limited distances, i. e., in which the azimuths of the *nearest points* forward and backward equal π, and which has been contemplated in speaking of the direct tracing out of our line. It is simply a composition of a series of lines each having the character of (*e*).

(*h*) A line of the same kind as preceding, but starting from the opposite end. The two lines are distinct. It can also be asserted that the length of these lines are practically equal, no one difference amounting to a millimeter, and 6 of these lines are packed in between the first two plane arcs. Hence it is immaterial which of these curves the computer may adopt, and in particular for the above steps of 20 miles they are absolutely undistinguishable one from the other. We may take then the geodetic line, or we may use the formulæ on page 463, Appendix 9, Report for 1885, which are quite rigorous enough, after they have been accommodated to the *inverse* problem.

Let us now examine the method of locating the *end points at Lake Tahoe* and near Mohave*, both from an astronomic and from a geodetic point of view.

3. THE LAKE TAHOE TERMINAL CONSIDERED ASTRONOMICALLY.

Select a point on the shore and as near as may be in the line. It will probably be less than 5 miles from the intersection of latitude 39° and longitude 120°. Observe here an astronomic latitude and an astronomic longitude, the latter by means of transfer of the nearest telegraphic longitude station, viz, at Genoa. It is but 6½ miles distant in an air line, but separated from our line by a high range of mountains (the pass is 3 300 feet above the lake); hence to get the difference of longitude by wire, by rockets, by azimuthal difference, or by chronometers would be equally difficult or impracticable. Suppose, however, we have it; hence also the dotted line (in figure).



To get a point on the boundary line we must necessarily know the azimuth of the boundary line. This can only be had approximately, as we do not know the difference in the local deflections of the end points of the line; my calculations make it 48° 41′ 29″·6, the longitude of the Colorado end being given (in 1885) as 114° 37′ 53″·5; but with the later longitude, 114° 38′ 45″·3, as given me in 1890, azimuth becomes 48° 40′ 23″·0; thus a few feet (7) of uncertainty will enter in our problem, one or the other longitude being assumed correct (may be neither is so). The solution of a spherical triangle with difference of latitude (say) as a side and angles, α and $\frac{\pi}{2}$, gives a point in the boundary line; comparing this point with the astronomic point, the direction and azimuth, the latter is to be shifted to get in line, becomes known. We thus secure the first boundary monument. The two maps referred to show a nonconformity with the law, inasmuch as the boundary line when produced backward fails to intersect latitude 39° in longitude 120°, but intersects in 120° 00′ 45″ nearly; the actual line is accordingly three-fourths of a mile too far west, taking off that much from California. Now it was known since 1874 (see my report of April 8 1874) that the boundary monument at Verdi was in longitude 120° 00′ 48″·6, and this seems to be the explanation for the difference shown on the map, the topography of which is correct, but not so the boundary line. There is no telling whether or not that erroneous longitude marked at Verdi was correctly transferred south to the lake; most likely not, since Assistant Davidson notes a heavy difference *north* of Verdi in latitude 42°. With this meridianal boundary line, however, we are not concerned at present.

4. THE LAKE TAHOE TERMINAL CONSIDERED GEODETICALLY.

Locate a point geodetically near the boundary and place the same in line as before, and the first boundary monument is secured. Not to depend on the present geodetic data of the triangulation, the later telegraphic longitude stations, Verdi, Virginia City, Carson City, and Genoa, should all be connected with the triangulation, a work which has to be done anyhow as part of the survey of the

*For Lake Tahoe, see Wheeler's topographical maps, United States Geological Surveys, scale 1 inch to the mile, and Atlas sheet No. 56 B. For Mohave, see sheet No. 74; also Explorers and Surveyors, War Department, Rio Colorado of the West, map No. 1, 1858. For intermediate parts of the line see maps Nos. 56 B, 57, and 66.

thirty-ninth parallel; it is already nearly three years since these longitudes were determined, and there is danger of losing the stations. The best sketch showing the triangulation is No. 10, Report for 1890, and there is Assistant Eimbeck's reconnaisance sketch of 1875. The only astronomical work required would be the measure of an azimuth at the boundary monument. The positions of a number of secondary triangulation stations (unoccupied) are already known, as *Peavine*, *Washoe*, Sage, Saddle, *Freels*, Cary's, etc.

5. THE COLORADO RIVER TERMINAL, CONSIDERED ASTRONOMICALLY AND GEODETICALLY.

Here we have the same problem and similar considerations as at the Tahoe end, only further complicated by the uncertainty of the boundary monument, it may or may not be in existence now; if not, it is to be reestablished as the course of the river was at a certain given former time or as it is found now. The required azimuth here is 134° 32′ 09″·8 or 134° 33′ 09″·3. The latitude and longitude of the monument may be had from a triangulation of about a dozen miles from Needles and the longitude must be had from the telegraphic longitude of Needles, viz: 114° 36′ 11″·0 nearly (Sinclair 1889). At the beginning of the line latitude and azimuth also should be observed. The latitude of the Needles is 34° 50′ 17″·90 ± 0″·14 (Sinclair, 1889). Fort (or camp) Mohave, Arizona, is said to be in latitude 35° 02′ 09″·0 and longitude 114° 35′ 54″·0 (Wheeler* in 1875 by connection with *iron monument* of California boundary, an important remark). The Colorado at Mohave was reached by Captain Sitgreaves in *1852*, by Lieutenant Ives in *1858*, and by Lieutenant Wheeler in *1871*, and there is more than one topographic sketch of the river at that point extant (see illustrations Nos. 1, 4, 5, 10, and 57). Mohave is about 2½ miles from the boundary terminus. (See also Wheeler's map of the Grand Cañon of the Colorado, 1871.) The positions of the two terminal line monuments being thus established the whole line may be run—

(1) By successive steps, starting from astronomic data and following the line in the manner already considered, and taking our chances to meet properly in the middle.

(2) By connecting the two terminal line monuments by triangulation (and computing the position of the line accurately) and locating in or close to it a number of points by triangulation, say 50 miles apart, and at all special points, and ascertaining by computation how far, and in what direction each is off the line, and finally placing them in the line.

The intervening line spaces can be run direct as in the first case. Here we have absolute certainty to succeed.

To make the geodetic connection of the end monuments two courses are open, one to follow the line via Conness triangulation point and Lone Mountain triangulation point southeastward, and the other to start from Utah on the line Pioche triangulation point and Tushar triangulation point where three peaks are indicated about latitude 37° and follow along the Utah-Nevada boundary southward. To reach the Colorado end by this route is considered by Assistant Eimbeck as perfectly feasible and it strikes me to be preferable to the other route, probably involving less exposure.

To sum up this somewhat lengthy dissertation, the modus operandi—i. e., whether it should be of a more astronomical or geodetical character, is first to be decided; this done there will be needed to place in the field "the Lake Tahoe party" to connect the telegraphic longitude stations with the primary triangulation and to establish the first boundary monument; also to start a second party, "the Colorado-Mohave party," to connect the astronomical station Needles with the boundary monument after locating the latter; and if geodetic connection is resolved upon to start a third party, "the California-Nevada or the Nevada-Utah triangulation party," as the case may be, to connect the two end monuments of the line; and lastly, to send into the field at least two parties to run the line or locate the line itself. Three years will be consumed, even with *full means*, and more years will be needed with inadequate annual means (of *men* and *money*). A total expenditure of $40,000 may be taken as a minimum with which to accomplish the work, one of the most difficult that could be offered to the geodesist.

Considering that a contribution toward elucidating the best means of dealing with the problem in hand may in the end save time and money, this report may not be taken as too lengthy.

I remain, sir, yours, respectfully,

CHAS. A. SCHOTT, *Assistant.*

*Tables of geographical positions, etc., Washington, 1885, p. 43.

C. COMPUTATION TO ACCOMPANY REPORT OF JULY 17, 1885, BY ASSISTANT C. A. SCHOTT, USING DATA OF JANUARY 4, 1890.

[See letter of Schott to the Superintendent, dated February 28, 1893—practically the same as his report of July 17, 1885.]

APPENDIX I.—*Length and azimuth of the geodetic line and computation of position.*

Colorado River	$\varphi = 35°$	$\lambda = 114° \; 38' \; 45''{\cdot}3$	(1890)
Lake Tahoe	$\varphi = 39°$	$\lambda = 120° \; 00' \; 00''{\cdot}0$	

[Spheroid of 1866, Clarke's Geodesy, 1880, Oxford edition.]

Meters.		
$a = 6\;378\;206{\cdot}4$	$\log a \quad 6{\cdot}804\;698\;57$	$e^2 = \dfrac{a^2 - b^2}{a^2}$
$b = 6\;356\;583{\cdot}8$	$\log b \quad 6{\cdot}803\;223\;78$	$\log e^2 \operatorname{cosec} 2'' = 2{\cdot}843\;90$
$e^2 = 0{\cdot}006\;768\;658\;0$	$\log e^2 \quad 7{\cdot}830\;502\;57 - 10$	
$1 - e^2 = 0{\cdot}993\;231\;342\;0$	$\log(1 - e^2) \quad 9{\cdot}997\;050\;42 - 10$	$\sqrt{1 - e^2} = \dfrac{b}{a}$
	$\log \sqrt{1 - e^2} \quad 9{\cdot}998\;525\;21 - 10$	
	$\log a\sqrt{1 - e^2} \quad 6{\cdot}803\;223\;78$	

Reduced latitudes $\varphi' = 35°$ | $\varphi_1 = 39°$

$\tan \mu = \dfrac{b}{a} \tan \varphi.$

$\log \tan \varphi'$	$9{\cdot}845\;226\;8$	$\log \tan \varphi_1$	$9{\cdot}908\;369\;2$
$\log \dfrac{b}{a}$	$9{\cdot}998\;525\;2$	$\log \dfrac{b}{a}$	$9{\cdot}998\;525\;2$
$\log \tan \mu'$	$9{\cdot}843\;752\;0$	$\log \tan \mu_1$	$9{\cdot}906\;894\;4$
μ'	$34° \; 54' \; 31''{\cdot}089$	μ_1	$38° \; 54' \; 17''{\cdot}558$
$\log \cos \mu'$	$9{\cdot}913\;848\;6$	$\log \cos \mu_1$	$9{\cdot}891\;085\;5$
Difference of longitude ω	$= 5° \; 21' \; 14''{\cdot}7$	$\log \sin \omega$	$8{\cdot}969\;930\;2$
		$\log \cos \omega$	$9{\cdot}998\;101\;1$

$\cos \sigma_0 = \sin \mu_1 \sin \mu' + \cos \mu_1 \cos \mu' \cos \omega$

$\log \sin \mu_1$	$9{\cdot}797\;979\;95$	$\log \cos \mu_1$	$9{\cdot}891\;085\;5$
$\log \sin \mu'$	$9{\cdot}757\;600\;6$	$\log \cos \mu'$	$9{\cdot}913\;848\;6$
	$9{\cdot}555\;580\;55$	$\log \cos \omega$	$9{\cdot}998\;101\;1$
	$0{\cdot}359\;402\;0$		$9{\cdot}803\;035\;2$
	$0{\cdot}635\;382\;5$		
$\cos \sigma_0$	$0{\cdot}994\;784\;5$	$\log \cos \sigma_0$	$9{\cdot}997\;729\;0$
$\log \sin \sigma_0$	$9{\cdot}008\;598\;7$	σ_0	$5° \; 51' \; 15''{\cdot}59$
		$\log \sec \sigma_0$	$0{\cdot}002\;271\;0$
		$\log \sec^{1/6} \sigma_0$	$0{\cdot}000\;76$
		$\log e^2 \operatorname{cosec} 2''$	$2{\cdot}843\;90$
		$\log \cos \mu_1 \cos \mu' \sin \omega$	$8{\cdot}774\;86$
		$\log \delta\omega$	$1{\cdot}619\;52$

$\delta\omega = e^2 \operatorname{cosec} 2'' \sec^{1/6} \sigma_0 \cos \mu_1 \cos \mu' \sin \omega$

$\delta\omega = +41''{\cdot}641$

$\sigma_1 - \sigma_0 = \delta\omega \cos \mu_1 \cos \mu' \sin \omega \operatorname{cosec} \sigma_0$

$\log \cos \mu_1 \cos \mu' \sin \omega$	$8{\cdot}774\;86$
$\log \delta\omega$	$1{\cdot}619\;52$
$\log \operatorname{cosec} \sigma_0$	$0{\cdot}991\;40$
$\log(\sigma_1 - \sigma_0)$	$1{\cdot}385\;78$

$\sigma_1 - \sigma_0 = +24''{\cdot}310$

	° ′ ″
$\tilde{\omega}_1 = \omega + \delta\omega =$	5 21 56·34
$\sigma_1 =$	5 51 39·90

$\sin \sigma_1 \cos U = \cos \mu_1 \cos \mu' \sin \tilde{\omega}_1$ and

$\kappa^2 = \tfrac{1}{4} \dfrac{e^2 \sin^2 U}{1 - e^2 \cos^2 U}$

$\log \cos \mu_1 \cos \mu'$	9·804 934 1
$\log \sin \tilde{\omega}_1$	8·970 864 7
$\log \operatorname{cosec} \sigma_1$	0·990 902 5
$\log \cos U$	9·766 701 3
$U = 54° 14' 24''·82$	
$\log \sin U$	9·909 274 8
$\log e^2$	7·830 502 6
$\log \cos^2 U$	9·533 402 6
$e^2 \cos^2 U = 0·002\ 311\ 56$	7·363 905 2

$\cos \Sigma \sin U = \sin \mu_1$

	° ′ ″
$\Sigma =$	$-39\ 17\ 28·7$
$2\Sigma =$	$-78\ 34\ 57·4$
$\sigma_1 =$	$+\ 5\ 51\ 39·9$
$2\Sigma - \sigma_1 =$	$-84\ 26\ 37·3$

$\log e^2$	7·830 502 6
colog 4	9·397 940 0
$\log \sin^2 U$	9·818 549 6
$\log (\frac{1}{4} e^2 \sin^2 U)$	7·046 992 2
$\log (1 + e^2 \cos^2 U)$	0·001 002 7
$\log k^2$	7·047 994 9
k^2	0·001 116 85

$\log \sin \mu_1$	9·797 979 95
$\log \sin U$	9·909 274 8
$\log \cos \Sigma$	9·888 705 2

$$N = e^2 \cos \mu_1 \cos \mu' \sin \tilde{\omega}_1 \operatorname{cosec} 2''$$

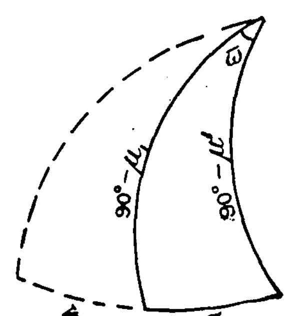
$$\delta \omega = \frac{e^2}{\sin 2''}\left(\frac{\sigma_0}{\sin \sigma_0}\right) \cos \mu_1 \cos \mu' \sin \omega$$

$$\omega - \tilde{\omega} = \frac{e^2}{2} \cos U \left\{ \sigma \left(1 + \frac{e^2}{4} - \frac{k^2}{2}\right) - \frac{k^2}{2} \cos (2\Sigma - \sigma) \sin \sigma \right\}$$

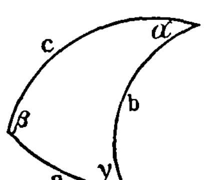
$$\tfrac{1}{4} e^2 = 0·001\ 692\ 16$$
$$\tfrac{1}{2} k^2 = 0·000\ 558\ 42$$
$$\frac{e^2}{4} - \frac{k^2}{2} = 0·001\ 133\ 74$$

$\log e^2$	7·830 503
$\log \cos \mu_1 \cos \mu'$	9·804 934
$\log \sin \tilde{\omega}_1$	8·970 865
$\log \operatorname{cosec} 2''$	5·013 395
$\log N$	1·619 697
$\log \cos \sigma_1$	9·997 724
$\log \sec \sigma_1$	0·002 276
$\log \sec^{\frac{1}{3}} \sigma_1$	0·000 759
$41''·731$	1·620 456
$\log \left(\frac{e^2}{4} - \frac{k^2}{2}\right)$	7·054 514
$+0''·047$	8·674 97
$\log N$	1·619 7
$\log \cos (2\Sigma - \sigma_1)$	8·986 0
$\log \frac{k^2}{2}$	6·746 9
$-0''·002$	7·352 6_n

$\tilde{\omega} = \omega + 41''·776 = 5° 21' 56''·476.$
$90 - \mu_1 = 51° 05' 42''·442.$
$90 - \mu' = 55° 05' 28''·911.$



For solution of spherical triangle:



$$\tan \frac{\beta + \gamma}{2} = \frac{\cos \frac{b - c}{2}}{\cos \frac{b + c}{2}} \cot \frac{\alpha}{2}$$

$$\tan \frac{\beta - \gamma}{2} = \frac{\sin \frac{b - c}{2}}{\sin \frac{b + c}{2}} \cot \frac{\alpha}{2}$$

$b - c = 90 - \mu' - 90 + \mu_1 \quad = + \quad 3° 59' 46''·469.$
$\tfrac{1}{2}(b - c) = \tfrac{1}{2}(\mu_1 - \mu') \quad = + \quad 1° 59' 53''·234.$
$b + c = 90 - \mu' + 90 - \mu_1 \quad = + 106° 11' 11''·353.$
$\tfrac{1}{2}(b + c) = 90 - \tfrac{1}{2}(\mu_1 + \mu') = + \quad 53° 05' 35''·676.$

$\log\cos\frac{b-c}{2}$	9·999 735 9
$\log\cot\frac{\alpha}{2}$	1·329 209 7
	1·328 945 6
$\log\cos\frac{b+c}{2}$	9·778 523 5
$\log\tan\frac{\beta+\gamma}{2}$	1·550 422 1
$\frac{1}{2}(\beta+\gamma)$	88° 23′ 13″·849
$\beta+\gamma$	176° 46′ 27″·70

$\log\sin\frac{b-c}{2}$	8·542 411 0
$\log\cot\frac{\alpha}{2}$	1·329 209 7
	9·871 620 7
$\log\sin\frac{b+c}{2}$	9·902 880 3
$\log\tan\frac{\beta-\gamma}{2}$	9·968 740 4
$\frac{1}{2}(\beta-\gamma)$	42° 56′ 23″·14
$\beta-\gamma$	85° 52′ 46″·28

$2\gamma =$ 90° 53′ 41″.42
$\gamma = (180-)$ 45° 26′ 50″·71
$=$ 134° 33′ 09″·29 = Az: At Colorado River.
$\beta = (180+)$ 131° 19′ 36″·99
$=$ 311° 19′ 36″·99 = Az: At Lake Tahoe.

$\alpha = \tilde{\omega} = 5° \, 21' \, 56''{\cdot}476$

$\frac{\tilde{\omega}}{2} = 2° \, 40' \, 58''{\cdot}238$

$A = a\sqrt{1-e^2}(1 + k^2 + \frac{13}{4}k^4)$

$B = a\sqrt{1-e^2}(\quad k^2 + 3k^4)$

$C = a\sqrt{1-e^2}(\quad -\frac{1}{8}k^4)$

$b = a\sqrt{1-e^2}$

$\log k^4 =$	4·095 986 — 10
$k^4 =$	0·000 001 247
$1 + k^2$	1·001 116 85
$\frac{13}{4}k^4$	0·000 004 05
sum	1·001 121 0
log sum	0·000 486 6
$\log b$	6·803 223 8
log A	6·803 710 4

Sin a sin γ = sin c sin α

$\log\sin c = \log\cos u_1 =$	9·891 085 5
$\log\sin\alpha = \log\sin\tilde{\omega} =$	8·970 867 9
	8·861 953 4
$\log\sin\gamma$	9·852 850 1
$\log\sin a = \log\sin\sigma$	9·009 103 3

$\sigma = 5° \, 51' \, 40''{\cdot}18 = 5°{\cdot}861 \; 161 \; 1$

k^2	0·001 116 85
$3k^4$	0·000 003 7
sum	0·001 120 6
log sum	7·049 450 6
$\log b$	6·803 224
log B	3·852 674

$$s = A\sigma + B\cos(2\Sigma - \sigma)\sin\sigma + C\cos(4\Sigma - 2\sigma)\sin 2\sigma$$

$-\frac{1}{8}k^4$	0·000 000 16
$\log(-\frac{1}{8}k^4)$	$3{\cdot}204 \; 12 - 10_n$
$\log b$	6·803 22
log C	$0{\cdot}007 \; 34_n$

$2\Sigma = -$	78° 34′ 57″·4
$-\sigma = -$	5° 51′ 40″·2
$2\Sigma - \sigma = -$	84° 26′ 37″·6
double $= -$	168° 53′ 15″

$\log\sigma$	0·767 983 6
log rad in °	1·758 122 6
	9·009 861 0
log A	6·803 710 4
log 1st term	5·813 571 4
	meters.
	650 985·7

log B	3·852 674
$\log\cos(2\Sigma - \sigma)$	8·985 98
$\log\sin\sigma$	9·009 10
	1·847 75
	meters.
	+ 70·429

log C	$0{\cdot}007 \; 34_n$
$\log\cos(4\Sigma - 2\delta)$	$9{\cdot}991 \; 78_n$
$\log\sin 2\sigma$	9·307 85
	9·306 97
	meters.
	+ 0·203

$s = 651 \; 056{\cdot}33 = 651{\cdot}056 \; k \; m = 404{\cdot}551$ st. miles

$\log s$ =	2·813 618 5
log factor =	9·793 355 0
$\log s$ (st. miles) =	2·606 973 5
s	= 404·551 statute miles

Check. According to the property of the geodetic line

$\cos\mu \; \sin\alpha = \cos\mu_1 \sin\alpha_1$;

hence for the terminal points $\begin{cases}\alpha' = 45° \, 26' \, 50''{\cdot}71 \\ \alpha_1 = 131° \, 19' \, 36''{\cdot}99\end{cases}$

$\cos\mu' \sin\alpha' = \cos\mu_1 \sin\alpha_1$

$\log\cos\mu'$	9·913 848 6	$\log\cos\mu_1$	9·891 085 5
$\log\sin\alpha'$	9·852 850 0	$\log\sin\alpha_1$	9·875 613 1
	9·766 698 6		9·766 698 6

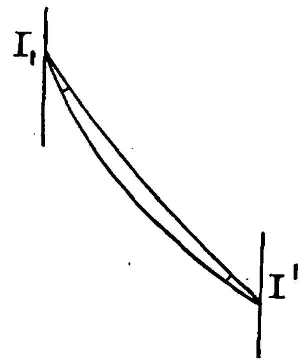
The angle of intersection of elliptic arcs through their respective normals and the opposite terminal point $I = e^2 \cos^2\mu \sin 2\alpha \sin^2\frac{c}{2}$

where c = length of line, μ at the southern point $= \mu'$, at the northern $= \mu_1$

For southern or Colorado point.		*For northern or Tahoe point.*	
$\log \cos^2\mu'$	9·827 70	$\log \cos^2\mu_1$	9·782 17
$\log e^2$	7·830 50		7·830 50
$\log \sin 2\alpha'$	9·999 95	$\log \sin^2 \alpha_1$	9·996 42_n
$\log \sin^2\frac{c}{2}$	7·417 28		7·417 28
	5·075 43		5·026 37
$\log \sin 1''$	4·685 57		4·685 57
	0·389 86		0·340 80
$I' = 2''{\cdot}454$		$I_1 = 2''{\cdot}192$	

$\alpha' = 45^\circ\ 26'{\cdot}8$ | $\alpha_1 = 131^\circ\ 19'{\cdot}6$

$2\alpha' = 90^\circ\ 53'{\cdot}6$ | $2\alpha_1 = 262^\circ\ 39'{\cdot}2$

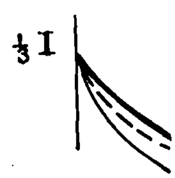


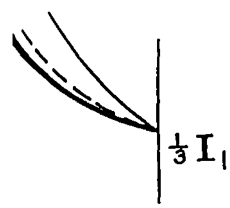
$c = 5^\circ\ 51'\ 40''$

$\frac{c}{2} = 2^\circ\ 55'\ 50''$

Deviation of geodetic line from elliptic arc

$\frac{1}{3} I' = 0''{\cdot}82$ | $\frac{1}{3} I_1 = 0''{\cdot}73$





Azimuth of elliptic arc at Tahoe point	Azimuth of elliptic arc at Colorado point
311° 19′ 36″·17	134° 33′ 08″·56

N. B.—Dalby's theorem may be applied to locate points of longitude in the arc. It is an approximate expression, still very close for any directly measurable line. (See Clarke's Geodesy, p. 106.) The formula answers to the chord method and does not specify the special nature of the connecting line. Applied to our case, we have $\tan \frac{1}{2}(\alpha + \alpha') = \frac{\cos \frac{1}{2}(\varphi' - \varphi)}{\sin \frac{1}{2}(\varphi' + \varphi)} \cot \frac{\omega}{2}$

For elliptic arcs.	For geodetic line.			
$\alpha = 45^\circ\ 26'\ 51''{\cdot}44$	$45^\circ\ 26'\ 50''{\cdot}71$	$\frac{1}{2}(\varphi' - \varphi) = 2^\circ$	$\log \cos \frac{1}{2}(\varphi' - \varphi)$	9·999 735 4
$\alpha' = 311^\circ\ 19'\ 36''{\cdot}17$	$311^\circ\ 19'\ 36''{\cdot}99$	$\frac{1}{2}(\varphi' + \varphi) = 37^\circ$	$\log \sin \frac{1}{2}(\varphi' + \varphi)$	9·779 463 0
$\alpha + \alpha'\ 176^\circ\ 46'\ 27''{\cdot}61$	$176^\circ\ 46'\ 27''{\cdot}70$			0·220 272 4
$\frac{1}{2}(\alpha' + \alpha)\ 88^\circ\ 23'\ 13''{\cdot}805$	$88^\circ\ 23'\ 13''{\cdot}85$	$\frac{1}{2}\omega = 2^\circ\ 40'\ 37''{\cdot}35$	$\log \cot \frac{\omega}{2}$	1·330 151 3
$\log \tan \frac{1}{2}(\alpha' + \alpha)$ 1·550 420 3	1·550 422 2		log term	1·550 423 7

To get a closer accord it would be necessary to change $\frac{1}{3} I'$ and $\frac{1}{3} I_1$ to their more correct values, but it is useless to enter further into this subject in connection with the present state of things.

D. OBLIQUE BOUNDARY BETWEEN CALIFORNIA AND NEVADA—COMPUTATION FOR LENGTH AND AZIMUTH OF GEODETIC LINE BETWEEN LAKE TAHOE (T_0) AND COLORADO RIVER TERMINAL (C_0).

APRIL 17, 1894.

$T_0 \begin{cases} \varphi_1 = 39^\circ \\ \lambda_1 = 120^\circ \end{cases}$ and $C_0 \begin{cases} \varphi' = 35^\circ \\ \lambda' = 114^\circ\ 37'\ 52''\cdot 02 \end{cases}$

Referring in part to my computation of January 4, 1890, we have with the present data:

Diff. of long. $\omega = 5^\circ\ 22'\ 07''\cdot 98$

		$\log \sin \omega$	8·971 125 6
		$\log \cos \omega$	9·998 090 5
		$\log \cos \mu_1$	9·891 085 5
$\sin \mu_1 \sin \mu' =$	0·359 402 0	$\log \cos \mu'$	9·913 848 6
$\cos \mu_1 \cos \mu' \cos \omega =$	0·635 366 9	$\log \cos \mu_1 \cos \mu' \cos \omega$	9·803 024 6
$\cos \sigma_0 =$	0·994 768 9	$\log \cos \sigma_0$	9·997 722 1
$\log \sin \sigma_0 =$	9·009 253 5	σ_0	$5^\circ\ 51'\ 47''\cdot 5$
		$\log \sec \sigma_0 =$	0·002 277 9
		$\log \sec^{1/3} \sigma_0$	0·000 76
		$\log e^2 \operatorname{cosec} 2''$	2·843 90
		$\log \cos \mu_1 \cos \mu' \sin \omega$	8·776 06
$\delta\omega = +$	$41''\cdot 756$	$\log \delta\omega$	1·620 72
		$\log \operatorname{cosec} \sigma_0$	0·990 75
$\sigma_1 - \sigma_0 = +$	$24''\cdot 408$	$\log (\sigma_1 - \sigma_0)$	1·387 53

$\tilde{\omega}_1 = \omega + \delta\omega = 5^\circ\ 22'\ 49''\cdot 736$

$\sigma_1 = 5^\circ\ 52'\ 11''\cdot 908$

$\log \cos \mu_1 \cos \mu'$	9·804 934 1
$\log \sin \tilde{\omega}_1$	8·972 060 1
$\log \operatorname{cosec} \sigma_1$	0·990 246 4
$\log \cos U$	9·767 240 6
$U = 54^\circ\ 11'\ 20''\cdot 21$	
$\log \sin U$	9·908 994 6
$\log e^2$	7·830 502 6
$\log \cos^2 U$	9·534 481 2
$e^2 \cos^2 U = 0·002\ 317\ 31$	7·364 983 8

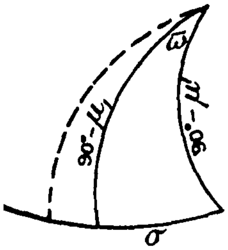
$\log e^2$	7·830 502 6
co-log 4	9·397 940 0
$\log \sin^2 U$	9·817 989 2
$\log (\frac{1}{4} e^2 \sin^2 U)$	7·046 431 8
$\log (1 + e^2 \cos^2 U)$	0·001 005 2
$\log K^2$	7·047 437 0
K^2	0·001 115 42
$\log \sin \mu_1$	9·797 979 95
$\log \sin U$	9·908 994 6
$\log \cos \Sigma$	9·888 985 3

$\Sigma = -39^\circ\ 14'\ 46''\cdot 0$

$2\Sigma = -78^\circ\ 29'\ 32''\cdot 0$

$\sigma_1 = 5^\circ\ 52'\ 11''\cdot 9$

$2\Sigma - \sigma_1 = -84^\circ\ 21'\ 43''\cdot 9$



$\log e^2$	7·830 503	
$\log \cos \mu_1 \cos \mu'$	9·804 934	
$\log \sin \tilde{\omega}_1$	8·972 060	
$\log \operatorname{cosec} 2''$	5·013 395	
$\log N$	1·620 892	
$\log \sec^{1/3} \sigma_1$	0·000 76	
	1·621 65	$+41''\cdot 846$
	7·054 5	
	8·676 2	$+0\cdot 047$
		$-0\cdot 002$

$\log \cos \sigma_1$	9·997 716 8
$\log \sec \sigma_1$	0·002 28
$\log \sec^{1/3} \sigma_1$	0·000 76
$\log N$	1·620 9
$\log \cos (2\Sigma - \sigma_1)$	8·992 3
$\log \frac{1}{2} K^2$	6·746 4
	$7·359\ 6_n$

$\tilde{\omega} = \omega + 41''\cdot 891 = 5^\circ\ 22'\ 49''\cdot 871$

$90 - \mu_1 = 51\ \ 05\ \ 42\ \ \cdot 442$

$90 - \mu' = 55\ \ 05\ \ 28\ \ \cdot 911$

$\log\cos\frac{b-c}{2}$	9·999 735 9	$\log\sin\frac{b-c}{2}$	8·542 411 0
$\log\cot\frac{\alpha}{2}$	1·328 009 1	$\log\cot\frac{\alpha}{2}$	1·328 009 1
	1·327 745 0		9·870 420 1
$\log\cos\frac{b+c}{2}$	9·778 523 5	$\log\sin\frac{b+c}{2}$	9·902 880 3
$\log\tan\frac{\beta+\gamma}{2}$	1·549 221 5	$\log\tan\frac{\beta-\gamma}{2}$	9·967 539 8
$\frac{1}{2}(\beta+\gamma)$	88° 22′ 57″·80	$\frac{1}{2}(\beta-\gamma)$	42° 51′ 38″·81
$\beta+\gamma$	176 45 55 ·60	$\beta-\gamma$	85 43 17 ·62
2γ	91 02 37 ·98	azimuth at C_0	134 28 41 ·0
$\gamma = (180-)$	45 31 18 ·99		
$\beta = (180+)$	131 14 36 ·61	azimuth at T_0	311° 14′ 36″·6

$\frac{1}{2}\tilde{\omega} = 2°\ 41'\ 24''·936$

$\frac{1}{2}\tilde{\omega} = 9\ 684''·936$

	1·
K^4	0·000 001 243
$\frac{13}{4}K^4$	0·000 004 04
K^2	0·001 115 42
	1·001 ·119 46
log sum	0·000 485 9
log b	6·803 223 8
log A	6·803 709 7
$K^2 + 3K^4$	0·001 119 1
log sum	7·048 87
log b	6·803 22
log B	3·852 09
log C	·007 3_n

$\log\sin c = \log\cos\mu_1$	9·891 085 5
$\log\sin\alpha = \log\sin\tilde{\omega}$	8·972 063 1
	8·863 148 6
$\log\sin\gamma$	9·853 405 4
$\log\sin a = \log\sin\sigma$	9·009 743 2

$\sigma = 5°\ 52'\ 11''·40$
$= 5°·8698333$

$$4\Sigma = -156°\ 59'\ 04'' \qquad 2\Sigma = -78°\ 29'\ 32''$$
$$2\sigma = +\ 11\ \ 44\ \ 23 \qquad \sigma = +\ 5\ \ 52\ \ 11$$
$$4\Sigma - 2\sigma = -168\ \ 43\ \ 27 \qquad 2\Sigma - \sigma = -84\ \ 21\ \ 43$$

$$s = A\sigma + B\cos(2\Sigma - \sigma)\sin\sigma + C\cos(4\Sigma - 2\sigma)\sin 2\sigma \ldots.$$

log σ	0·768 625 8	log B	3·852 09	log C	0·007 3
log r in °	1·758 122 6	log cos $(2\Sigma - \sigma)$	8·992 31	log cos $(4\Sigma - 2\sigma)$	9·991 5_n
	9·010 503 2	log sin σ	9·009 75	log sin 2σ	9·308 3_n
log A	6·803 709 7		1·854 15		9·307 1
log first term	5·814 212 9		+71·5 m.		+0·2 m.
	651 949·0 m.				
$s =$	652 020·7 m.				
	652·021 km.				

log s	= 2·814 261 4
log factor	= 9·793 350 3
log s (miles)	= 2·607 611 7
s	= 405·146 st. miles.

Check on azimuths: $\cos u' \sin\alpha' = \cos u_1 \sin\alpha_1$

$\alpha' =$ 45° 31′ 18″·99	log cos u' 9·913 848 6	log cos u_1 9·891 085 5
$\alpha_1 =$ 131 14 36 ·61	log sin α' 9·853 405 4	log sin α_1 9·876 168 5
	9·767 254 0	9·767 254 0

C. A. SCHOTT.

E. *REPORT OF ASSISTANT C. A. SCHOTT.*

COMPUTING DIVISION, COAST AND GEODETIC SURVEY,
March 8, 1894.

Dr. T. C. MENDENHALL.

SIR: The Office computation of the triangulation connecting Needles, Cal., and Fort Mohave, Ariz., was completed some time ago, but the report was delayed by the meetings of the conference.

This triangulation was made in 1893 by Subassistant W. B. Fairfield, and the computations by the observer and by Mr. Courtenay, aided by Mr. Kummell. The main figure was adjusted by least squares, and the results proved quite satisfactory. The base was measured by a 100-meter steel tape and has a length of 1·7 kilometers (about). The triangulation extends over 14 statute miles nearly, and fixes the position of 38 points, all of which have been inserted in the registers.

The astronomic data are as follows: The latitude is that observed at Von Schmidt's 35° latitude post of 1873, viz, 35° 00′ 15″·02±0″·08 (C. H. Sinclair, May, 1893). The azimuth is that observed at the same station, viz, Azimuth of mark 142° 41′ 56″·0 (C. H. Sinclair and W. B. Fairfield, June, 1893). The longitude is that determined telegraphically at Needles, viz, 114° 36′ 11″·04 (C. H. Sinclair and R. A. Marr, May and June, 1889). * * *

The triangulation connecting two astronomic latitude stations brought to light a large local differential deflection in the meridian, viz, between Von Schmidt's 35° post and Needles.

Difference latitude, astronomic, 35° 00′ 15″·02 ± ″·08 — 34° 50′ 17″·90 ± ″·14 = 9′ 57″·12 ± ″·16
Difference latitude, geodetic, 35° 00′ 15″·02 — 34° 50′ 08″·71 = 10′ 06″·31

Differential local deflection 9″·19

which is at the rate of 0″·92 per minute (nautical mile) if supposed equally distributed.

This large deflection, which relative to the vertical at Needles, indicates an attraction of the plumb-line northward as we approach the Mohave end, or boundary end, has an important bearing on the determination of the southeastern terminus of the California and Nevada boundary.

Instead of taking a mean latitude for the geodetic latitude, as usual, the retention of the 35° post latitude was preferred for the triangulation for the reason that it is nearer to the parallel of 35°, hence only demands a small reduction for differential deflection, viz, one-fourth of 0″·92 or 0″·23, i. e., 7·1 meters (about 23 feet). This, of course, assumes a uniform change of deflection, but it is the only assumption we can make in the absence of direct observational test of the actual astronomic latitude of 35° as demanded by law for the southern limit of the boundary. This parallel is therefore 15″·02 + 0″·23 or 15″·25 or 470 meters south of Von Schmidt's 35° latitude post.

The longitude of the terminus of the boundary is defined physically, i. e., the mid-channel of the Colorado River where it is intersected by the parallel of 35°. Owing to the meanderings of the river this point is ever changing, but if we take the middle point on the parallel of 35°, between the more stable gravel bluffs on both sides, we shall get a definite position for the terminus of the boundary, as follows:

Longitude of Sinclair's 35° post on western shore,	114° 39′ 21″·30
Longitude of Sinclair's 35° post on eastern shore,	114° 36′ 20″·69
Difference	3′ 00″·61

3′ 00″·61 in latitude 35° equals 4 580 meters.

Distance of western post from foot of bluff 83 meters, and of eastern post 135 meters, sum 218 meters, which subtracted from 4 580 gives 4 362 meters for width of river bed between the bluffs. Half of this (2 181 meters) added to 135 meters, or 2 316 meters converted into angular measure equals 1′ 31″·33, hence longitude of center or of mid-channel 114° 37′ 52″·02; the latitude of the same is 34° 59′ 59″·77 as expressed in our coordinates. Call this point C_0.

Mr. Sinclair established two stations in the line, as near as this could be done in the field, and it will be necessary to ascertain how near they are to their correct position. Position of southeast line post is in latitude 35° 01′ 23″·06 and longitude 114° 39′ 34″·64. The difference of this line post and the above center is difference of latitude, 1′ 23″·29 or 2 566·7 meters, and difference of longitude 1′ 42″·62 or 2 602·0 meters, hence tan α = 44° 36′ 32″, and the azimuth C_0 to the southeast line post 134° 36′ 32″, but the true azimuth of the boundary is (as near as can be ascertained) 134° 28′ 41″·0. This shows the southeast line post to be too far north by 11·69 meters (0″.38), hence by laying off this amount due south of the southeast line post the first point C_1 in the boundary line will have been established. Nothing further seems to be demanded at this end of the line. The northwest line post would have to be shifted in the same direction but for a somewhat greater distance; however, this is not required in the prosecution of the work. The Von Schmidt iron boundary monument of 1873 was washed over the bluff, but was hauled up again and put farther back, its position is therefore of no further value, but it shows that the boundary of 1873 was about 850 meters distant (to the west and south) from the site now proposed. The reason for this is that Von Schmidt took the mid-channel of the river as he found it in 1873, and as it was again in 1889 in latitude 35°, the latter of course is but a curious coincidence.

The position of C_1 as here determined ($\varphi = 35° 01' 22''.89$, $\lambda = 114° 39' 34''.64$) may be taken as known with as much precision as the case admits of under our hypothesis.

It will also be of interest to compare the position of the Fort Mohave flagstaff as assigned by the United States engineers and by this Office. Captain Wheeler* found, by connection with the above iron boundary monument, the latitude 35° 02′ 09″ and the longitude 114° 35′ 54″, elevation 756 feet; the survey of 1893 gave latitude 35° 02′ 31″·6 and longitude 114° 37′ 13″·9. Mr. W. Minto in 1889 made it latitude 35° 02′ 39″·2, starting from Needles, hence 35° 02′ 30″·0 when starting from latitude station of 1893 or present data and longitude 114° 37′ 14″·5. Mr. Minto's determination rests on an independent triangulation.

Yours, respectfully,

CHAS. A. SCHOTT.

F. COMPUTATION OF THE TERMINI OF THE CALIFORNIA AND NEVADA BOUNDARY LINE.

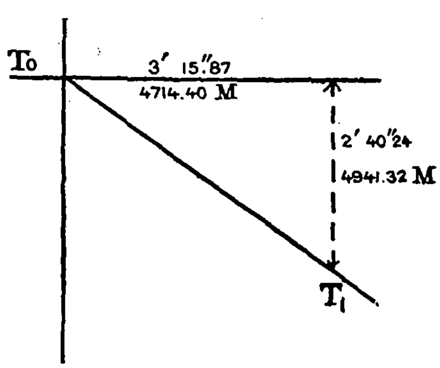
1. LAKE TAHOE TERMINUS OF THE LINE.

The astronomic station Lake Tahoe, southeast end, occupied in August, 1893, near Lakeside Tavern, 61½ feet south and 33 feet west of Von Schmidt's second granite monument, is in—

Latitude 38° 57′ 19″·76 ± 0″·06
Longitude 119° 56′ 44″·13 or $7^h\ 39^m\ 46^s·94$,

hence also the above granite monument;

Latitude, V. S. second granite monument . . . . . . 38° 57′ 20″·368
Longitude . . . . . . 119° 56′ 43″·712 or $7^h\ 59^m\ 46^s·914$



The position of the boundary in Lake Tahoe is defined as in (astronomical) latitude 39° and in longitude 120°, and it remains to determine how far the 1893 astronomic station is off the true boundary. We have in latitude 38° 58′·9,

1″ in meridian = 30·837 meters,
1″ in parallel = 24·069 meters,

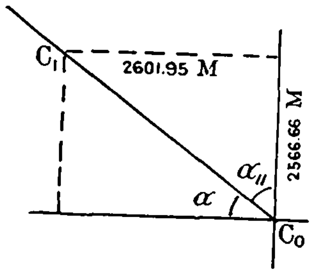
hence tan, $\alpha = \dfrac{4941·32}{4714·40}$ $\qquad \alpha = 46° 20' 46''·5$.

Now the azimuth of the boundary line, as near as that can be had without a geodetic connection, is about 311° 15′ ± 1′, hence the angle α should be 41° 15′·0 instead of 41° 20′·8. In other words, the astronomic station, southeast end of Lake Tahoe, 1893, is too far south, and we have to go north in the meridian 806·39 meters or 26″·150, hence the latitude of the point T_1 becomes 38° 57′ 19″·76 + 26″·150 = 38° 57′ 45″·91 nearly, and its longitude as above 119° 56′ 44″·13.

The new computation of the geodetic line, herewith appended (April 17, 1894, p. 238), makes the azimuth at T_0 = 311° 14′ 36″·6 or α should be 41° 15′ 38″·2 (mean

* Table of geographical positions, etc., Washington, D. C., 1885.

of forward and back azimuth $\dfrac{41^\circ\ 14'\ 36''\cdot6}{41^\circ\ 16'\ 38''\cdot8} = 41^\circ\ 15'\ 37''\cdot7 \pm 1$), or we have to go north in the meridian of the 1893 astronomic longitude station $4\ 941\cdot32 - 4\ 136\cdot17 = 805\cdot15$ meters, which will bring us in latitude $38^\circ\ 57'\ 19''\cdot76 + 26''\cdot11$ or T_1 latitude is $38^\circ\ 57'\ 45''\cdot87$. The distance T_0 to T_1 is 6 271·7 meters.



2. THE COLORADO TERMINUS.

At the Colorado end of the line the azimuth at C_0 should be $134^\circ\ 28'\ 41''\cdot0$ instead of the approximate value $134^\circ\ 29'\ 48''$.

We have $\delta\ \lambda = 1'\ 42''\cdot62 = 2\ 601\cdot95$ meters

and

$$\begin{aligned} \varphi &= 35^\circ\ 01'\ 23''\cdot06 \\ &- 34^\circ\ 59'\ 59''\cdot77 \\ \hline \delta\varphi &= 1'\ 23''\cdot29 = 2\ 566\cdot66 \text{ meters} \end{aligned}$$

hence $\tan \alpha_{11} = \dfrac{2\ 601\cdot95}{2\ 566\cdot66}$, $\alpha_{11} = 45^\circ\ 23'\ 28''$
$\alpha_1 = 44^\circ\ 36'\ 32''$ or azimuth $= 134^\circ\ 36'\ 32''$

but it should be.. $134^\circ\ 28'\ 41''$

hence new abscissa is 2 601·95 tan $44^\circ\ 28'\ 11''\cdot55$ $\left(\dfrac{44^\circ\ 28'\ 41''\cdot0}{44^\circ\ 27'\ 42''\cdot1}\right.$ mean of forward and backward azimuth) = 2 554·24 meters, which equals $\dfrac{2\ 554\cdot24}{30''\cdot816} = 82''\cdot89$, hence C_1 is in latitude $35^\circ\ 01'\ 22''\cdot89$ astronomic, $2\ 566\cdot66 - 2\ 554\cdot24 = 12\cdot42$ meters ($0''\cdot40$) south of Sinclair's line post. Distance C_0 to C_1 = 3 646·1 meters.

G. PREFACE TO OFFICE COMPUTATION OF AZIMUTH AT T_1.

The station called "Turning Point 1894," by Assistant Sinclair, is identical with my station T_1 when computing its position in April, 1894; it is a point in the boundary line and from it starts the transit line marking out the boundary. T_1 stands for first point of line at Lake Tahoe. The astronomic position is—

$$\varphi = 38^\circ\ 57'\ 45''\cdot87$$
$$\lambda = 119^\circ\ 56'\ 44''\cdot13$$

The geodetic position is quite different ($\varphi = 38^\circ\ 57'\ 36''\cdot13$ as actually laid out on the ground), it is less by $9''\cdot74$; this large deflection of the vertical in the meridian has been known for some time.

	°	′	″
The Office computation makes the astronomic azimuth of Folsom triangulation station	171	16	26·2 ± 1·0
Geodetic azimuth	171	16	23·0
The angle laid off from Folsom to back azimuth of boundary (so-called initial point T_1)	39	59	28·7
Hence actual starting azimuth of boundary T_1 to C_1	311	16	54·3
Astronomic azimuth of same (Report April 20, 1894)	311	16	39·8

Hence deviation at starting, $14''\cdot5$.

C. A. SCHOTT.


GREAT AMARGOZA DESERT
ASH MEADOWS
STEWART VALLEY
FUNERAL MOUNTAINS
FUNERAL MOUNTAINS
lofty, rugged and bare
OLD BED OF THE AMARGOSA RIVER
CHUNGUP MOUNTAINS
Great sand hill
Von Schmidt 446 Miles
Von Schmidt's line
Von Schmidt 475 Miles
V.S. 474
Sage brush and greasewood
Sage brush and greasewood
Franklin Well
Shoshone 2158
King
Watkins
Mesquites
Butte
Rose
Sage brush
Old lake bed
soft brownish red soil
Sand and gravel
A few mesquites
white alkali
From Ash Meadows
To Pahrump Ranch
From Pahrump Ranch
To Resting Spring
To Valley Wells
No. 97
No. 99
No. 100
No. 101
No. 102
No. 103
No. 104
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H. RESULTS OF THE ASTRONOMIC MEASURES AT T_1 AND C_1.

COMPUTING DIVISION, COAST AND GEODETIC SURVEY,
April 20, 1894.

Dr. T. C. MENDENHALL,
Superintendent Coast and Geodetic Survey.

SIR: The results of the astronomic measures taken in connection with the fixation of the end points of the California and Nevada oblique boundary line have been reported. I herewith present the final results for the positions of the initial monuments at either end, based upon a recomputation of the whole geodetic line and upon a more exact computation of these points than could be had before. Below, the letters T and C refer to the Tahoe and the Colorado end of the line, respectively. These results are:

Total length of geodetic line T_0 to C_0 = 652 020 meters, or 405·146 statute miles.

	Meters.	Statute miles.
T_0 to T_1	6 272	3·897
C_0 to C_1	3 646	2·266
Distance T_1 to C_1	642 102	398·983

Azimuth of line at T_1, 311° 16′ 39″·8.
Azimuth of line at C_1, 134° 27′ 42″·1.

The point T_1 is 805·15 meters north of the astronomic station of 1893 and very near to the point marked "Turning point" on Assistant Sinclair's map of that year. The point C_1 is 12·42 meters south of Assistant Sinclair's line post of 1893. Here no further notice of effect of local deflection could be taken, since it would not be safe to carry a supposed law of change beyond the actual parallel of observation.

A line of sight in which the forward and backward azimuth at any point in the line shall always lie 180 degrees apart can now be traced out from T_1 toward C_1, starting with the above azimuth at T_1. This line when transited through to the opposite end should pass through C_1, and any deviation from it will have to be corrected proportionately along the whole line. * * *

I append a copy of the computation showing the dependence of the points T_0 and T_1, and C_0 and C_1.

Yours, respectfully,

CHAS. A. SCHOTT, *Assistant.*

Astronomic data.—Position computation, secondary triangulation.

		° ′ ″
α	C_0 to C_1	134 28 41·0
$\Delta\alpha$		— 58·9
		180
α'	C_1 to C_0	314 27 42·1

	° ′ ″			° ′ ″
φ	35 00 00·00	C_0	λ	114 37 52·02
$\Delta\varphi$	+ 1 22·89	$s = 3\ 646^{m}·08$	$\Delta\lambda$	+ 1 42·62
φ'	35 01 22·89	C_1	λ'	114 39 34·64

Astronomic data.—Position computation, secondaay triangulation—Continued.

	° ′ ″	s	3·561827	s^2	7·124
½ (φ + φ′)	35 00 41	Cos α	9·845492	Sin² α	9·707
		B	8·511226	C	1·250
	″				
First term	−82·898	h	1·918545		8·081
Second term	+ ·012				
− Δφ	82·89				

s	3·561827		
Sin α	9·853405		
A	8·509242	Δλ	2·0112
sec φ′	0·086758	Sin ½ (φ + φ′)	9·7587
	2·011232		1·7699
	″		″
Δλ	102·62	— Δα	58·9

			° ′ ″
α	T_0	to T_1	311 14 36·6
Δα			+ 2 03·2
			180
α′	T_1	to T_0	131 16 39·8

	° ′ ″			° ′ ″
φ	39 00 00·00	T_0	λ	120 00 00·00
Δφ	— 2 14·13	$s = 6\ 271^{m}·7$	Δλ	— 3 15·87
φ′	38 57 45·87	T_1	λ′	119 56 44·13

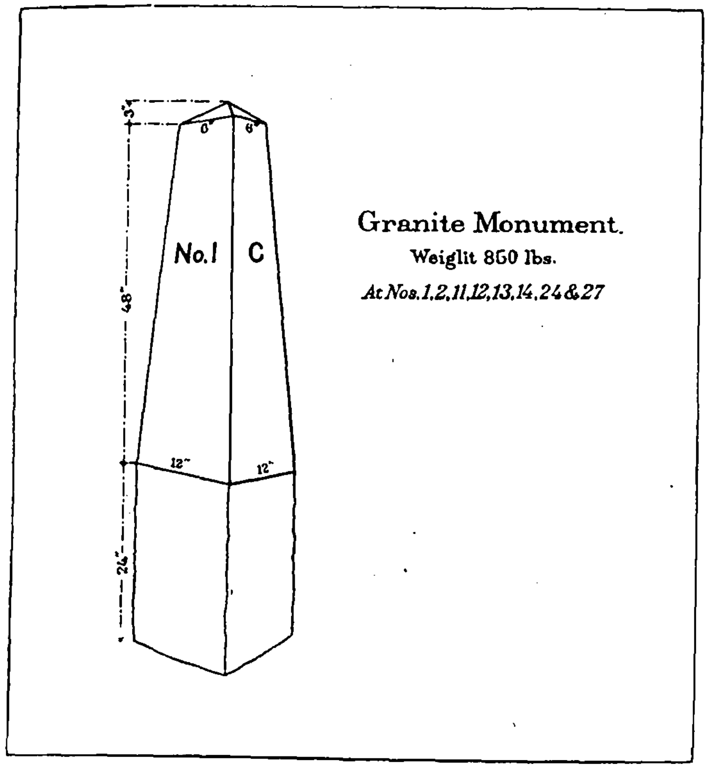
	° ′ ″	s	3·797385	s^2	7·595
½ (φ + φ)	38 58 53	Cos α	9·819057	Sin² α	9·752
		B	8·510927	C	1·313
	″	h	2·127369		8·660
First term	+134·08				
Second term.	+ ·05				
—Δφ	+134·13				

s	3·797385		
Sin α	$9·876168_n$		
A	8·509146	Δλ	2·2920
sec φ′	0·109269	Sin ½ (φ+φ′)	9·7987
	$2·291968_n$		2·0907
	″		″
Δλ	195·87	—Δα	123·2

VII. DESCRIPTION OF STATIONS ON THE RANDOM AND CORRECTED LINES CALIFORNIA AND NEVADA OBLIQUE BOUNDARY.

No. 1 (initial 1894).

This station was established in 1894 on the shore of Lake Tahoe, and marked by a granite stone with a copper bolt in it. The stone projects about 14 inches above ground, and was not disturbed when a granite monument was placed alongside it in June, 1899. The monument was set in concrete, and the hole was enlarged so as to include the old stone in the concrete mass. Being the first stone in the oblique boundary, it was called "No. 1."



The monument is of granite 6 feet long, 12 by 12 inches at the base and 6 by 6 inches at the top; weight about 850 pounds. (See illustration.)

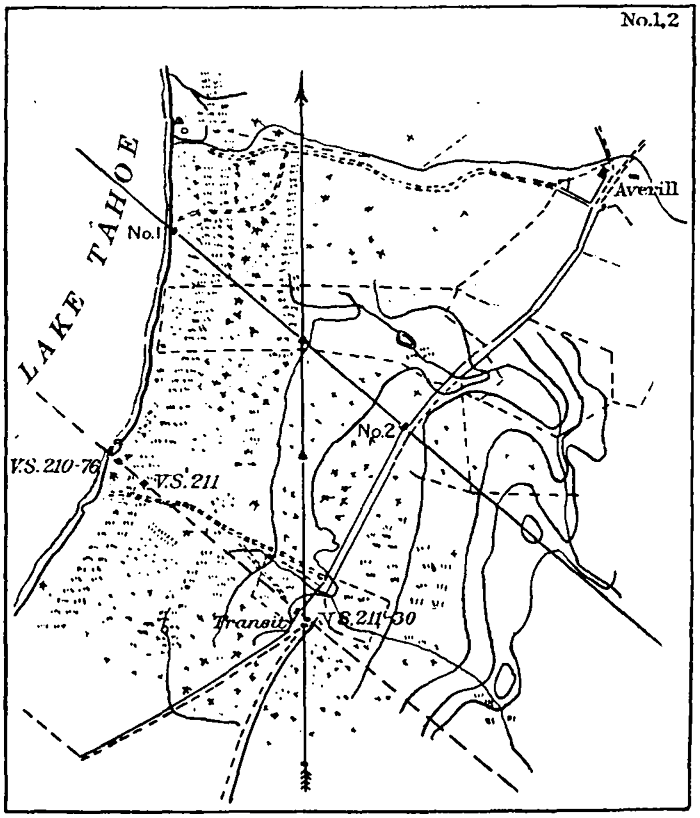
The boundary monuments are designated as No. 1, No. 2, etc., the marks on the random line as T 1, T 2, etc., counting from Lake Tahoe.

The monument has "C" cut on the California side, "N" on the Nevada side, and "No. 1" marked on the northwest face in black paint.

The old "T_1" (turning point and azimuth station, 1894), was not disturbed, but it is not called a line mark, as it is too close to "No. 1" and "No. 2" (at the road), which are about 834 meters apart. It is marked by a copper bolt in a granite block projecting 12 inches above ground, as described in the work of 1894.

No. 2.

This is a line station and is on the north side of the road that runs from Glenbrook to Bijou. It is about one-half mile northeast of the Lake Side Hotel. △ is marked by a granite post, 10 inches by 10 inches by 6 feet, set in ground just outside the fence line. Stone projects above ground 1 foot, and a copper bolt in top marks the station.



This point was marked by a granite monument, like the one at "No. 1," placed alongside the granite block with copper bolt, which was not disturbed. The monument has "C" cut on the California side, "N" on the Nevada side, and "No. 2" painted in black on the northwest face. A large pine tree, 3 feet in diameter, stands about 6 feet southeast of monument on line. A triangular blaze was cut on this tree on the northwest side and one at the southeast side.

T 3.

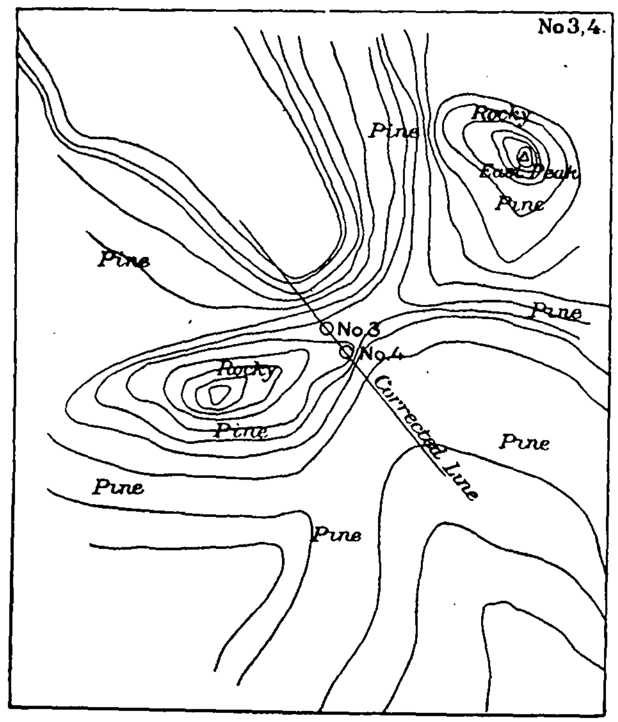
This station is located on the northern slope of a spur putting out northwest from the main range and about 300 yards northwest of the first summit. The slope is rocky, bare of grass, and covered with tamarack and yellow pine timber. The station overlooks Lake Tahoe to the northwest and Castle Rock to the north. The country road on east side of lake is about 2 miles northwest, and Kingsbury grade crosses summit of range about 3 miles northeast of this station.

The signal rests on a rock, 3½ by 7 feet, that projects 1 foot from above surface of ground. A 1-inch hole drilled into the rock marks the triangulation station.

The point on the corrected line, called "No. 3," was placed 90° from line to the eastward 0·82 meters, thence 0·5 meter northwest in the direction of the line. Marked by drill hole in solid rock. A pine post, marked "C. N. 3," was set up over hole and a cairn built around post.

T 4.

Located about 100 yards northwest of the summit of first ridge southeast of Lake Tahoe; ridge bears nearly north and south. This station is nearly 300 yards southeast of station "T 3" and overlooks Lake Tahoe on the northwest. The ground slopes to



north and is sandy and rocky, and the timber is tamarack. Station is on a granite rock, 5 by 5 feet, that projects 2 feet above the surface of ground, and is marked by a drill hole in said rock.

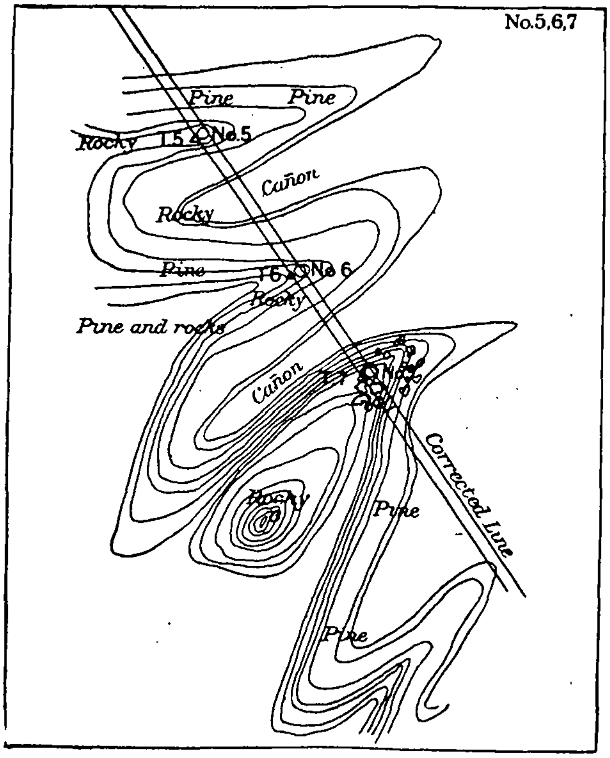
The point on the corrected line, "No. 4," was put in at right angles to the line from the above station, to the eastward, distant 0·88 meter, and was marked by a drill hole in the same rock. A pine post marked "C. N. 4," and a cairn around it marks the station.

T 5.

This station is located on crest of main ridge between Lake Tahoe and Carson Valley. Course of ridge is nearly north and south, and the summit is a regular backbone of large rocks, some of them projecting 20 feet high. The station overlooks Carson

Valley on the east and southeast and the mountains beyond. It is about 6 miles south of the crossing of the summit by the Kingsbury Grade. Trail follows up ridge, passing to the northwest of flume reservoir 4½ miles after leaving Kingsbury Grade. Station is on a large granite rock, marked by a drill hole, and a cairn 5 feet high and 5 feet at base was built on line 6 feet northwest of station.

The point on the corrected line, to be called "No. 5," should be at right angles to this station, to the eastward, and distant 1·11 meters. At the time this station was visited, in June, 1899, the snow was 15 feet deep over the station, and it was not practicable to put in the corrected point.



T 6.

This station is located on the rocky crest of spur that extends northeast from main ridge and is about 100 feet lower than the crest at station "T 5." Can be reached most easily by following around side of ridge to southeast from station "T 5." It overlooks Carson Valley to the east and southeast.

The station is on a large rock, marked by a drill hole, and a cairn 5 feet high and 5 feet at base was built on line 6 feet northwest of station.

The point on the corrected line, to be called "No. 6," should be at right angles from the line at this station, to the eastward, distant 1·26 meters. When the station was visited in June, 1899, it was not found practicable to put in the corrected point, as the snow was 15 feet deep over the station, even the signal pole being out of sight.

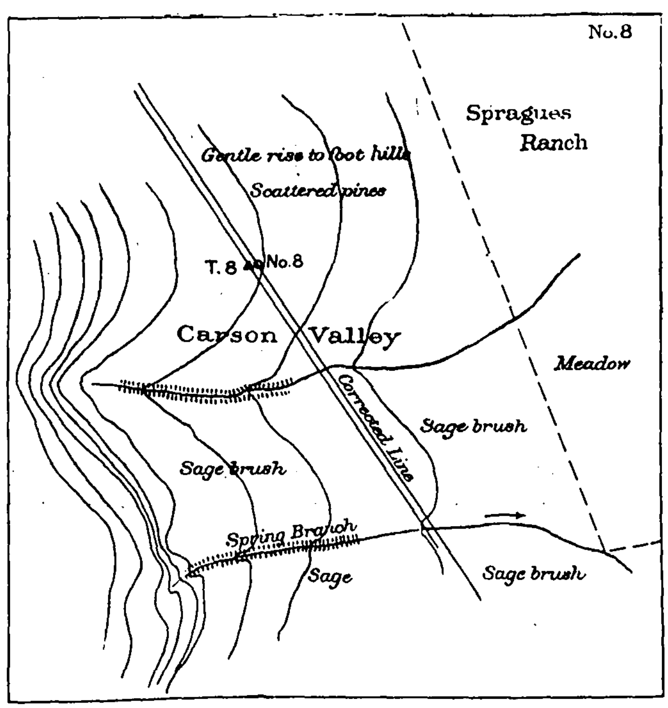
T 7.

This station is located on a bold, rocky spur that puts out from the main range in a northeasterly direction. The point of intersection with the main range is a high peak, known as "Monument Peak." From this station a fine view can be had of Carson Valley to the east and southeast, and the mountains beyond. The road along the west side of Carson Valley runs along foot of mountain, about 2 miles below the station. It can be reached most easily by following along east side of ridge from station "T 5." Station is on a large granite rock that projects about 10 feet above the general surface of the spur, and is marked by a hole drilled in the rock. A rock, 25 feet higher than station, is 15 feet southwest of same.

The point on the corrected line, "No. 7," was put in at right angles from the line, to the eastward, distant from triangulation station 1·41 meters, and was marked by a drill hole, the hole being about 1 foot from the north edge of rock. A pine post, marked "C. N. 7," was placed in center of rock 1·4 meters south of drill hole, and around post was built a cairn, the station being too near the edge of the rock to admit of the cairn being built over it.

T 8.

This station is located on the brow of a low spur projecting eastward from the main range, and from which the line leaves the foothills and enters Carson Valley. The

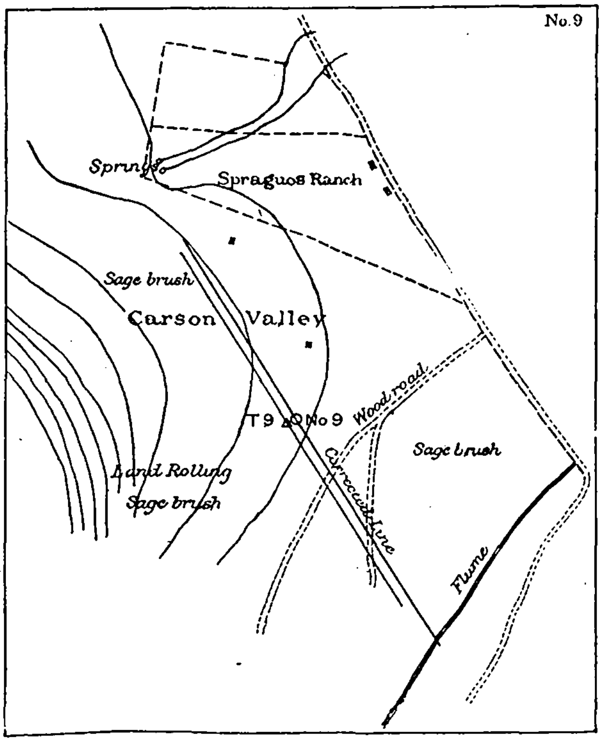


county road along west side of Carson Valley runs one-half mile east. Station was marked by a pine stake driven down to the surface of ground.

Point on corrected line, "No. 8," put in at right angles from line, to eastward, distant 3·15 meters, marked by a drill hole in a granite rock, and by a pine post 8 inches in diameter and 7 feet high, marked "C. N. 8," placed over drill hole. A sand mound 5½ feet high and 12 feet in diameter was thrown up around post. A circular trench was made outside of the mound.

T 9.

This station is located at the edge of the foothills on the west side of Carson Valley, just west of the Sprague ranch, and about a quarter of a mile west of the county road that runs along the west side of Carson Valley. It is in the sagebrush, ground rolling and sandy, marked by a pine stake 5 inches in diameter, driven within 5 inches of the surface of the ground.



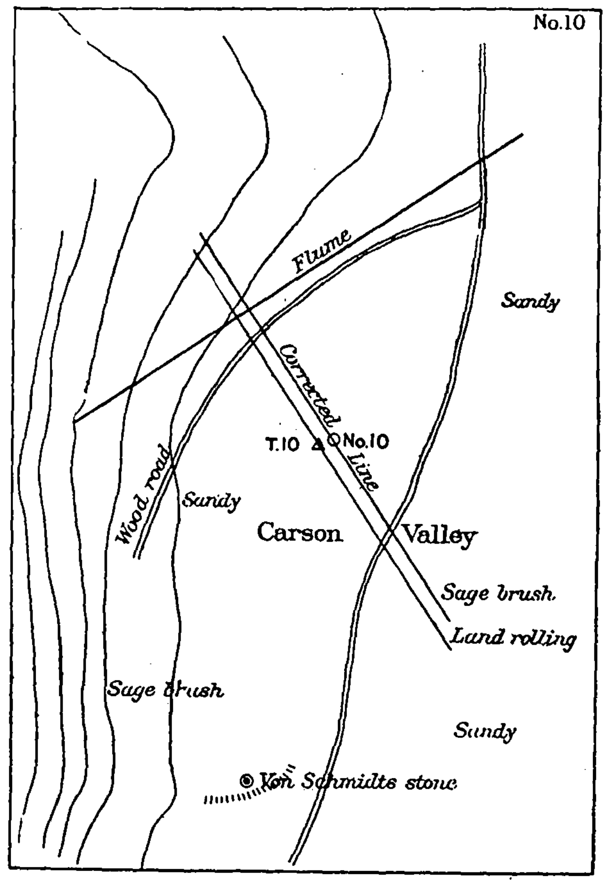
Point on corrected line, "No. 9," put in at right angles to line, to the eastward, distant from triangulation station 3.57 meters, and marked by drill hole in granite rock. Over hole was placed a cedar post 8 inches in diameter and 7 feet long, marked "C. N. 9." A sand mound 10 feet in diameter and 5 feet high was thrown up around post. A circular trench outside of mound.

T 10.

ANGLES.

	°	′
Station "T 7"	259	57
Gable of Sprague's east barn	282	45
Cupola of Fay's red barn	320	56
Cupola of schoolhouse	2	43
North chimney of Baldwin's house	67	55
Von Schmidt's cairn, west of Baldwin's house	90	50

This station is located about a quarter of a mile east of the Fairview ranch house (Fay's) and about 500 yards west of the main road on the west side of Carson Valley. The land is rolling and covered with sagebrush. A grove of small, scattered cottonwood trees is about a hundred yards west of this station, and the ground immediately surrounding the station is covered with rocks and bowlders. The triangulation station is on one of these rocks, and is marked by a hole drilled in the rock.



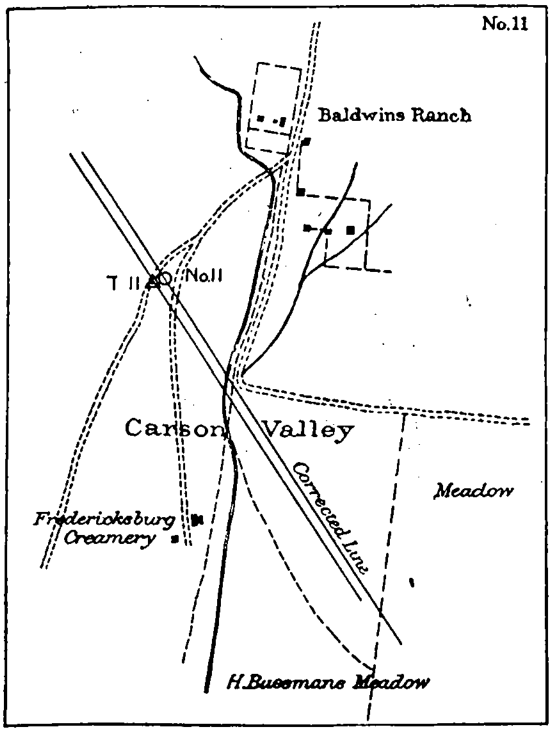
Point on the corrected line, called "No. 10," was put in at right angles from the line, to eastward, distant from triangulation station 3·91 meters, marked by drill hole in a flat granite stone, and by a cedar post 8 inches in diameter and 7 feet long, marked "C. N. 10." A cairn 5½ feet high and 6 feet in diameter at base was built around cedar post.

T 11.

ANGLES.

	°	′	″
Station "T 7"	0	00	00
Genoa cone	332	13	30
Northeast chimney of Baldwin's house (center)	299	56	30
Southeast gable of Baldwin's barn	283	51	15
Northeast cupola, dairy (Wilson's)	153	35	15

This station is located about 300 yards southwest of Baldwin's house and about 200 yards northeast of Fredericksburg creamery, at the forks of the county road, one road going to the creamery and the other bearing higher up on the higher ground



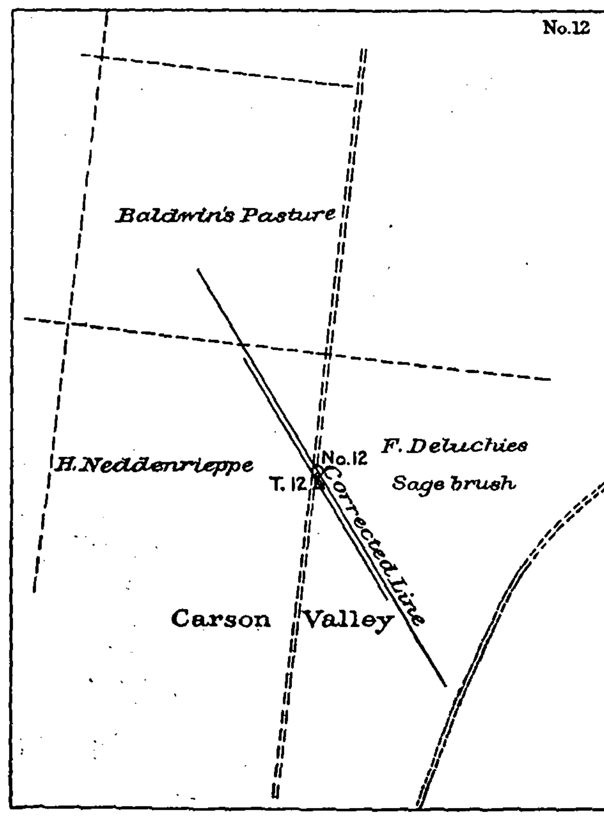
along the west side of the Carson Valley. The ground surrounding is rolling and sandy, covered with sagebrush. The triangulation station is marked by a pole 5 inches in diameter, around which was built a cairn 6 feet high and 4 feet at base.

Point on corrected line, "No. 11," put in at right angles to line, to eastward, distant 4.23 meters from triangulation station; marked by a cut granite monument, similar to the one at "No. 1," on the lake shore. The top of monument was broken off and fastened together again with hoop iron. "C" cut on California and "N" on the Nevada side. A cairn was built up around the monument, and some stones were left around the old triangulation station; "No. 11" painted on northwest face.

T 12.

This station is located east of the county road, on the F. Deluchies' ranch, about one-fourth mile from West Branch of Carson River. The ground surrounding station is nearly level and covered with sagebrush, and the soil is sandy, covered with small bowlders, projecting here and there, scattered over the surface. Station was marked by a post 6 inches in diameter, projecting 8 inches from the ground.

Point on corrected line, "No. 12," put in at right angles to line, to eastward from triangulation station, distant 4·77 meters, thence 3·35 meters to northwest parallel to

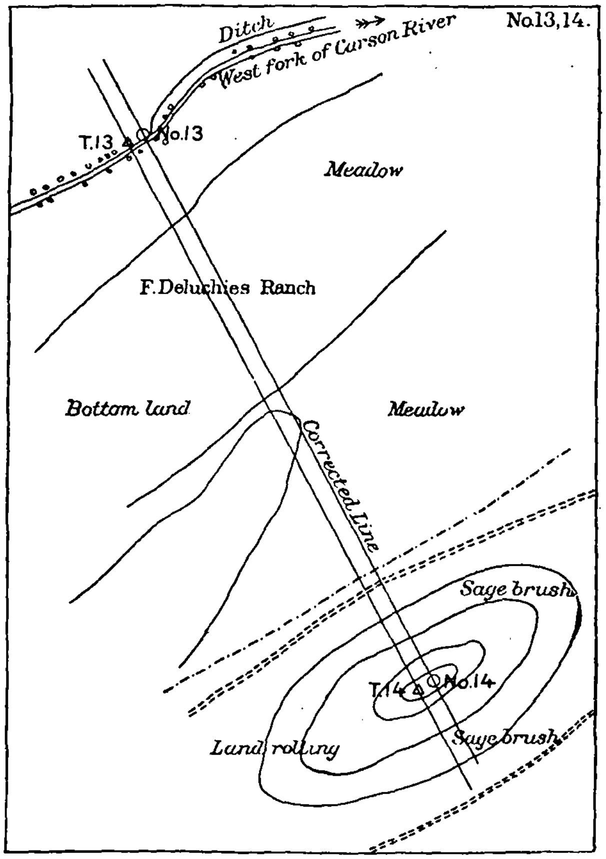


line, so as to place it 18 inches from the east fence line and in the road. Marked by cut granite monument, similar to No. 1. "C" cut on the California side, "N" on the Nevada side, and "No. 12" painted on the northwest face.

T 13.

This station is located about one-fourth mile south of F. Deluchies' house, on the west bank of West Branch of Carson River. Ground is rolling and sandy, with some projecting bowlders. An irrigation ditch leaves the river near the station, and the dam for the same here crosses the river. Station was marked by a post 6 inches in diameter, projecting 6 inches above the ground.

Point on corrected line, "No. 13," put in at right angles to line from old station, to eastward, distant 4·90 meters, marked by a cut granite monument, similar to the one at No. 1. It is on the west side of the West Fork of the Carson River, about 8 feet from the edge of trees. "C" cut on California side, "N" on Nevada side, and "No. 13" painted in black paint on northwest face.



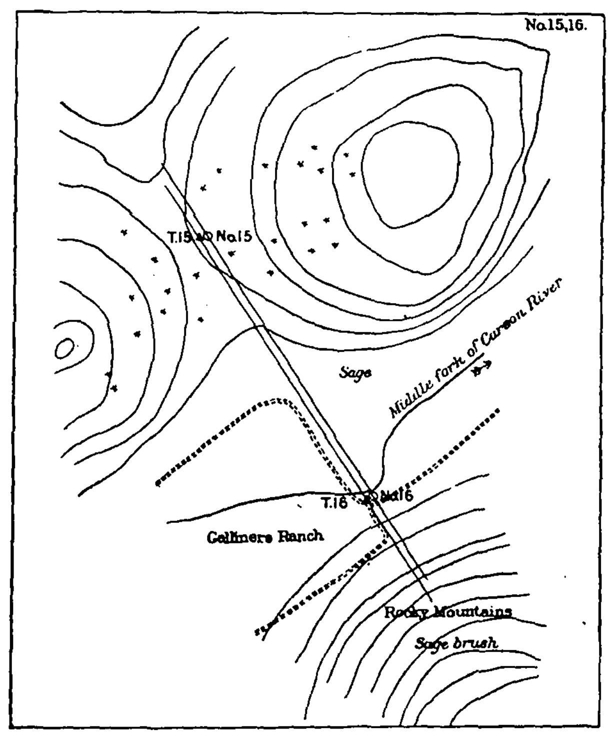
T 14.

This station is located on the first low ridge on the east side of Carson Valley, about three-fourths mile from the crossing of the West Branch of Carson River and about 200 yards east of the road on east side of valley that goes to Diamond Valley. The land surrounding the station is rolling and covered with sagebrush, and the soil is sandy, with some gravel, rocks, and bowlders.

Point on corrected line, "No. 14," put in at right angles to the line, to the eastward from old station, distant 5·14 meters, marked by a cut granite monument similar to the one at No. 1. "C" cut on the California side, "N" on the Nevada side, and "No. 14" painted in black on northwest face.

T 15.

This station is located on summit of the low divide between Diamond or Dutch Valley and the valley of the West Branch of the Carson River. It is about three-fourths mile north of Mr. George Galliner's house and about one-fourth mile northwest of the road on west side of Dutch Valley. The land at triangulation station is rocky



and is covered with sagebrush and scattering scrub cedars and pine. Station marked by a post 4 inches in diameter, projecting 6 inches above ground.

Point on corrected line, "No. 15," put in at right angles from old station, to the eastward, distant 5·76 meters, marked by a drill hole in a stone, and a pine post, 2 inches by 4 inches by 4½ feet, marked "C. N. 15." Around post was built a cairn 5 feet high.

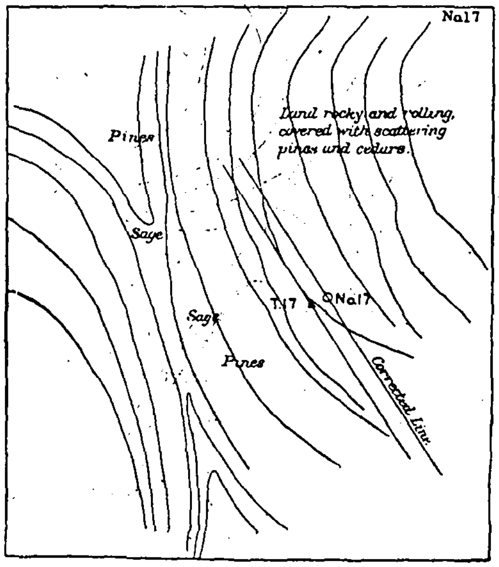
T 16.

This station is located on the east side of the Middle Fork of Carson River, 50 feet from the bank of the stream and 50 feet from the road running down the valley. It is about 200 feet north of the north fence of Galliner's ranch and about one-half mile north from his farm buildings. Station was marked by a post 5½ feet high and 7 inches square, marked "U.S.C.& G.S." on northwest, "Cal." on southwest, "1894" on southeast, and "Nev." on northeast. The land around station is sandy and covered with sagebrush.

Point on corrected line, "No. 16," put in at right angles to line from old station, to the eastward, and distant 5·94 meters, marked by a drill hole in a stone and a post marked "C. N. 16." Around post a cairn was built 4½ feet high.

T 17.

This station is located on the summit of the divide between the Middle and East forks of the Carson River, about a mile southeast of the Middle Fork and about one-fourth mile north of the county road running from the Middle Fork to the East Fork, and about 1½ miles northeast of George Galliner's house. The land at station is rocky, and there are scattered, stunted pine trees. Triangulation station is marked by

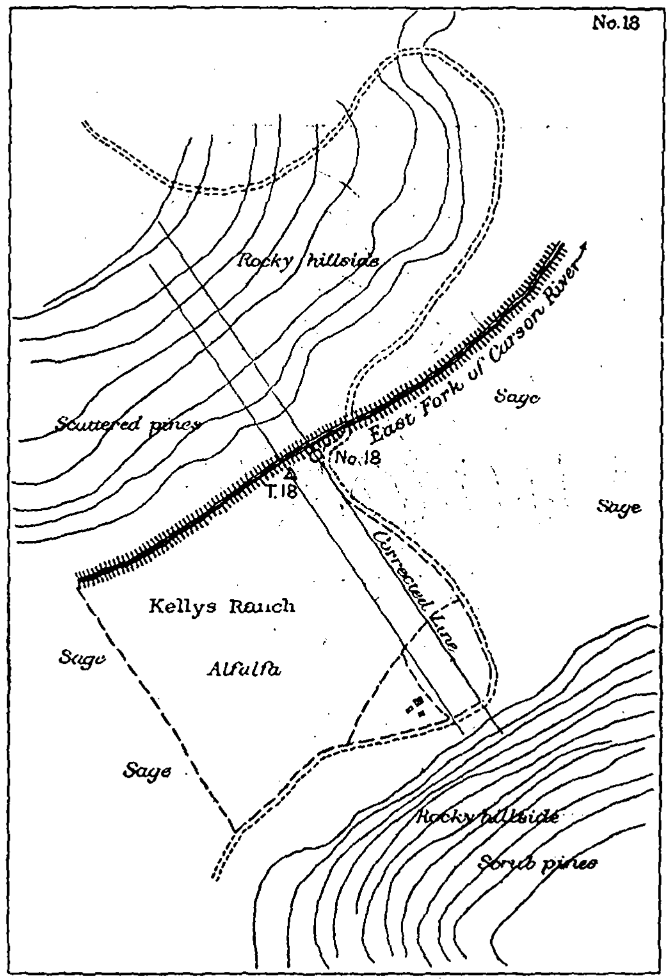


a hole drilled in a rock, projecting 8 inches above surface of ground. A 65-foot pole was erected at this triangulation station in order to be seen from Rock Cliff triangulation station, and rocks were piled around the foot of it.

Point on corrected line, "No. 17," put in at right angles to line from old point, to the eastward, and distant 6·33 meters, marked by a drill hole in flat rock and a pine post marked "C. N. 17." Around post there was built a large cairn.

T 18.

This station is located on the east bank of the East Fork of the Carson River, on the Kelley ranch, just south of the wire fence on the north side of the ranch and about one-fourth mile northwest of Kelley's house. Land around station is rolling, soil sandy and covered with sagebrush. Triangulation station was marked by a post 5 by 8 inches and 6 feet high, "Nev." on northeast, "U.S.C. & G.S." on northwest, "Cal." on

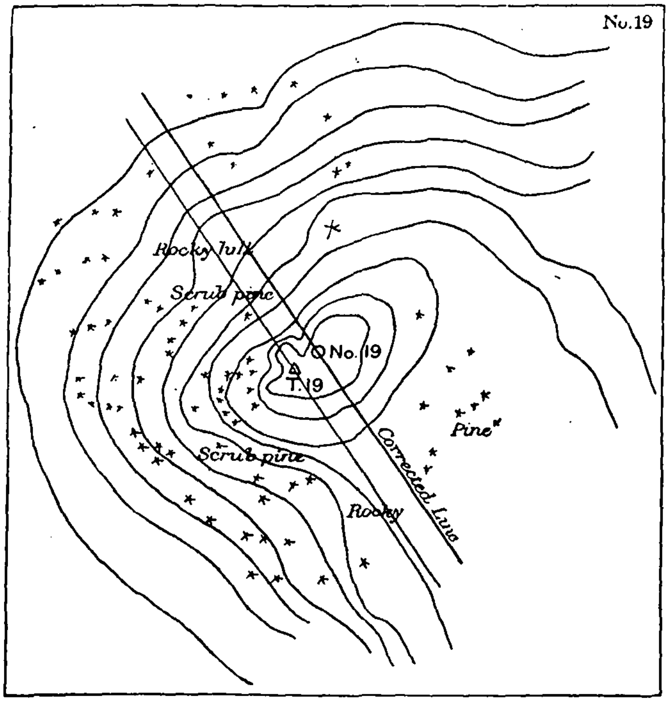


southwest, and "1894" on southeast. A cairn 5 feet high and 4 feet base was built around post. The road from Diamond Valley to Kelley's ranch runs 50 feet north of station.

Point on corrected line, "No. 18," put in at right angles to line from old station, to the eastward, and distant 6·79 meters, marked by drill hole in a circular stone and a pine post marked "C. N. 18." Around post was built a cairn. Point is on the fence line, on the north side of the Kelley ranch.

T 19.

This station is located on the first ridge east of the East Fork of the Carson River, about one-half mile southeast of the Kelley ranch, from which the pole that marks it can be seen. A trail to station leaves the road at Kelley's ranch. The station is on a rocky part of the ridge, there being many large rocks and bowlders projecting from the

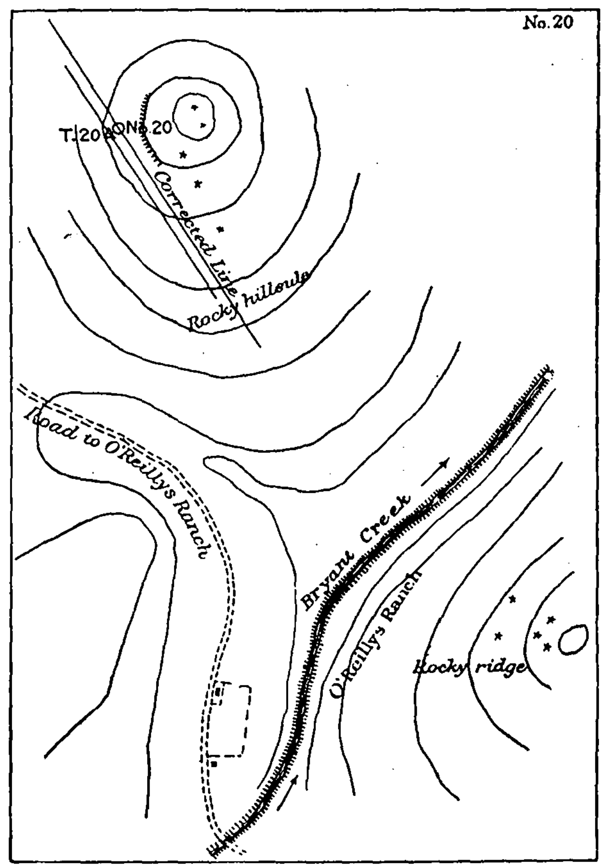


ground, on one of which the triangulation station is marked by a hole drilled in the rock. The northwest side of ridge is covered with second-growth pine timber; on the summit the timber is more scattering.

Point on corrected line, "No. 19," put in at right angles to line from old station, to eastward, distant 7·08 meters, marked by drill hole in stone and pine post marked "C. N. 19." Around post there was built a large cairn. The pole at the old station was left standing.

T 20.

This station is located on the south side of a low rocky butte that is on the west side of Bryant Creek and just west of Barney O'Reilley's ranch. Triangulation station is about a mile west of O'Reilley's house and about one-fourth mile from the road running from east fork of Carson River to O'Reilley's. Triangulation station is about 100 feet lower than the highest point of the butte. Land is rocky, slopes to the south, and is

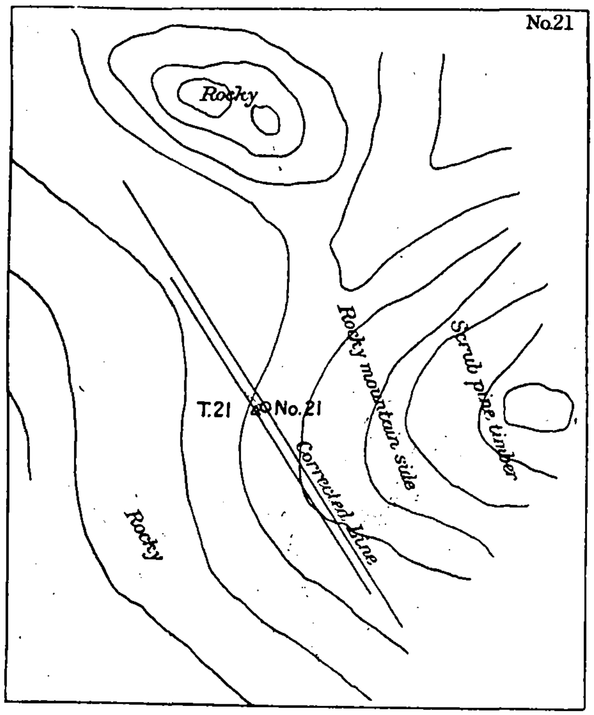


covered with scattered sagebrush, with a few small pines. Triangulation station is marked with a 4-inch pine pole, around which is built a cairn 4 feet high and 4 feet base.

Point on corrected line, "No. 20," put in at right angles to line from old point to the eastward, and distant 7·35 meters, marked by a drill hole in a stone, and a pine post marked "C. N. 20." Around post was built a large cairn.

T 21.

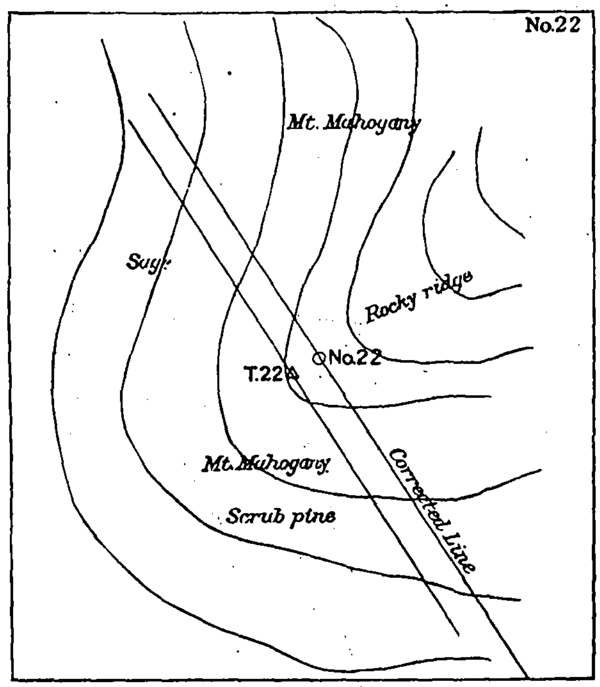
This station is located on the north side of Bryant Creek, on the southwest slope of a steep bluff, almost bare of vegetation and covered with small bowlders and loose rock. It is about 400 feet above the bed of the creek and more than that below the summit of the ridge. It is about 1½ miles up the creek from O'Reilley's house. The triangulation station is marked by a 5-inch dry pine pole, around which was built a cairn 5 feet high and 4 feet base.



Point on corrected line, "No. 21," put in at right angles to line from old station to the eastward, and distant 8·02 meters, marked by drill hole in stone. A pine pole 5 feet long, marked "C. N. 21," and around pole a cairn was built.

T 22.

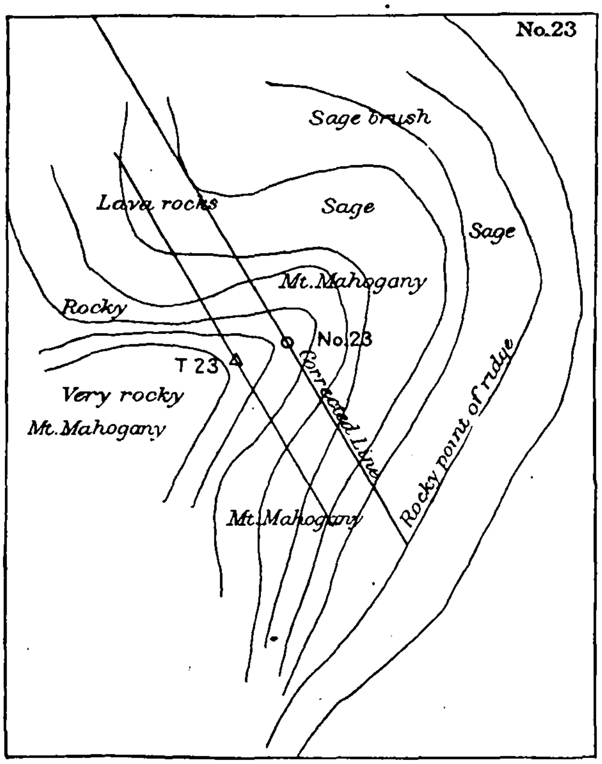
This station is located on the summit of the main ridge between Carson River Valley and the west fork of Walker River, on the brow of the ridge and about half a mile north of Bryant Creek Cañon, and overlooking Carson and Walker River valleys. Station is about 2 miles southwest of Mountain House, on the Carson and Bodie road, and is reached from there by a pack trail going up first cañon to the northwest of Mountain House, about a mile to foot of ridge, thence south up the ridge to flat on mountain, thence west on flat and low ridge to main ridge, thence along side of main ridge to station on point of mountain. Land at triangulation station is rocky, with some sagebrush, mountain mahogany, and small pines. Station is marked by a hole drilled in solid rock, a pole 6 inches in diameter, and a cairn around same, 6 feet high and 5 feet base.



Point on corrected line, "No. 22," put in at right angles to the line from old station, to the eastward, and a mountain mahogany post 6 feet long, marked "C. N. 22." Around post there was built a large cairn.

T 23.

This station is located on the summit of the first ridge to east of the main divide between Carson and Walker River valleys, is about a mile southeast of Knoll triangulation station, and is 300 or 400 feet higher than that station. It overlooks the valley of Walker River and Alkali Lake. It is easily reached from Mountain House, by trail to flat on mountain, thence 1½ miles southeast by easy ascent round ridge to station.

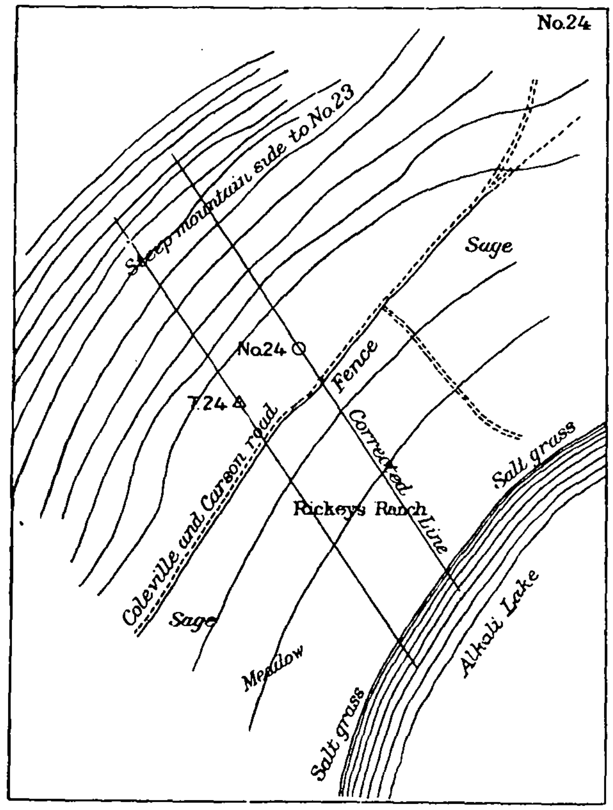


The land at station is rocky and covered with thicket of mountain mahogany. Triangulation station is marked by a hole drilled in rock, projecting above ground. A pole 6 inches in diameter was erected, and cairn 5 feet high and 4 feet base built.

Point on corrected line, "No. 23," put in at right angles to line, from old station to the eastward, and distant 10·07 meters, marked by a drill hole in stone and a pine post marked "C. N. 23." Around post a large cairn was built.

T 24.

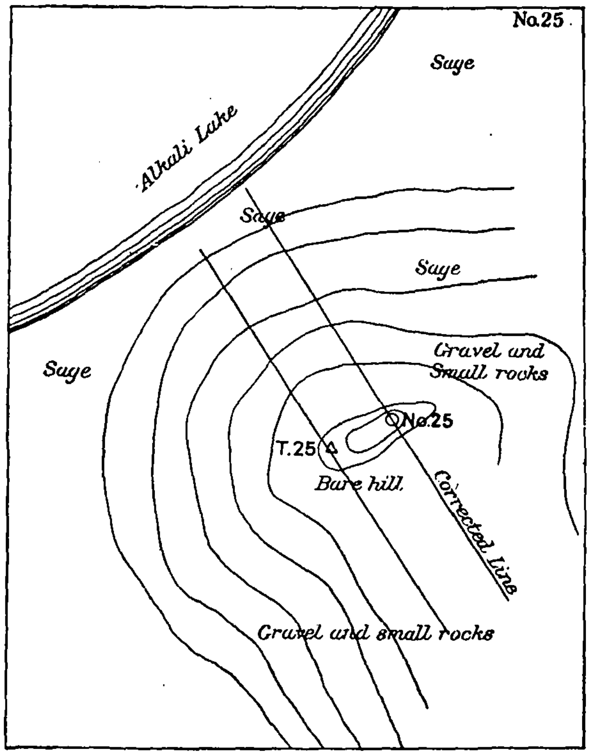
This station is located on northwest side of Alkali Lake, about one-fourth mile from same, and just west of the Carson City and Coleville road, at the foot of steep side of mountains. Station was marked by a pole, with cairn 4 feet high and 4 feet base built around it.



Point on corrected line, "No. 24," put in at right angles to line from old station, to eastward, distant 10·79 meters, and was marked by a cut-granite monument similar to the one at "No. 1." "C" is cut on California side, "N" on Nevada side, and "No. 24" painted in black on the northwest face. A cairn was built around monument

T 25.

This station is located on the summit of the first hill southeast of Alkali Lake, about one-fourth mile from the edge of the lake and about the same distance north of the wire fence on the north side of Thomas Rickey's hay meadows, and about 3 miles from ranch buildings. Triangulation station is just in Antelope Valley, on the north side, and is some 4 miles from Mountain House.



Point on corrected line, "No. 25," put in at right angles to line from old station, to the eastward, and distant 11·34 meters; marked by drill hole in stone and pine post marked "C. N. 25." Around post was built a large cairn.

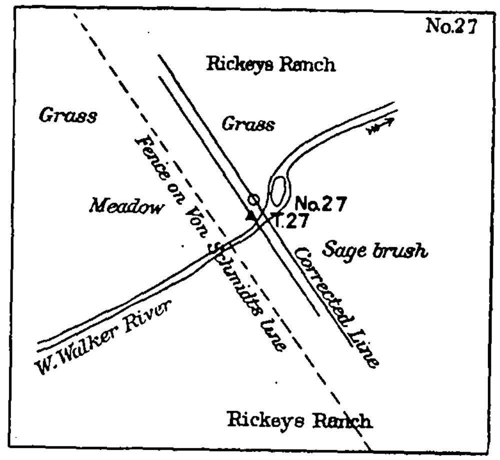
T 26.

This station was only used as a temporary one in 1894.

T 27.

This station is located on the west side of west branch of Walker River, in the hay meadow of the Rickey ranch, about 2 miles below the ranch house, and about a mile southeast of the main road of the ranch running up valley. The triangulation station is marked by a post 6 inches diameter, projecting 6 inches above ground. Here the valley of the West Walker River is called Antelope Valley; is owned almost entirely by Thomas Rickey, and is a great cattle ranch, and a large quantity of hay is grown.

Point on corrected line, "No. 27," put in at right angles to line from old station, to eastward, distant 12·21 meters, thence 39·37 meters in a northwest direction parallel to the line to get on good ground on the bank of West Walker River. Point was marked



by a cut granite monument, similar to the one at "No. 1." A circular ditch, 12 feet in diameter, was cut around monument, and a mound of earth 4 feet high thrown up. "C" cut on California side, "N" on Nevada side, and "No. 27" painted in black on the northwest face.

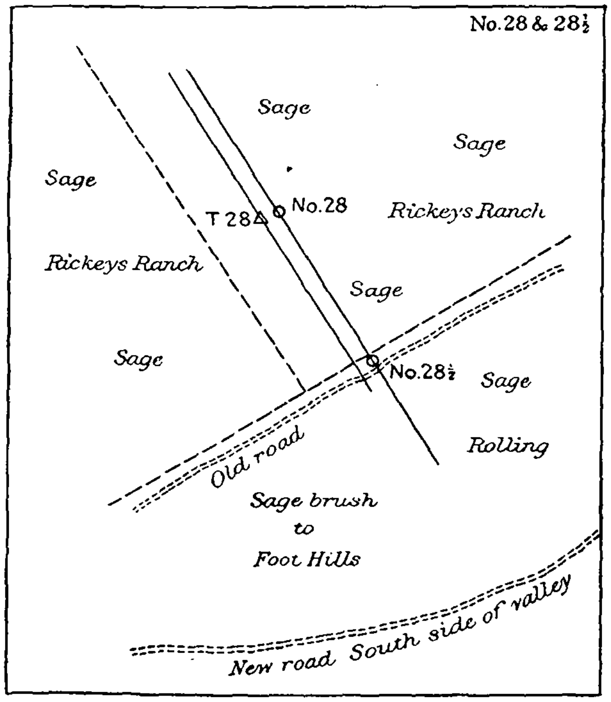
T 28.

This station is located on the southeast side of the west branch of Walker River, Antelope Valley, about 2 miles southeast of the stream and about 1 mile northwest of the edge of the foothills. The wire fence on east side of Rickey's ranch is one-fourth mile southeast of station. An old road running through the valley north and south is just outside of this fence, and the new road is about one-half mile to the southeast of this road, and runs along at the edge of the foothills. Station was marked by a post projecting 6 inches above the ground.

Point on corrected line, "No. 28," put in at right angles to line, from old point, to the eastward, and distant 13·09 meters. Station marked by a cedar post 7 feet long and 8 inches in diameter, set in the ground and marked "C. N. 28." Southeast of post and touching it was placed a large stone with drill hole in it. A circle of stones was laid around post 6 feet in diameter and a mound of gravel thrown up around post and stone. Station is about 2 miles south of the Rickey ranch house.

No. 28½.

This station was lined in from stations "No. 27" and "No. 28," and the distance measured from "No. 28" with a steel tape. It is 494·5 meters southeast of "No. 28," 15 feet southeast of the wire fence, on east side of Rickey's ranch, and 15 feet northwest of the old road through Antelope Valley, north and south from Rickey's ranch to Wellington. One-half mile southeast of this road is the new road through the valley from Coleville to Wellington, running along at the edge of the foothills and clear of the Rickey ranch. Station was marked by a cedar post 7 feet long and 8 inches in diameter, marked "C. N. 28^2," set in the ground 2 feet. A stone with drill

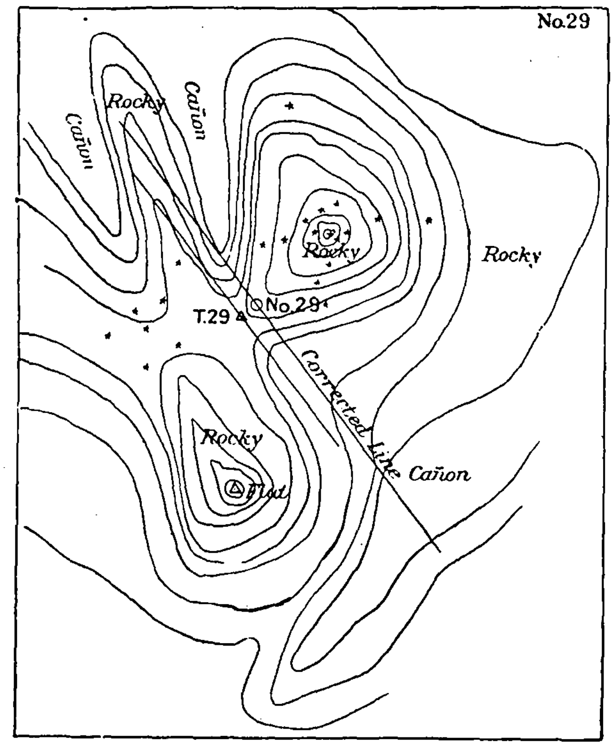


hole in it was placed southeast, touching post. A circle of stones 6 feet in diameter was laid around post and stone, and a mound of gravel thrown up about them.

T 29.

This station is located on the first wooded ridge to the west of the main range between the Sweetwater and West Walker river valleys. It is in a saddle and about 300 yards to the north of the bare peak on which is located triangulation station Flat. The land at the station is rocky and covered with scrub piñon timber. The triangulation station is about 7 miles east of Topaz, or the Rickey ranch, and is reached from there by following up their wood road into the mountains about 4 miles, thence up pack trail through ravine to top of ridge and station. Triangulation station marked by a hole drilled in a rock. A pole 5 inches diameter was erected and cairn built around it. The trail up to the station is very steep and rocky.

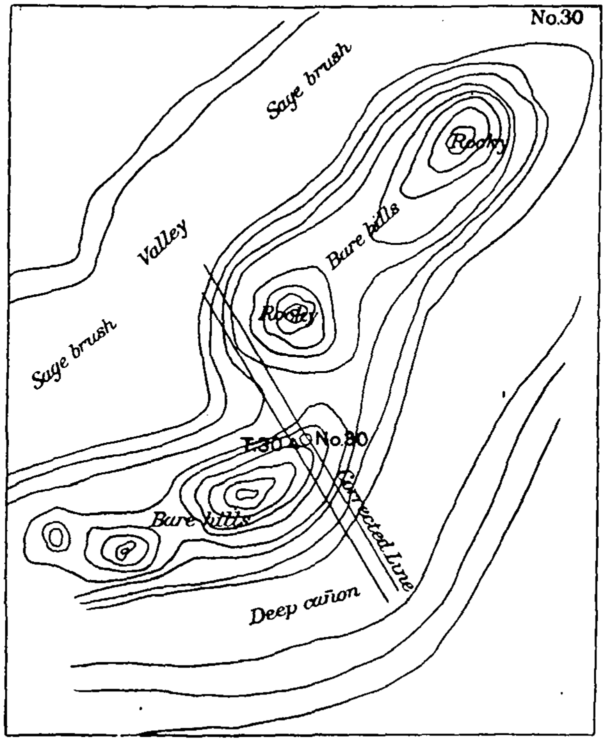
Point on corrected line, "No. 29," put in at right angles to line, from old point, to the eastward, distant 14·97 meters, thence 5·39 meters northwest in the direction of



the line, in order to place point on top of ridge. Marked by drill hole in solid rock; over this is a nut-pine pole, marked "C. N. 29;" and around pole a cairn. Triangulation station is not on the highest part of hill, but on the southwest slope, about 200 yards from the summit. Point very rough and rocky, covered with nut pine.

T 30.

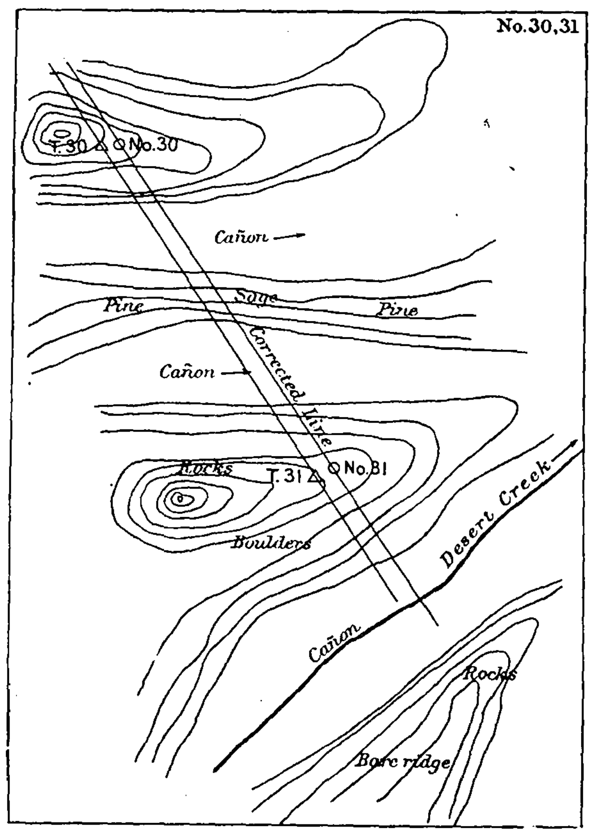
This station is located on the second prominent ridge, to the west of the main range, between the Sweetwater and West Walker river valleys. The ridge is nearly bare of vegetation, covered with gravel or small bowlders, and its course is nearly north and south. Triangulation station was marked by a hole drilled in a rock on summit of ridge, and a pole 5 inches diameter erected over same.



Point on corrected line, "No. 30," put in at right angles to line from old station, to the eastward, and distant 15·84 meters, thence 6·30 meters southeast in the direction of the line, to place the station on top of ridge. Marked by a drill hole in stone set in place and a birch post marked "C. N. 30," and around post a cairn and gravel. Triangulation station is not on the highest point of the ridge, but on the northeast slope and some 200 yards from the summit.

T 31.

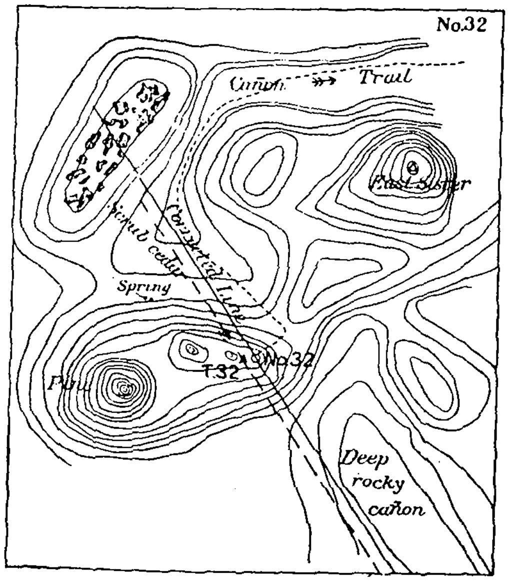
This station is located on the second highest ridge between the Sweetwater and West Walker river valleys, and is the first prominent ridge west of the main ridge and extends nearly parallel with it. It is bare of vegetation and covered with gravel, small rocks, and bowlders. Triangulation station was marked by a hole drilled in rock on summit of ridge, and a pole 6 inches diameter erected over same.



Point on corrected line, "No. 31," put in at right angles to line from old station, to the eastward, and distant 16·31 meters, thence 3·83 meters northwest in the direction of the line, to place station on a solid rock. Marked by a drill hole in solid rock, over this a pine post marked "C. N. 31," and a cairn around post. Station is on the first high ridge west of Desert Creek, where the line crosses; not on the highest point, but on the north slope, some 400 yards from summit, in a small sag.

T 32.

On the summit of the main range of the Sweetwater Mountains, on the middle of one of the three peaks known as the "Three Sisters." Triangulation station is not on the highest part of the peak, but about 300 feet below it, on the north side of same. The peak is rocky and bare of vegetation. Triangulation station is marked by a hole drilled in the solid rock, and a pole 6 inches diamater was erected above same. This peak is difficult of access, as it is very steep on all sides and high, being over 11 000

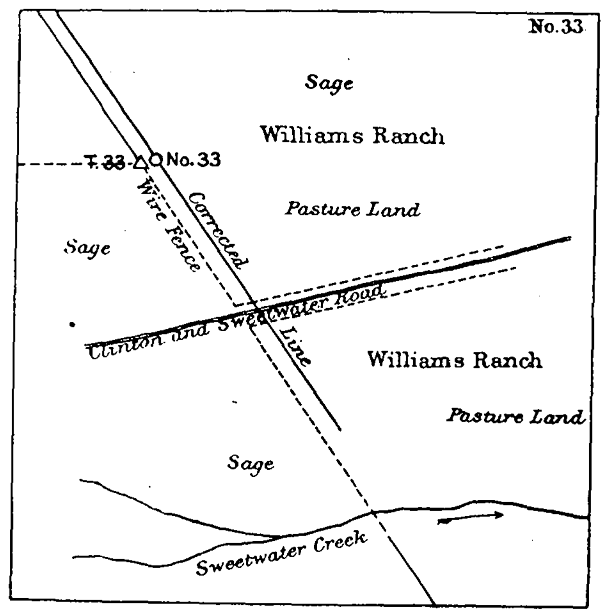


feet above sea level. It may be reached from the Williams ranch, in Sweetwater Valley, by climbing on foot the steep slope from the east side, or by leaving the Bodie road one-half mile south of Dalzells Station, and following a pack trail around north and west side of mountain to within one-half mile of station, thence up steep west slope of Middle Sister to station.

Point on corrected line, "No. 32," put in at right angles to the line from old station to the eastward, distant 17·77 meters, thence southeast 7·76 meters in direction of line, to put station on ridge. Marked by drill hole in stone set in place, and a nut-pine pole marked "C. N. 32," and a cairn 6½ feet high around post. Station is on the north slope, about 350 feet from the summit.

T 33.

In the Sweetwater Valley, on the Williams ranch, about 1½ miles west of the Sweetwater post-office, and about one-half mile northwest by the line from the road from Clinton to Sweetwater post-office. Triangulation station is at the corner of a wire fence, and is marked by a post projecting 6 inches above ground. Station is easily reached from Sweetwater post-office by following the Clinton road for 1½ miles, thence northwest along wire fence to station.



Point on corrected line, "No. 33," put in at right angles to line from old station to the eastward, distant 19·75 meters, thence 14·40 meters southeast in direction of line, to place station on highest ground. Marked by a drill hole in solid rock and a willow post marked "C. N. 33," and a cairn around pole. Station is 50 feet east of the fence corner. Ground covered with sagebrush, rocks, and small bowlders.

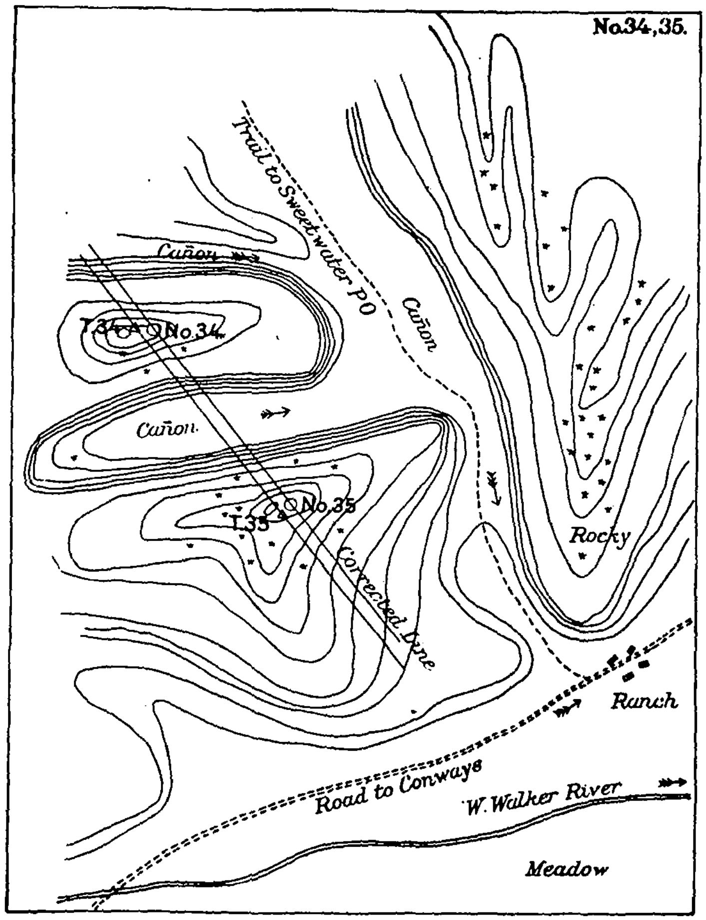
T 34.

Station is on one of the low ridges lying on the west side of West Walker River, and about 1 mile from the same. Ridge is rocky and wooded with scattering second-growth pine. Triangulation station is marked by hole drilled in rock and a pole 5 inches diameter erected over same, and cairn. Station is reached by following wood road southwest from Roache's ranch (in Sweetwater Valley) 2 miles to ridge, thence southeast on ridge to station.

Point in corrected line, "No. 34," put in at right angles to line from old station to the eastward, distant 20·99 meters, thence southeast in direction of line 13·70 meters to place station on top of ridge. Station is marked by a drill hole in stone, set in place, and a nut-pine pole marked "C. N. 34," and a cairn around pole. Station is on the second ridge northwest from the West Walker River, and only 621 meters from No. 35, which is separated from it by a deep cañon.

T 35.

On the first low ridge to the west of West Walker River, overlooking and about one-half mile from same, and also from Bridgeport road, which runs through the valley. Ridge is wooded with second-growth pine timber. Triangulation station is marked by a hole in rock, and a pole 5 inches diameter erected over same. Station is reached from Bridgeport road at Fulston's ranch by ascending a slope one-half mile west to station.

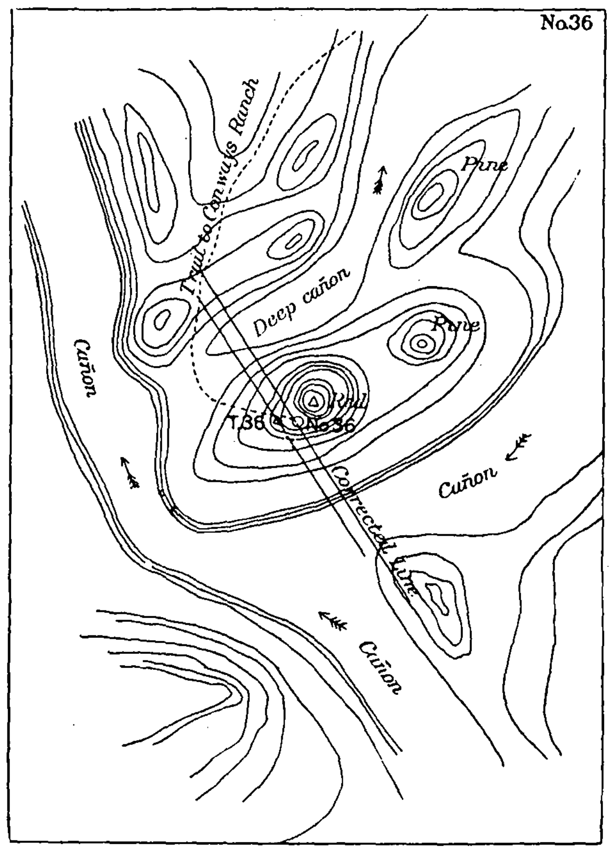


Point on corrected line, "No. 35," put in at right angles to line from old station to eastward, distant 21·14 meters, thence 8·65 meters northwest in direction of the line to place station on top of ridge. Marked by a drill hole in solid rock; over this a cedar post marked "C. N. 35," and a cairn around post. Ridge covered with nut pine and some cedar. Just northwest of this station there is a deep cañon separating T 34 from this station.

T 36.

On a wooded peak about 4 miles southeast of West Walker River. Station is not on highest part of peak, but about 250 feet to the west of the summit and some 100 feet below it. Triangulation station is marked by a drill hole in the solid rock and pole 5 inches diameter erected over same.

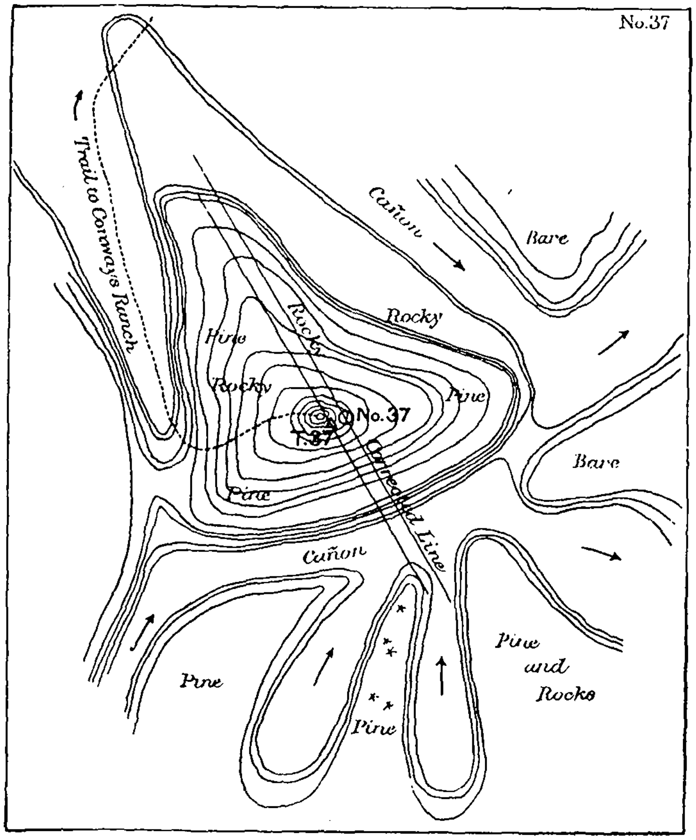
Point on corrected line "No. 36," put in at right angles to line from old station to the eastward, distant 22·45 meters, thence southeast in direction of the line 11·37 meters to place station on highest part of ridge and on a solid rock. Marked by drill hole in the rock; over this a cedar post, marked "C. N. 36," and a cairn around post.



Station is about 3½ miles south of Conway's ranch, on a high, conical, heavily wooded hill, very rocky on top and on the north side. The peak is the first high peak east of the peak known as Masonic Peak, distant about 1½ miles. From the reddish color of the soil as seen from a distance this peak is known in this locality sometimes as Red Peak. A trail and wood road from Conway's ranch goes to within three-fourths of a mile of station, which is on the western slope, about 150 feet from summit. Road ends on east side of hill. Triangulation station Red, and a Von Schmidt post, 4 feet southeast of Red Station, are on the summit.

T 37.

This station is located on a high, wooded peak 1 mile northwest of the main divide between West Walker River and the Bodie Creek depression. The sides of this peak are rocky and covered with nut-pine timber. This is one of the most prominent peaks of what are known locally as the Red Hills, and from it a view can be had of the Sweetwater and West Walker River Valley. It can be reached most easily from West Walker River by following a wood road from the Compton ranch south and southwest along a ridge heading the cañon; thence southeast, following trail in cañon to station

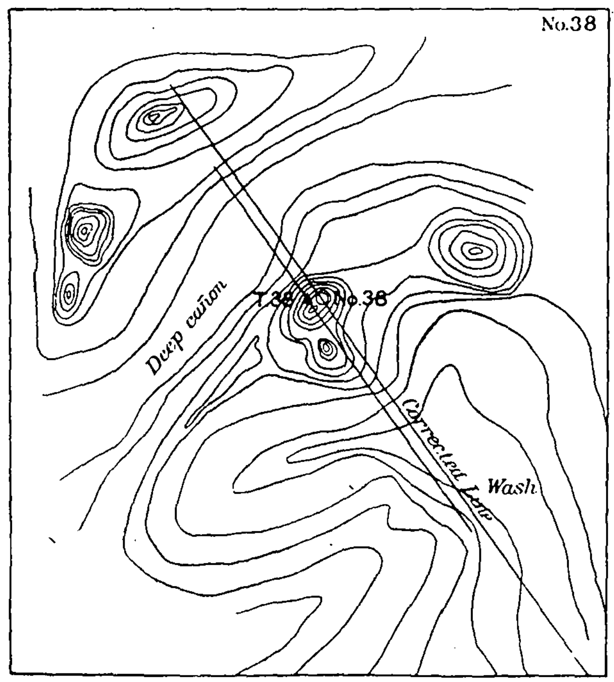


on peak. Station is not on highest part of peak, but on the northeast slope, about 100 feet below the summit. Marked by drill hole in rock, pole, and cairn.

Point on corrected line "No. 37," put in at right angles to line from old station to eastward, distant 23·43 meters; thence 1·97 meters southeast in direction of line to place station on a solid rock. Marked by drill hole in the solid rock, and willow post marked "C. N. 37," and a cairn around post. Station is on the northeast slope of the peak, about 150 yards from the summit and some 125 feet below it.

T 38.

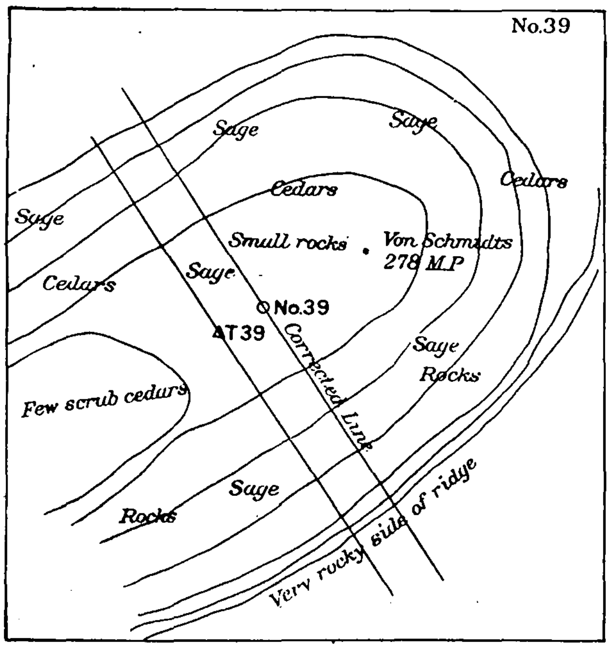
On a rocky ridge which forms part of the main divide between the West Walker Valley and the Bodie Creek watershed. It is about 4 miles northwest of the Gregory ranch, and can be reached from there by following pack trail to Chinese wood choppers' camp; thence northwest up side of ridge to station. Ridge at station is very rocky, and there are a few scrub cedars growing on summit of ridge east of station. Station is not on the highest part of ridge, but about 60 feet southwest of summit. Marked by drill hole in solid rock and pole over same.



Point on corrected line, "No. 38," put in at right angles to line, from old station, to the eastward, distant 24·03 meters, thence southeast in direction of line 6·57 meters to place station on top of peak. Station marked by drill hole in solid rock; over this a birch post marked "C. N. 38" and a cairn around pole. Peak at station is very rocky, being composed of large bowlders. Station is on the northern edge of the summit, about 20 feet north of the station "T 38 Ecc." About 400 yards south of this peak is another rocky peak on the same ridge and about the same height.

T 39.

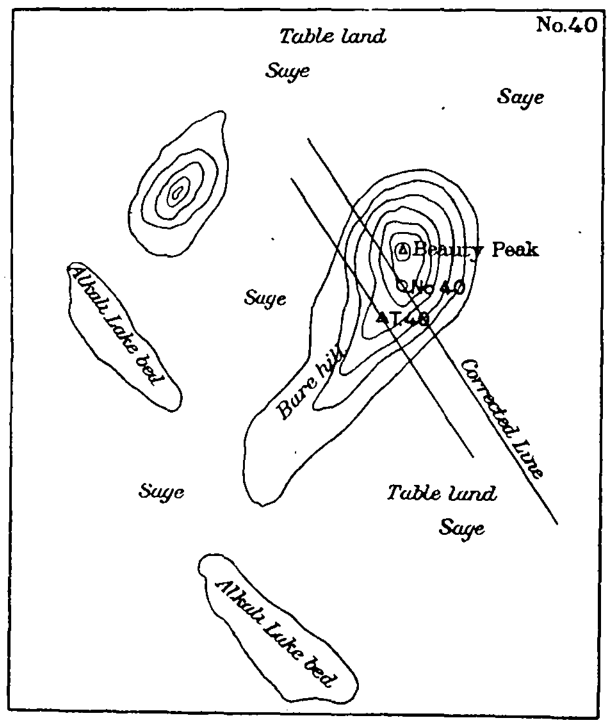
About 1½ miles northwest of Gregory's ranch, on Rough Creek, on flat, rocky ridge, the course of which is nearly east and west. Ridge at station is bare of vegetation except a few scattered scrub cedars, and stunted sagebrush. Station marked by a drill hole in rock, 4-inch pole, and cairn. Von Schmidt's "278 M. P." is about 190 yards north of this triangulation station.



Point on the corrected line, "No. 39," put in at right angles to line, from old station, to eastward, distant 25·19 meters, marked by a drill hole in a solid rock, and a pine pole over same, marked "C. N. 39," with a cairn around pole. Station is located on the flat ridge or table-land that is just north of Rough Creek, and is about 1½ miles northwest of the Gregory ranch. A trail from ranch goes up the southeast slope from Rough Creek. The station is east of the place where the trail tops the ridge or flat, and the cairn is visible from this point.

T 40.

This station is located on "Beauty Peak," a peak that rises from the table-land west of Bodie Creek, and is about 1½ miles northwest of Bodie Creek at Sunshine, and about 3 miles east of Gregory's ranch. Beauty Peak triangulation station is about 200 yards north of this station, on same peak. The ground at station is lava rock, almost void of vegetation; and station is marked by a hole drilled in the lava rock, with pole and cairn. Station is reached from Gregory's ranch by following a trail east



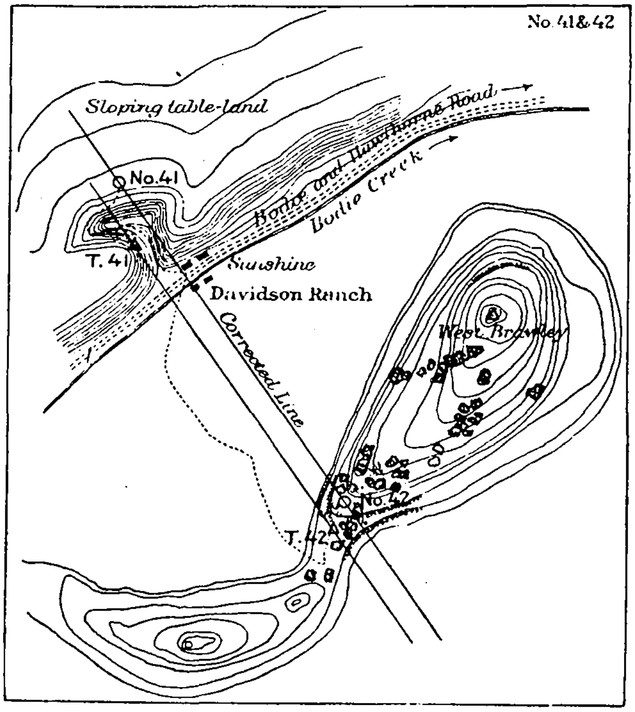
2 miles to top of table-land, thence a mile to foot of peak, thence up side of peak to station. This is the highest and most prominent peak rising from the table-land, and is northeast about 1 mile from two large alkali lakes.

Point on corrected line, "No. 40," put in at right angles to line, from old station, to the eastward, distant 26·52 meters; thence northwest in direction of the line 18·04 meters to place station on top of ridge. Marked by a drill hole in a large rock; over this a birch pole marked "C. N. 40," and a large cairn around pole. Station is on the south slope of the peak. The main road from Gregory's ranch to Bodie passes 1 mile to south of peak, near an alkali lake.

T 41.

On the top of the high, rocky bluff just north of Bodie Creek, and near Sunshine, or Davidson's ranch, on the Aurora and Bodie road, and can be seen from the road that runs along the valley at foot of bluff. Station marked by pole and pile of stone, and drill hole in stone.

Point on corrected line, "No. 41," put in at right angles to line, from old point, to the eastward, distant 27·03 meters, thence 90·0 meters northwest in direction of line, in order to place station on the north side of the small cañon that separates this point from the old station. This cañon enters the valley at the Davidson ranch, the ranch house being visible from the station. There is a trail, or old wood road, about three-fourths of the way up the cañon, but very steep. The cañon comes to an end on the table-land, about 200 yards southwest of the station. Station marked by a drill hole in a solid rock; over this a pine pole marked "C. N. 41" and a cairn around pole.



T 42.

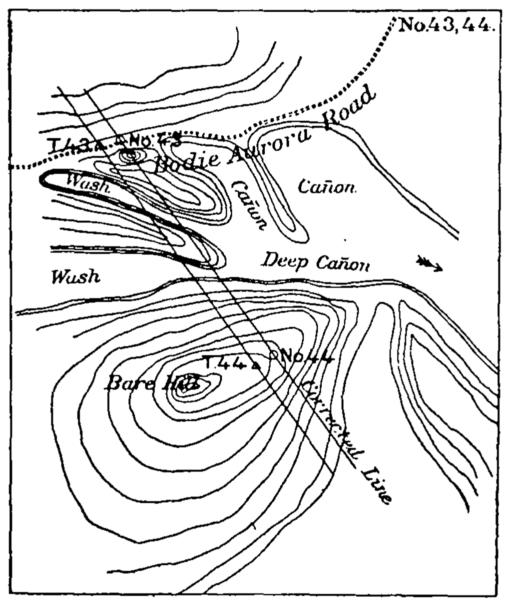
In sag on summit of Brawley Mountain, 2 miles southeast of Sunshine, or Davidson ranch, on Bodie and Hawthorn road. Ridge at station is rocky and bare of vegetation. Triangulation station is marked by a drill hole in solid rock, a pole erected over this and a cairn around same. Brawley Mountain is one of the most prominent elevations between the Sweetwater and White Mountains. Station can be reached from Bodie road at Davidson ranch by following trail from there up the side of mountain 2 miles to top of mountain to gap, thence up steep rocky side 200 feet to station.

Point on the corrected line, "No. 42," put in at right angles to line from old station to eastward, distant 27·90 meters, thence northwest in direction of line 8·81 meters in order to place station on top of ridge and on a solid rock. Marked by drill hole in the solid rock. Just southeast of drill hole and 2 feet from it was placed a pine post marked "C. N. 42," and around post and bowlder was built a cairn. Ground near station covered with very large bowlders and rocks.

T 43.

On east side of Brawley Mountain, about 1½ miles from summit, at the Bodie and Aurora road, about 4 miles south of Aurora. The land at station is sandy and rocky, some sagebrush and scattered pines and scrub cedars. Station is marked by a hole drilled in a rock about 2 feet in diameter and pole erected over same.

Point on the corrected line, "No. 43," put in at right angles to line from old station to eastward, distant 28·53 meters, marked by drill hole in stone set in place; over this a cedar post marked "C. N. 43," and a cairn and gravel thrown up around post. Station is 75 feet northwest of the Bodie and Aurora road, about 4 miles south of Aurora. A short distance beyond the station, to the west, the road dips down into a deep cañon. On the east side of road and not more than 150 yards from it, in Nevada, rises a small knoll covered with scrub cedars, this knoll being some 50 feet higher than the station.



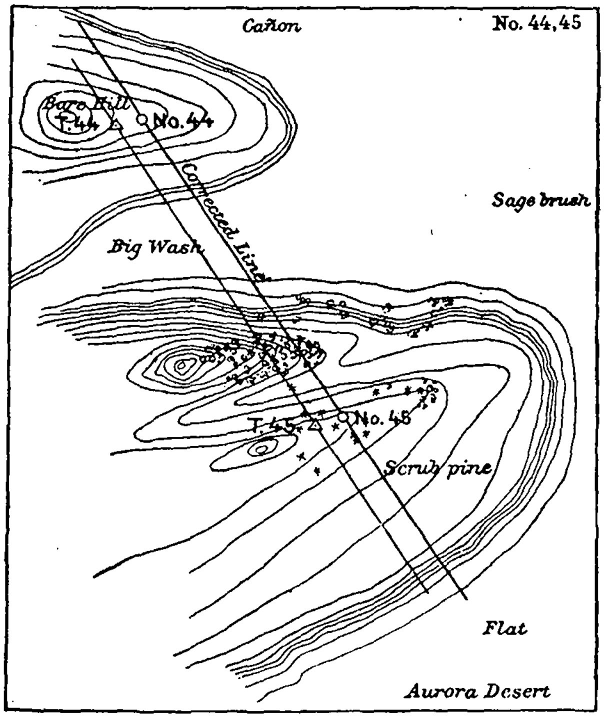
T 44.

On a peak of lava rock nearly bald that stands almost isolated about 5 miles south of Aurora and about 3 miles east of Mono Lake. Station is not on highest part of peak, but about 100 feet below it on east slope. Ground at station is very rocky, and there is some scattered sagebrush, two scrub cedars, and pines. Station is marked by hole drilled in a rock, a pole erected, and a cairn built. Station is reached by following the Bodie road south from Aurora 3 miles, thence taking the old road to Mono Lake 2 miles to north side of peak, thence up peak to station.

Point on the corrected line, "No. 44," put in at right angles to line, from old station, to eastward, distant 29·20 meters. Marked by a drill hole in set stone, over this a pine pole marked "C. N. 44," and a cairn around pole. Station is on the northeast slope, about 200 yards from the summit.

T 45.

On a double-peaked wooded mountain that stands 3 miles east of Mono Lake and about 3 miles west of the Aurora and Benton road. Station is on southeasterly one of two peaks and about a quarter of the distance from the summit to the foot, from the summit, on the east slope of same. The land at station is rocky and sandy and covered with piñon timber. Station marked by a hole drilled in a rock and a pole 5 inches in diameter erected over same. Station is reached from Aurora by following out the



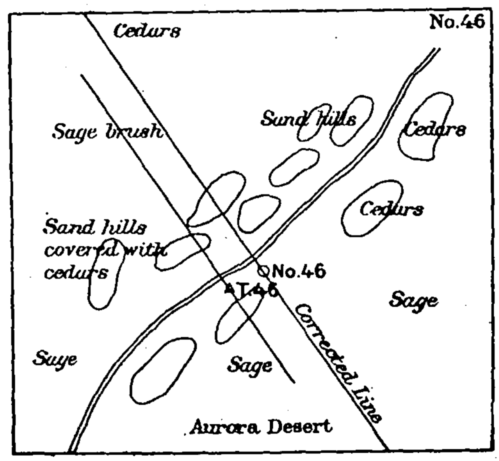
Benton road about 9 miles, thence 2 miles west to foot of north ridge of mountain, thence by trail to near top of west peak of mountain, thence across ravine to east peak and station.

Point on corrected line, "No. 45," put in at right angles to line, from old point, to eastward, distant 30·24 meters, thence northwest in direction of line 20·42 meters in order to place station on top of ridge and on a large bowlder some 10 or 15 feet high. On the northeast side it is perpendicular, and the station is on top, within 1 foot of the edge. Marked by a drill hole. Seven feet west of hole and on top of bowlder was placed a pine post marked "C. N. 45," and around post was built a cairn.

T 46.

On the desert at the crossing, by the line, of the Benton and Aurora road, about 12 miles from Aurora. Station stands about 100 feet east of road. Ground at station is sandy and covered with scattered scrub junipers. Station is marked by a post 4 inches in diameter, driven into the ground to within 3 inches of its top, and a cedar pole 10 inches in diameter was erected over this. Station is reached from Aurora by following out the Benton road 12 miles.

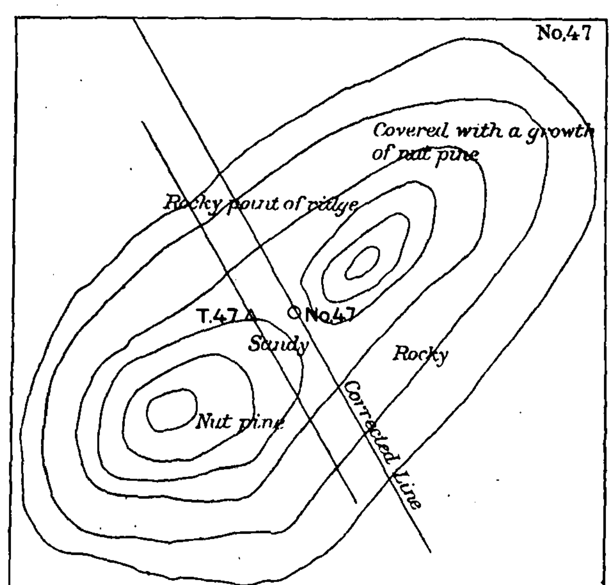
Point on corrected line, "No. 46," put in at right angles to line, from old point, to eastward, distant 31·97 meters, marked by a cedar post marked "C. N. 46," firmly set in the ground. Southeast of post and touching it was placed a stone with drill hole



in it; a mound of earth was then thrown up around the post and stone. Station is about 150 feet southeast of road at crossing of line.

T 47.

On the summit of a rocky wooded ridge about 1 mile southeast of the Benton and Aurora road. Where the line crosses it the summit of ridge is rocky and covered with

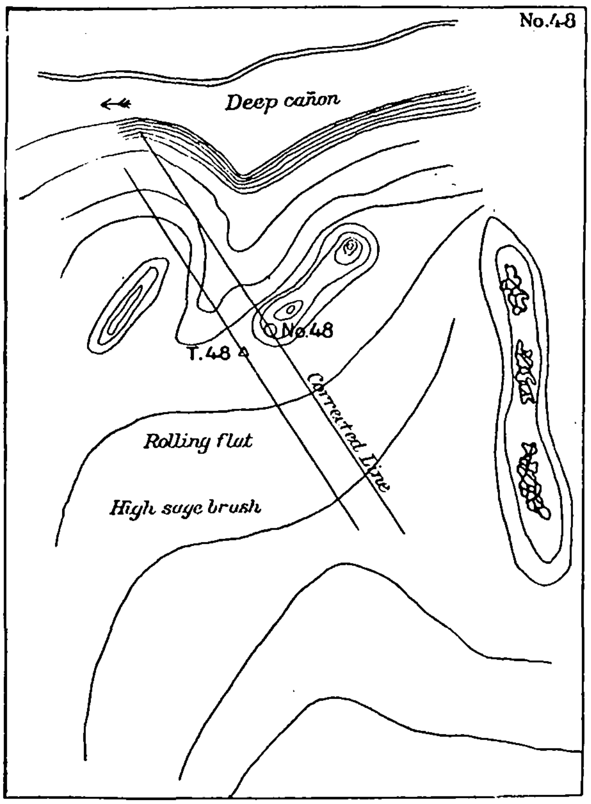


piñon timber. Station was marked by a drill hole in rock, pole over it, and a cairn. Station is reached from Aurora by following out the Benton road 12 miles, thence southeast 1 mile to foot of ridge, thence up the northwest point of ridge to station.

Point on corrected line, "No. 47," put in at right angles to line from old point, to the eastward, distant 32·83 meters, thence southeast in direction of the line 31·04 meters, in order to place station on the crest of the ridge. Marked by a nut-pine post, marked "C. N. 47," firmly planted in the ground. Southeast of post and touching it was placed a stone with drill hole in it; a cairn of stones and gravel was then built around post and rock. Station is on the east slope, some 200 feet from the highest point.

T 48.

On the high table-land to the east of the Aurora and Benton road, on the desert, and about 4 miles from the same. It is reached by following the Aurora and Benton road from Aurora about 14 miles, thence east 1 mile to cañon, thence up cañon



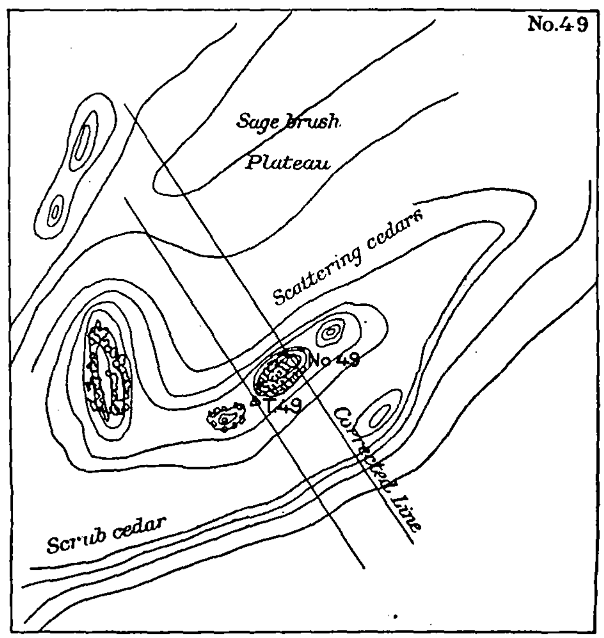
2 miles to near its head, thence southeast up sides of mountain to station. Ground at station is sandy, with some lava ledges projecting, and is covered with sagebrush 3 or 4 feet high. Station marked by hole drilled in rock projecting 1 foot above ground. A pole 4 inches in diameter was erected over same.

Point on corrected line, "No. 48," put in at right angles to line, from old point, to eastward, distant 33·86 meters, thence 8·51 meters northwest in direction of line, to put station on top of ridge and upon a solid rock. Station marked by drill hole in solid rock; over this a cedar post marked "C. N. 48," and a cairn around pole. Station is on the western edge of one of the small lava knolls.

T 49.

On the same high plateau as station T 48, near the eastern edge, and some 1 040 meters southeast of that station. It can be reached from the Aurora road by following up the cañon to station T 48, thence across plateau to station T 49. Station is located on a projecting lava ledge, and is marked by a hole drilled in the lava rock. A pole 6 inches diameter was erected over same. The ground at station is rocky, and below the lava ledge is sandy and covered with sage brush.

Point on corrected line, "No. 49," put in at right angles to line, from old point, to eastward, distant 34·11 meters, thence 0·57 meter northwest in direction of line, to



place station on a solid rock. Marked by drill hole in the rock; over this a cedar post marked "C. N. 49," and around post a cairn. Station is on the northern end of the northern of two small lava peaks or ledges rising from the eastern edge of the plateau.

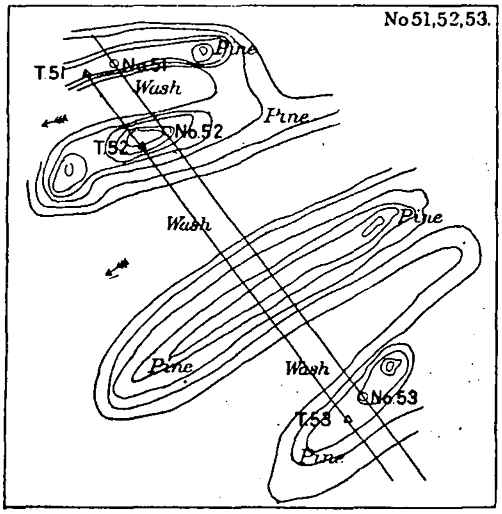
T 50.

This station is 6 730 meters southeast of T 49, and 4 203 meters northwest from T 51. It is on the top of a small round hill that lies a short distance southeast of the trail through Hontoun Valley.

This point, that should be "No. 50," was omitted on the corrected line; but it would fall at right angles to the line to the eastward, distant, 35·69 meters. The point can be put in whenever the line is marked.

T 51.

Point on corrected line, No. 51, put in at right angles to line from old station, to eastward, distant 36·67 meters, marked by a drill hole in solid rock; over this a nut-pine pole marked "C. N. 51," and around pole a cairn. Station on the north edge of a large flat ridge heavily wooded with nut pine. A small, round, wooded hill is about one-fourth mile east of station. Station reached most easily from Bertrand's ranch, to T 54, then following the line northwest to T 52, thence to station.

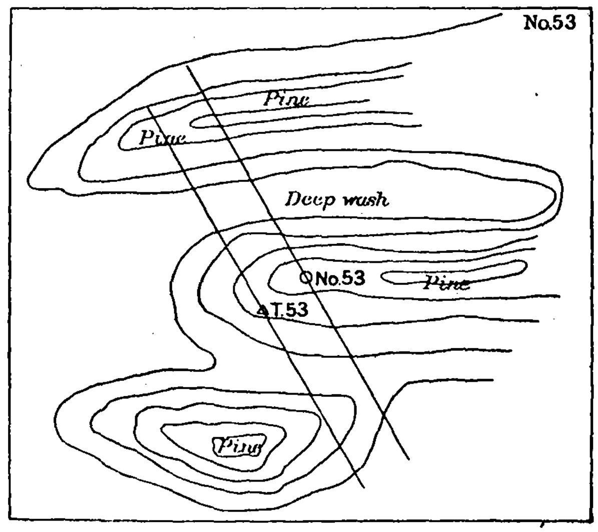


T 52.

Point on corrected line, No. 52, put in at right angles to line from old station, to eastward, distant 36·86 meters. Marked by a drill hole in a solid rock; over this a nut-pine pole marked "C. N. 52," and around pole a cairn of rocks. Station is on the eastern slope of a small, round, heavily wooded hill, the timber being nut pine. About one-half mile to the north is another wooded hill, somewhat higher, and on the ridge that runs off from the hill to the southwest is located T 51. The distance between T 51 and T 52 is only 812 meters. A deep wash is between the two stations. Best way to reach station is from Bertrand's ranch, following along the line northwest from T 54. The whole stretch of country from T 49 to T 58 is a rough, broken country, cut up by deep, rocky cañons, with high hills and heavily wooded ridges running in all directions, and with no house nearer than Bertrand's. Adobe meadow lies just to the west of this mass of hills.

T 53.

Point on corrected line, No. 53, put in at right angles to line from old station, to eastward, distant 37·70 meters, thence northwest in direction of line 5·92 meters to place station on solid ledge and crown of ridge. Marked by drill hole in solid rock; over this a nut-pine pole marked "C. N. 53," and around pole a cairn. Station is on the west-



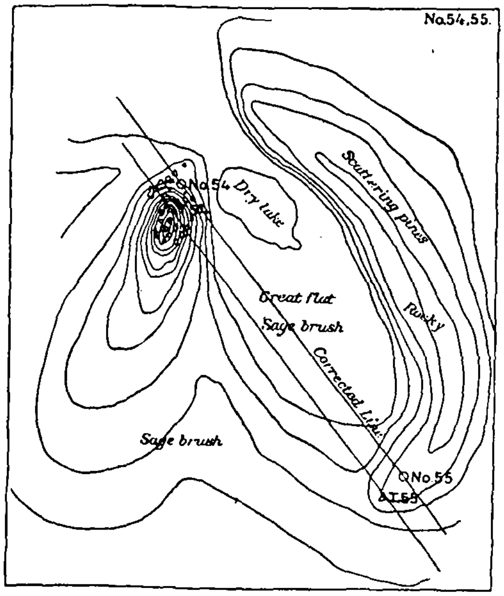
ern slope of a high wooded hill, on the top of which is located Trail triangulation station. Shaw's ranch and the south end of the northern lake in Adobe Meadow are in line and bear S. 41° W (mag.). The whole of Adobe Meadow is visible from this station.

The best way to reach this station is from Bertrand's ranch, via the Dry Lake and T 54, thence northwest along the line to the hill on which the station is located. There are cattle trails all over this section, but no roads or well-marked trails.

T 54.

Point on corrected line, No. 54, put in at right angles to line from old point, to eastward, distant 39·13 meters, thence northwest in direction of line 11·38 meters to place station on crest of ridge. Marked by a drill hole in solid rock; over this a nut-pine pole marked "C. N. 54," and around pole a cairn. Station is about 6 miles northwest of the Bertrand ranch, on the rocky point just west of the Dry Lake. A trail leads from Bertrand's ranch to the Dry Lake (a water place for cattle) and to within a quarter of a mile of the station, which is visible from the lake. Station about 9 miles from Bertrand's by the trail.

The old station is higher up the hill, on the crest of ridge, and is marked by a drill hole in a large bowlder. The whole point is very rocky and steep, with a few scattered scrub pines.

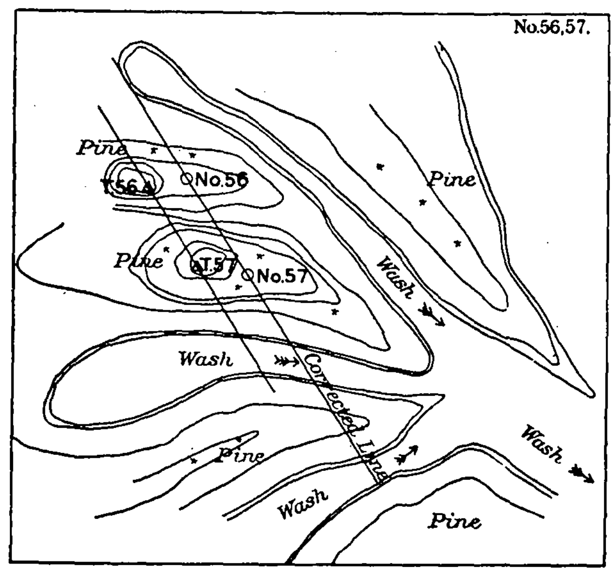


T 55.

Point on corrected line, No. 55, put in at right angles to line from old station, to eastward, distant 39·31 meters. Marked by a drill hole in stone set in place; over this a nut-pine pole, marked "C. N. 55," and around pole a cairn. Station is on the western slope of a rocky hill that is just east of the Dry Lake, about 6 miles northwest of Bertrand's ranch, and about 150 feet from the top of hill. A trail leads from Bertrand's ranch to the Dry Lake, and a trail from lake up onto the hill, on which T 55 is located. T 54 is on the northwest side of the same Dry Lake. This hill on which T 55 is located is almost bare of vegetation, there being only a few scattered nut pines.

T 56.

Point on corrected line, No. 56, put in at right angles to line from old station, to eastward, distant 39·55 meters; marked by drill hole in solid rock, over this a nut-pine pole marked "C. N. 56," and around pole a cairn. Station is on the eastern slope of a small wooded knob, covered with nut pine. About 200 feet south of station is a round bare hill some 50 feet higher than the ridge, and west of station about one-half mile is a sharp little hill some 400 feet higher than station, and with some few nut-pine trees on top. The best way to reach this station is from Bertrand's ranch, via the Dry Lake and T 55, the distance between T 55 and T 56 being only 1 057 meters.

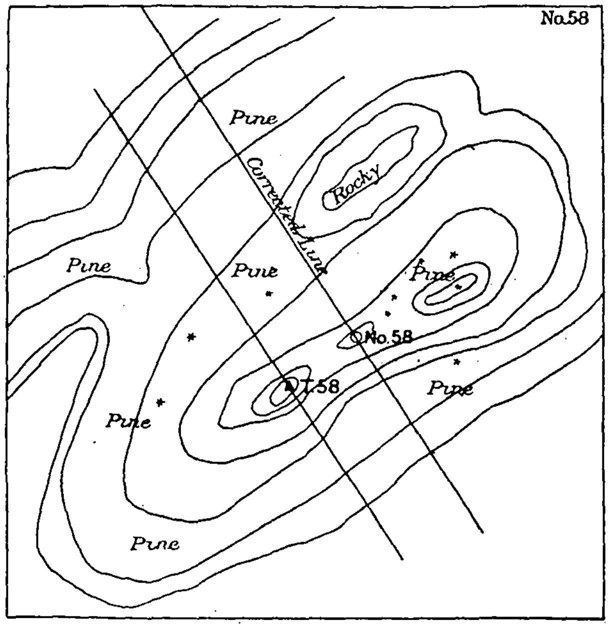


T 57.

Point on corrected line, No. 57, put in at right angles to line from old station, to eastward, distant 39·66 meters, thence southeast in direction of line 70·41 meters to bring point on top of ridge. Marked by drill hole in solid rock. Over this was placed a nut-pine pole marked "C. N. 57," and around pole a cairn was built. Station is on the east slope of a small rounded hill, partly covered with nut-pine timber, and only 452 meters southeast from the ridge on which T 56 is located. Station can be reached from Bertrand's ranch by trail to Dry Lake and T 55 and T 56, or from the ranch via station T 58. Bertrand's ranch, in the Benton Valley, is a very good place to stop, and in fact the only place from which the stations from T 51 to T 59½ can be reached readily. It is about 6 miles from the town of Benton, Cal.

T 58.

Point on corrected line, No. 58, put in at right angles to line from old station, to eastward, distant 40·22 meters, thence northwest in direction of the line to place the point on top of the ridge. Marked by a drill hole in solid rock; above this a nut-pine pole marked "C. N. 58," and around pole a large cairn was built. Station is on the



first high wooded ridge that the line crosses north of Benton Valley, and is about 3 miles north from the Bertrand ranch, from which it is easily reached by riding over the mesa, then climbing up the spur of the hill on the south side to the station. The point is well covered with a growth of nut-pine timber and is very rocky on the top.

T 59.

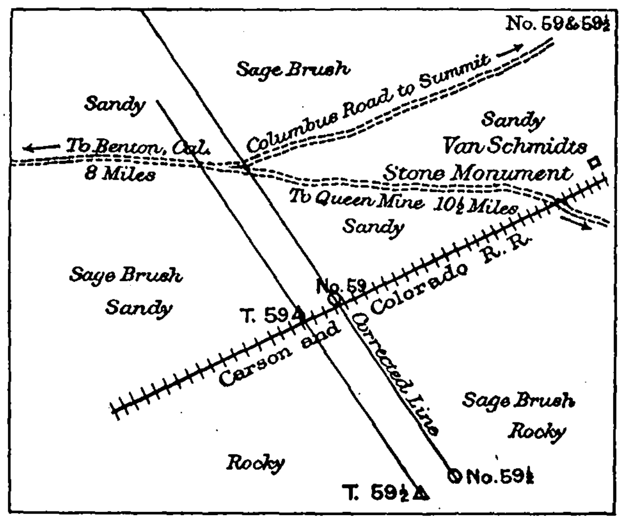
On northwest side of Carson and Colorado Railroad, and about 25 feet from the center of track, and some 1 340 feet south of where the road from Bertrand's ranch to the Queen mine crosses the Carson and Colorado Railroad track. The station is also the south end of the White Mountain Base Line. Marked by a drill hole in large stone set in place, with pole and cairn. Ground slightly rolling, sandy, and covered with sagebrush. Six hundred and five meters east of this station is the stone monument, set some 50 feet south of the railroad track, to mark the crossing of the Von Schmidt line.

Point on corrected line, No. 59, put in at right angles to line from old station, to the eastward, distant 41·34 meters, thence northwest in direction of line 12·88 meters to place point far enough from the railroad track. Marked by a drill hole in a large stone set with its top level with the surface of ground. Over this was placed a cedar post 7 inches in diameter and 6 feet long, marked "Cal. Nev. 59." Around post was built a large cairn. Station is 21·0 meters northwest from the center of the track of the Carson and Colorado Railroad, and about 3 miles east of Bertrand's ranch.

T 59½.

Station is about 1½ miles south of the Carson and Colorado Railroad, and on the sloping mesa at the foot of the White Mountains. Marked by a drill hole in bowlder with pole and cairn.

Point on corrected line, "No. 59½," put in at right angles to line, from old station, to eastward, and distant 42·06 meters, marked by a large stone with drill hole in it.

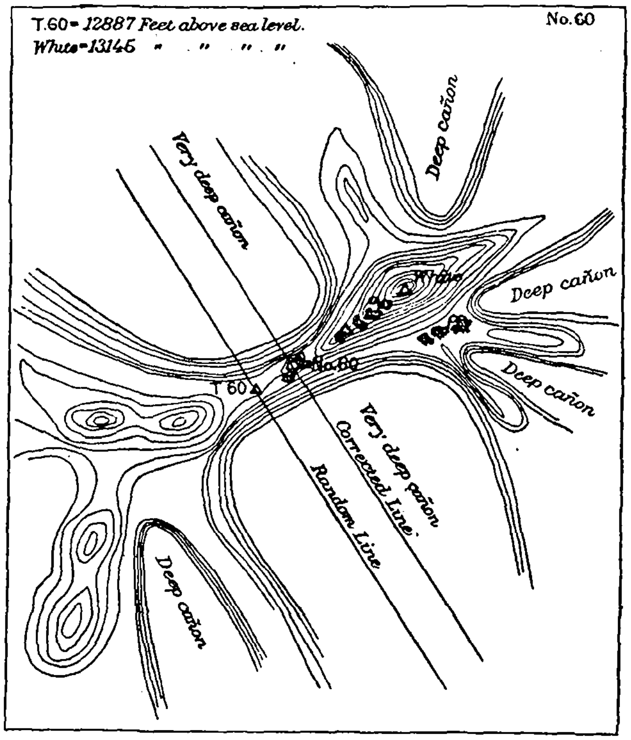


Above this a nut-pine pole, marked "C. N. 59½." Around pole was built a cairn. Station is about one-half mile from the foot of the White Mountains, on the east side of the wash that comes down from the White Mountains, near station T 60. Some 150 yards northeast of station are a few small nut-pine trees. Ground at station rolling and rocky, covered with sagebrush.

T 60.

Is on the backbone of the White Mountains, between the two lofty peaks that form the north end of the range, and known as the "Montgomery Peaks," over 13 000 feet above sea level. Station is in lowest part of gap, marked by drill hole in stone, and a pole with pile of stones around it.

Point on corrected line, "No. 60," put in at right angles to line, from old station. to eastward, distant 43·72 meters; thence northwest in direction of line 12·5 meters to place station on crest of ridge. Station is now on the first rocky point east of the saddle



that is between the two high peaks at east end of White Mountains. This point is composed of high, sharp, needle-like rocks and very large bowlders, and is a difficult place to get up on, being a sharp hogback. Station is on one of the large bowlders, marked by drill hole, with a pine board above marked "C. N. 60" and a cairn around pole. "No. 60" is some 50 feet higher than the old station T 60. The station is a very difficult one to get to, the mountain being very steep and rocky, with snow on part of it the year round, and for the upper 5 000 feet there is no trail. It is reached most easily from the Queen Mine, 7 miles to the eastward.

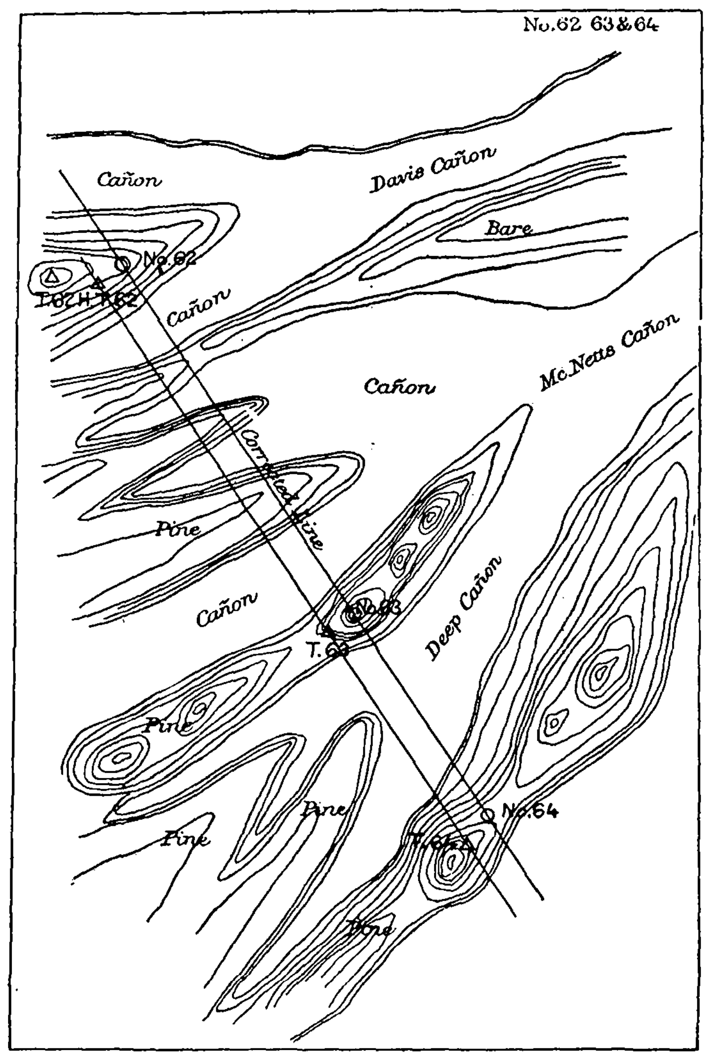
(No. 61 omitted.)

T 62.

On the northeast slope of a bare, high ridge that is just at the head of Davis Cañon, which divides at this ridge, one branch going in a northwest and the other in a southwest direction. The Davis ranch is visible from here down cañon to northeast to about

3 miles distant, and about 3 miles beyond can be seen part of the Fish Lake Valley. This ridge terminates in a round, sharp peak, and on this peak was located station T 62 High, marked by a drill hole, pole, and cairn. Station "T 62" marked by a drill hole in rock and pole.

Point on corrected line, "No. 62," put in at right angles to line, from old station, to eastward, distant 46·17 meters; thence northwest in direction of line 8·96 meters to



place station on crest of ridge. Marked by drill hole in solid rock; over this a birch pole marked "C. N. 62," and a cairn around pole. Station is some 75 feet south of a bluff or cropping out of large rocks. Ground covered with small stones and sagebrush. The best way to reach this station is from the Davis ranch, following up the Davis Cañon to where it forks, about 3 miles, then up bare ridge between the two branches to the station.

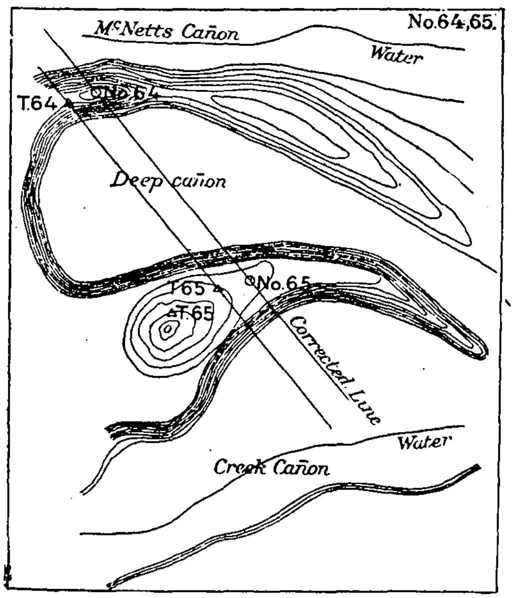
T 63.

On an isolated ridge dividing the two cañons which join and make the McNett or Indian Cañon, the water from which flows down to the McNett ranch. The station is on the ridge where it slopes to the south, about halfway from the summit on the north to the sag on the south. Marked by drill hole in granite rock, and pole. The ridge is sparsely covered with mountain mahogany and nut pine, and very steep on either side, going down precipitately into deep cañons.

Point on corrected line, "No. 63," put in at right angles to line, from old station, to eastward, distant 47·03 meters. Marked by drill hole in solid rock; over this a nut-pine pole marked "C. N. 63," and around pole a large cairn. Station on the south slope of ridge, about 50 feet south of the first little rocky knob north of the gap. The best way to reach station is from McNett's ranch, by following up the old wood road up cañon about 3 miles to where the cañon forks, then up the steep ridge between the forks to the station. Ridge very steep from the cañon up to station.

T 64.

Station is on the first high ridge that the line crosses, south of the McNett or Indian Cañon, and the second prominent ridge from the White Mountains southeast,

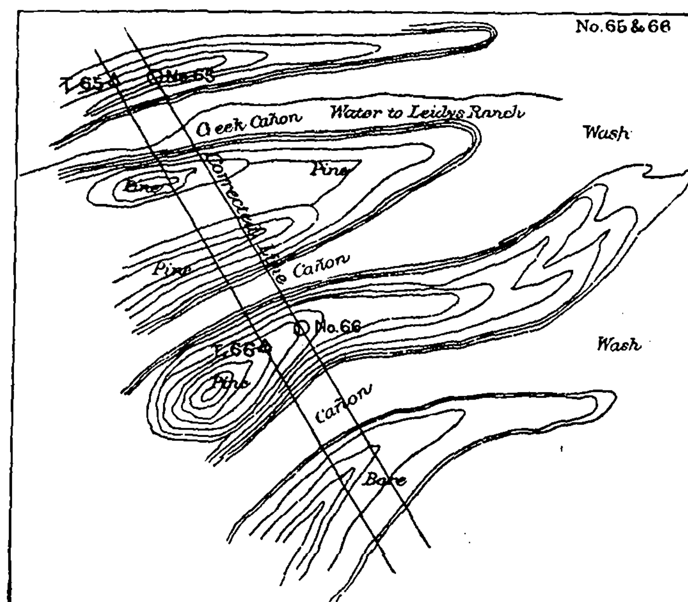


over which the line crosses. Station is in a small sag on the ridge, marked by a drill hole in stone, and pole. Ridge is covered on both sides with a stunted growth of nut pines.

Point on corrected line, "No. 64," put in at right angles to line, from old station, to eastward, distant 47·39 meters; thence northwest in direction of line 18·11 meters to place station on top of ridge. Marked by a drill hole in large stone set in place, top level with surface of ground; over this a nut-pine pole marked "C.N. 64," and around pole a cairn. Station is reached from Fish Lake Valley by going up the ridge just north of the first cañon north of the Leidy, or Robinson Cañon; take the ridge at mouth of cañon and follow it up for about 4 miles to top, when the station will be found. Station T 64 High is on the same ridge, some 225 meters to the eastward. Ridge here is a simple hogback with deep cañons on either side. The whole of Fish Lake Valley is visible from this point.

T 65.

Station is on the high ridge (a spur of the White Mountains) that is just north of the cañon from which flows the water to Leidy's ranch, called Creek Cañon. The Robinson Cañon, just north, is between this station and station T 64. Station is on northeast slope, overlooking Fish Lake Valley. Marked by drill hole in rock, and



pole. Station is reached by going up the ridge on north side of Creek Cañon, following up point of ridge until station is reached. Very steep, rough, and rocky, and covered with nut pine.

Point on corrected line, "No. 65," put in at right angles to line, from old station, to eastward, distant 47·91 meters; thence 15·60 meters southeast in direction of line to place station on point of ridge. Marked by drill hole in a large, flat rock. Above this is a nut-pine post marked "C. N. 65," and around post a large cairn.

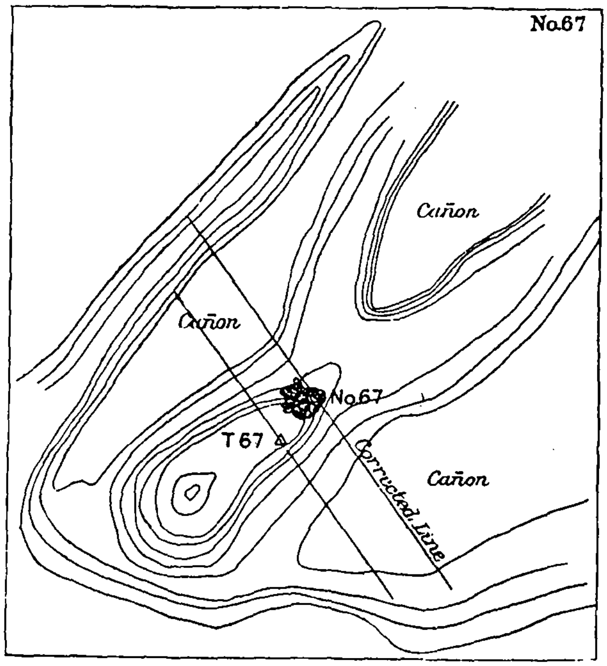
T 66.

On the east slope of a hill or ridge sparsely covered with nut pines, and overlooking Fish Lake Valley to east and south. The hill is part of the first prominent ridge that the line crosses southeast of the cañon, from which flows the water that supplies the Leidy ranch, and is about three-fourths of a mile southeast of cañon. There are two more ridges to the southeast between this one and the final one, on which T 67 is located. Marked by a drill hole in stone set in place, and pole. This point used as a triangulation point. Station is reached from Leidy's ranch by following the water course to mouth of cañon, thence up the ridge on south to station.

Point on the corrected line, "No. 66," put in at right angles to line, from old point, to eastward, distant 48·82 meters; thence 3·30 meters northwest in direction of line to place point on top of ridge. Marked by drill hole in stone set in ground; over this a nut-pine post marked "C. N. 66," and a cairn around post.

T 67.

On the last of the ridges or spurs of the White Mountains, over which the line crosses before entering Fish Lake Valley. Station is on the northeast slope of hill and about 300 yards from the summit. The hill is the first bare hill north of the cañon, from which flows the water that supplies Piper's lower, or north, ranch. Hill bare of all

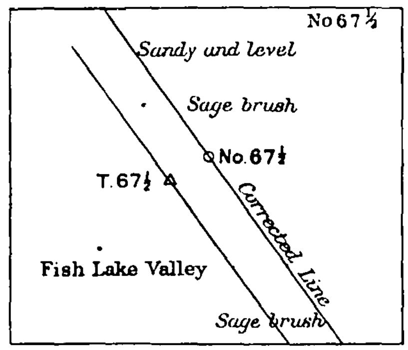


vegetation and covered with large rocks and bowlders, with rocky ledges cropping out here and there. Marked by drill hole in rock, and pole, and was used as a triangulation point. Piper's lower ranch is due east, the Leidy-McAfee ranch about 30° north of east and the H. G. McAfee ranch 35° south of east. It is about 3 miles from Piper's lower, or north, ranch.

Point on the corrected line, "No. 67," put in at right angles to line, from old station, to eastward, distant 50·36 meters; thence 13·51 meters northwest in direction of line to place point on a very large granite bowlder that stands up about 12 feet above the surface of ground. A mass of granite rocks crops out at this place on the ridge, and station is on the most eastern one, on the highest part and 2 feet from eastern edge. Marked by a nut-pine post and cairn around it, on top of rock.

T 67½.

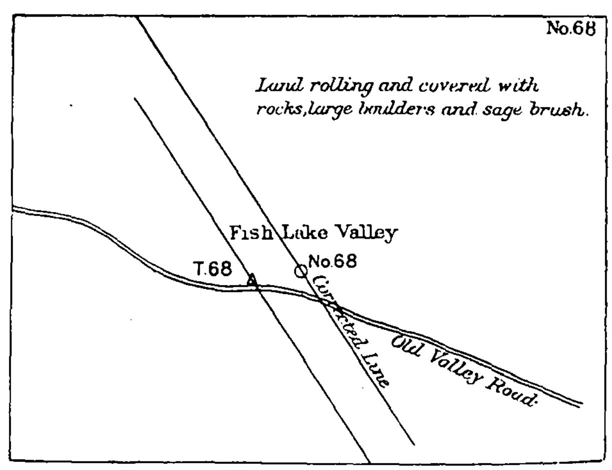
On the west side of Fish Lake Valley. The first station in the valley after the line leaves the foothills of the White Mountains. It is about 1 mile east of the mouth of the cañon from which flows the water that supplies the A. G. McAfee ranch, and a little over a mile south of the same ranch. Soil sandy, rolling, and covered with stones and sagebrush. Marked by a drill hole in rock, and a pole.



Point on the corrected line, "No. 67½," put in at right angles to line from old point, to eastward, distant 52·01 meters. Marked by drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 67½," and a large cairn around post. An old wood road from A. G. McAfee's ranch goes within a quarter of a mile of station to the north.

T 68.

On the west side of Fish Lake Valley, about 1 mile from the foothills, and south from A. G. McAfee's ranch about 2 miles; and the old valley road from McAfee's ranch



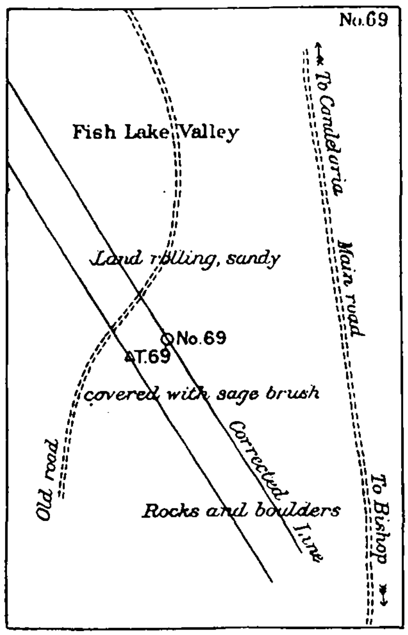
to Piper's ranch passes only a short distance south of station. It is on a rolling ridge between two washes coming down from the mountains, and the ground is covered with sagebrush and very large stones and bowlders brought down from the mountains by the washes during a cloud-burst some few years ago. Marked by drill hole in stone set in place, and a pole.

Point on corrected line, "No. 68," put in at right angles to line from old station, to eastward, distant 52·80 meters, thence southeast in direction of line 2·37 meters to place point on a large solid rock. Marked by drill hole in rock; over this was placed a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 68," and a large cairn was built around post. Station is on the north side of the old valley road, and about 40 feet from it.

T 69.

On the west side of Fish Lake Valley, about 6 miles south of the A. G. McAfee ranch. Ground rolling and covered with sagebrush and large, loose bowlders. Marked by drill hole in granite bowlder, and pole.

Point on corrected line, "No. 69," put in at right angles to line, from old station, to eastward, distant 53·50 meters. Marked by a stone with drill hole in it, and set in

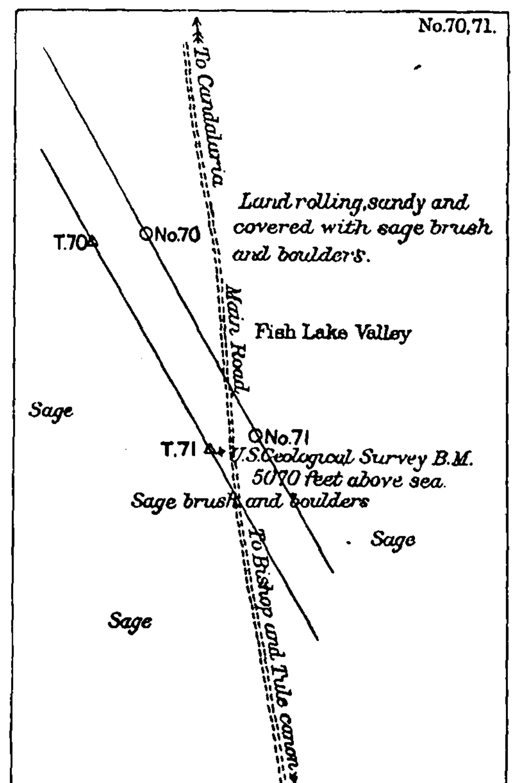


ground even with the surface. Just northwest of stone was set a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 69," and a mound of stones and dirt thrown up around post and stone. Station is north of the main county road through the valley, and about 75 meters south of the old road (not used at this time).

T 70.

On the west side of Fish Lake Valley, about 8 miles north of Piper's main (south) ranch and about 400 yards from the main road running through the valley on the northwest side. It is on a rolling ridge formed by two large washes coming from the mountains to the westward; is covered with sagebrush and numerous large bowlders. The valley road crosses the line between the stations T 70 and T 71, nearest to T 71. Station T 70 was also a triangulation point, and was marked by a drill hole in lava rock, and a pole.

Point on corrected line, "No. 70," put in at right angles to line, from old point, to eastward, distant 53·80 meters, thence southeast in direction of line 12·34 meters to place station on the highest part of ridge. Marked by a drill hole in solid rock; over this a 4-inch by 4-inch by 5-foot pine post, marked "C. N. 70," and a large cairn.



T 71.

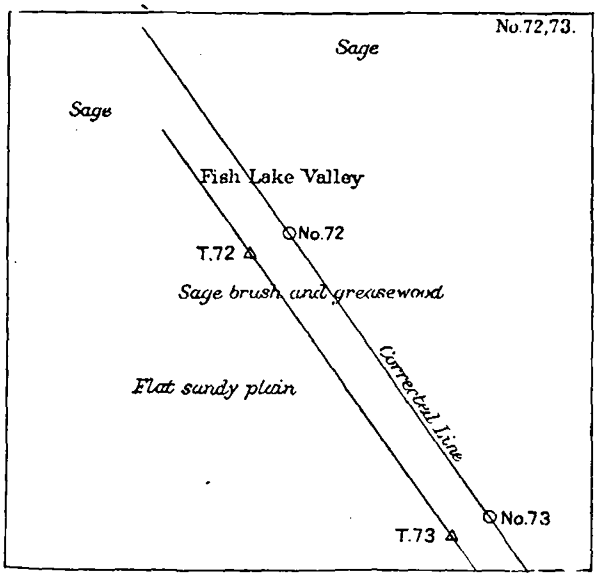
In Fish Lake Valley, about 7 miles north of Piper's main ranch, on the southeast side of the main valley road, and about 200 feet from it. Marked by a drill hole in stone, and pole. At this station there is a United States Geological Survey bench mark (iron pipe projecting 2 feet above the ground) giving the height above sea level as "5 070 feet, datum C. C."

Point on corrected line, "No. 71," put in at right angles to line, from old station, to eastward, distant 54·12 meters. Marked by a stone with drill hole in it, and a pine post 4-inches by 4-inches by 5½ feet set in the ground 2 feet. Post marked "C. N. 71;" a mound of stone and sand thrown up around post and stone. Land rolling and covered with sagebrush and small bowlders.

T 72.

Station is about in the center of Fish Lake Valley, from east to west, and some 4 miles north of Piper's main ranch. Land around station sandy, thickly covered with high sagebrush. Marked by stone with drill hole, and pole, with mound of sand.

Point on corrected line, "No. 72," put in at right angles to line, from old point, to eastward, distant 55·18 meters. Marked by stone with drill hole in it; above this a pine post 4-inches by 4-inches by 5⅓-feet set in the ground, and a mound of stones and sand thrown up around post and rock. Post marked, "C. N. 72." Letters and numbers made with small nails driven into the post. All the posts along this corrected line were marked in a similar manner.



T 73.

In Fish Lake Valley, on the east side, a little east of north from Piper's main ranch, and about 1½ miles distant from same, in level sandy flat, covered with large sagebrush; about one-fourth mile to east of station the land begins to rise gently toward the foothills to the east. Station is 2 800 meters northwest of the point where the road from Piper's main ranch to Silver Peak mining camp crosses the line. Station marked by drill hole in stone, and a pole.

Point on corrected line, "No. 73," put in at right angles to line, from old station, to eastward, distant 56·45 meters. Marked by a nut-pine post marked "C. N. 73"; set in the ground 2 feet was a stone with drill hole in it, placed just southeast and touching post. A mound of sand was then thrown up around post and stone.

T 74.

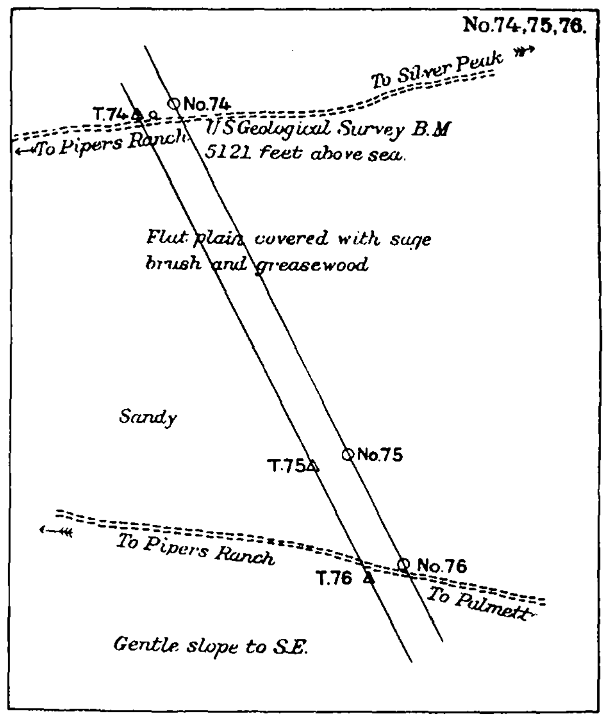
Station is in Fish Lake Valley, on east side and about one-half mile from the foothills on the east side of valley, just north of the road across the valley from Piper's main ranch to Silver Peak. Land level and sandy, and covered with sagebrush. Marked by stone with drill hole, and a pole, with mound of sand. At this station there is a

United States Geological Survey bench mark giving the height above sea level as "5 121 feet, datum C. C."

Point on corrected line, "No. 74," put in at right angles to line, from old station, to eastward, distant 57·11 meters. Marked by a 4-inch by 4-inch by 5⅓-foot pine post marked "C. N. 74." Set 2 feet in ground, just southeast of post was placed a small stone with drill hole in it, and a mound of earth was thrown up around post and stone. Station is about 150 feet north of the road, and is practically the same level as the old station.

T 75.

This station is in Fish Lake Valley, south end and east side, about three-fourths of a mile from foothills on east side and some 3 miles from foothills, where line leaves the valley, on the south; and is 4 145 meters southeast from the road from Piper's



ranch to Silver Peak, or from T 74. Land rolling and sandy and covered with sagebrush. Station marked by stone with drill hole in it, and a pole.

Point on corrected line, "No. 75," put in at right angles to line, from old station, to eastward, distant 58·08 meters. Marked by a large stone with drill hole in it, set in the ground, and a 4-inch by 4-inch by 5⅓-foot pine post marked "C. N. 75," and a mound of sand thrown up around post and stone.

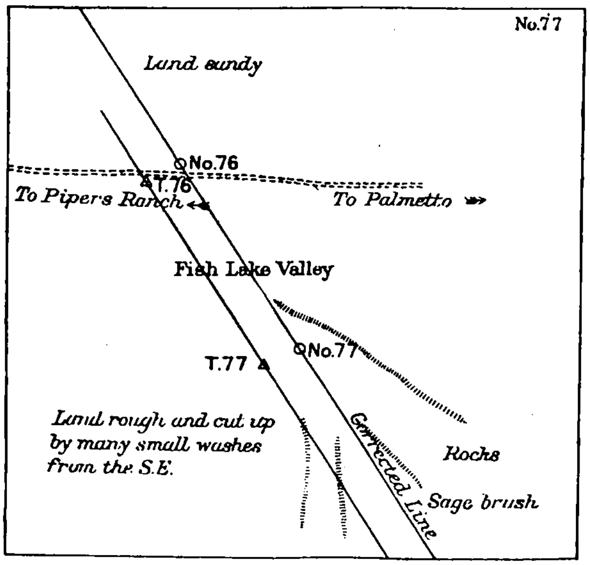
T 76.

Station is in Fish Lake Valley, east side and south end, and is some 75 feet south of the road from Piper's ranch to Palmetto, where it crosses the line. Land rolling and sandy and covered with sagebrush. Marked by cross in stone set in sand, and a pole.

Point on corrected line, "No. 76," put in at right angles to line, from old point, to eastward, distant 58·36 meters. Marked by a granite post set in ground, with drill hole in it. The stone at the old station was taken up and used at this station. Then a 4-inch by 4-inch by 4-foot pine post set in the ground to southeast, marked "C. N. 76," and a mound of sand thrown up around post and stone. Station is about 25 feet north of the Palmetto road. From T 76 to T 75 is 1 181 meters.

T 77.

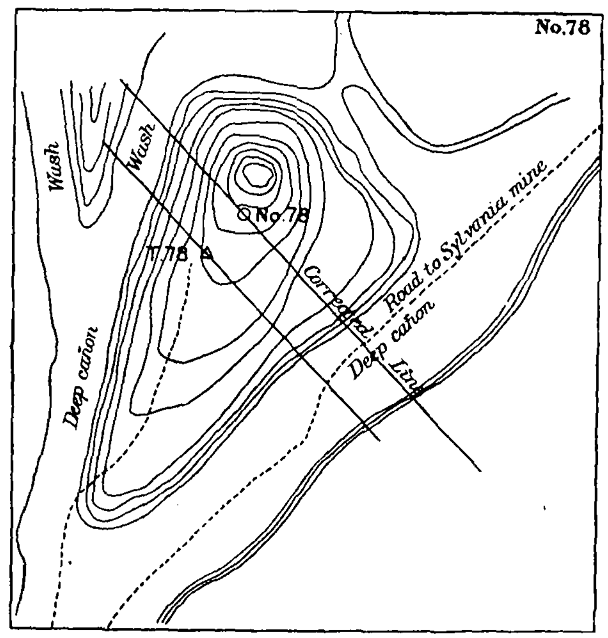
This is the last station in the Fish Lake Valley, in the eastern part and extreme southern end. The land at this point begins to rise to the Sylvania Mountains. Station is between two small washes that come down from the Sylvania Mountains. Land broken and rough from many washes; covered with small stones and bowlders and sagebrush. Station marked by drill hole in stone, and pole.



Point on corrected line, "No. 77," put in at right angles to line, from old station, to eastward, distant 58·82 meters. Marked by a large stone with drill hole in it, and a 4-inch by 4-inch by 5⅓-foot pine post, marked "C. N. 77," set in the ground, and a cairn and earth thrown up around post and stone. This station is 1 968 meters southeast of the Palmetto road at line crossing, or from T 76.

T 78.

This station is on the first prominent ridge of the Sylvania Mountains that the line crosses after leaving Fish Lake Valley. It is a bare, gravelly ridge, with a few scattering palmetto trees on it. The point is on the ridge on the west slope. To the north and south are deep cañons, and the sides of the ridge are very steep. The best way to reach the point is by the old road from Piper's ranch to the Sylvania mining camp,



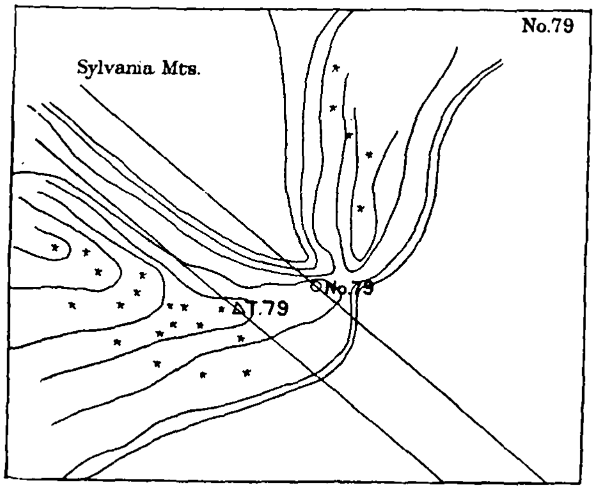
leaving the road about a mile from the mouth of the big wash, and going up the ridge to the north to the highest part, on which the station is located. Marked by stone with drill hole in it, and a pole.

Point on corrected line, "No. 78," put in at right angles to line, from old station, to eastward, distant 60·09 meters. Marked by a drill hole in stone, over which was placed a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 78," and a cairn of stone and gravel thrown up around them. Station is on the west slope, about 75 feet from the summit.

T 79.

Station is on the highest peak of the Sylvania Mountains, on the east slope, not far from the top. The mountain is covered with nut pine and a very little cedar. The point overlooks Fish Lake Valley and also Tule Cañon, which is the head or northern end of Death Valley. The old mining town of Sylvania is about 2 miles north of station, and the best way to reach station is from the old mining town, following up the ridges to the south until the highest one is reached. Nearly all of the ridges are timbered with nut pine. Station marked by a drill hole in granite rock, and a pole.

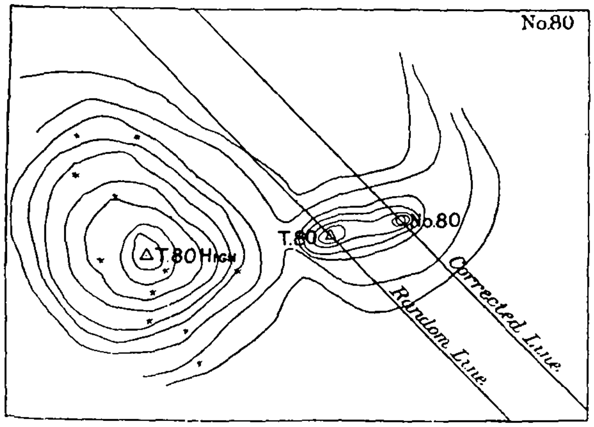
Point on corrected line, "No. 79," put in at right angles to line, from old station, to eastward, distant 61·29 meters; thence 23·23 meters to southeast in direction of line, to place station on crest of ridge. Marked by drill hole in solid rock; over this a



4-inch by 4-inch by 4-foot pine post, marked "C. N. 79," and a large cairn built around post. Station on east slope, about 400 feet from the summit. There are very deep cañons on both the north and south side of the ridge.

T 80.

Station is on the first prominent ridge of the Sylvania Mountains over which the line crosses, south of the main ridge of those mountains. Between these two ridges is a very deep cañon, opening to the west into the southern part of what is known as

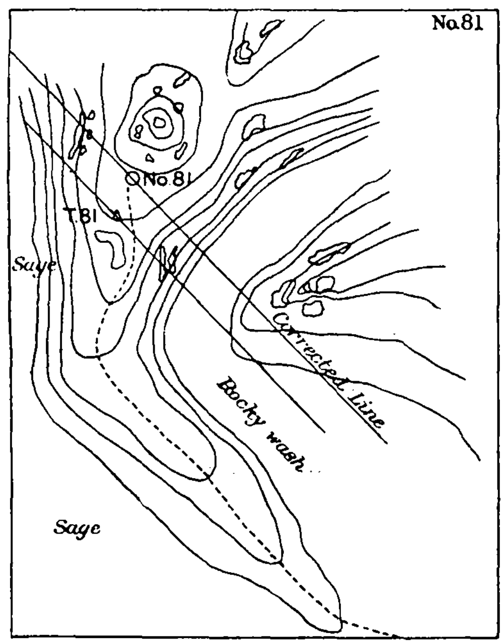


Fish Lake Valley. To the south the point overlooks the upper end of Death Valley, where the State line crosses the same. In the cañon to the north of this ridge and about three-fourths of a mile from station is a spring (Kokomongo). There is a pipe leading from the spring, out of which flows a nice stream of cool, good water. This ridge, like the ridges of the Sylvania Mountains, is covered with nut pine. Station marked by hole in granite stone, and a pole.

Point on corrected line, "No. 80," put in at right angles to line, from old station, to eastward, distant 63·14 meters; thence 78·48 meters southeast in direction of line, in order to place station on top of hill. Marked by drill hole in solid rock; over this a nut pine post, marked "C. N. 80," and a cairn of stone and gravel around same. About one-half mile west is the highest point of this ridge, on the summit of which is located station T 80 High.

T 81.

Station is on one of the low red hills in the upper part of Death Valley, and about 1 mile northwest of the lower part of Tule Cañon, or where it spreads out into Death

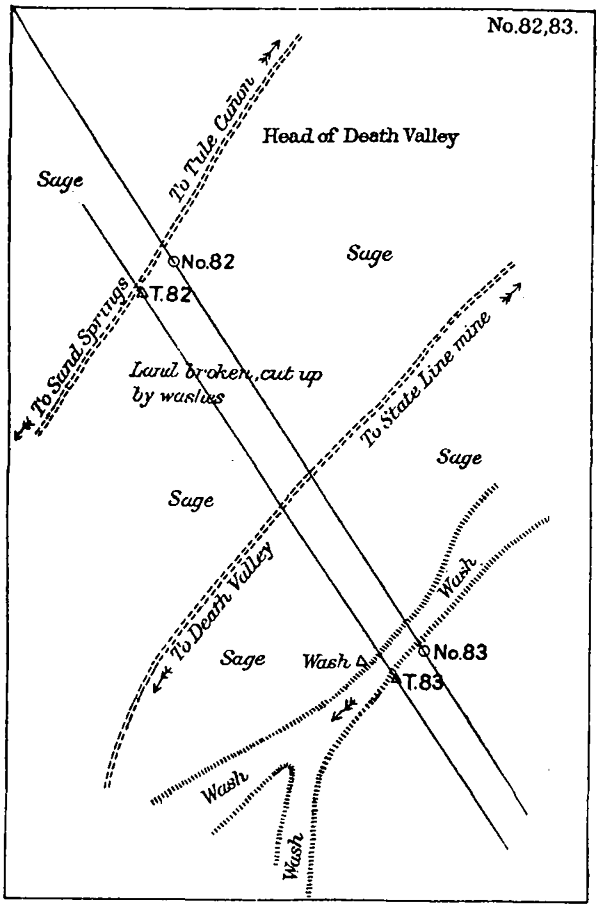


Valley. Station is on the southern end of these red hills, not the highest part, but on the southern slope, and is marked by a hole drilled in the solid rock, a small pole, and cairn.

Point on corrected line, "No. 81," put in at right angles to line, from old station, to eastward, distant 65·72 meters; thence 18·79 meters northwest in direction of line, to place point on crest of ridge. Marked by drill hole in large rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 81," and a cairn around it. Station is on the second cluster of red hills north of the mouth of Tule Cañon, and on southwest end of said cluster.

T 82.

Station is out on the level plain in the upper part of Death Valley. It is about 50 feet south of the road from Tule Cañon to Sand Springs, where the line crosses, and about 4 miles east from Sand Springs. Land level and sandy, cut up by washes and covered with sagebrush and greasewood. Station marked by bowlder with drill hole in it, a pole and cairn.



Point on corrected line, "No. 82," put in at right angles to line, from old station, to eastward, distant 66·77 meters. Marked by a stone with drill hole in it; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 82," and a cairn of stone and sand around post. Station is 180 feet southeast of road where the line crosses. Water at Sand Springs 4·2 miles to the west, in white sand hills.

T 83.

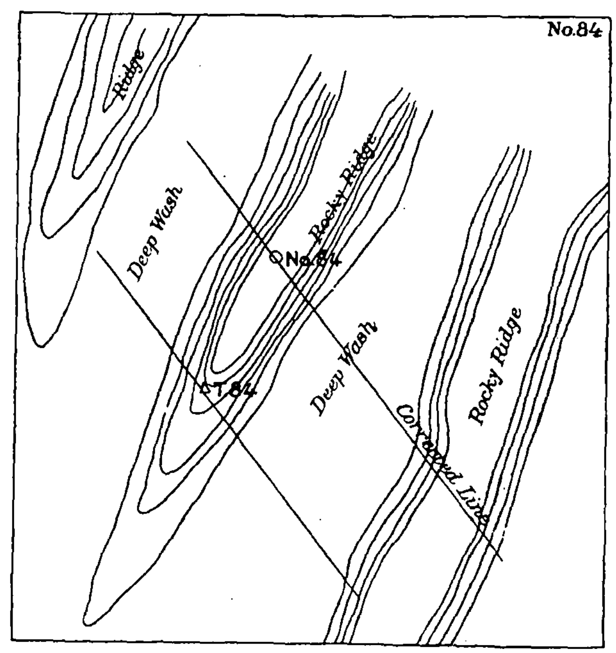
Station is on the east side of the upper part of Death Valley, on the south bank of the first big wash that enters the valley; south of the State Line or Oriental Wash, and about 2 miles south of the road going up that wash to the old mining camp of State

Line, and is some 5 miles south of the mouth of Tule Cañon. Land rolling and rising gently to the east. Very much cut up by washes from the hills to the east, covered with bowlders, small rocks, and sagebrush and cacti. Triangulation station Wash is about 200 yards west of this station, on the north bank of same wash. Marked by drill hole in rock, pole, and cairn.

Point on corrected line, "No. 83," put in at right angles to line, from old station, to eastward, distant 68·44 meters, thence 44·01 meters southeast in direction of line to place point in best location. Marked by drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 83," and a cairn of stone and earth around post.

T 84.

Station is on the highest of the ridges that are just south of the upper part of Death Valley, where the line crosses, and is on the second ridge north of the great wash that flows into Death Valley from the high mountains to the east. Station is

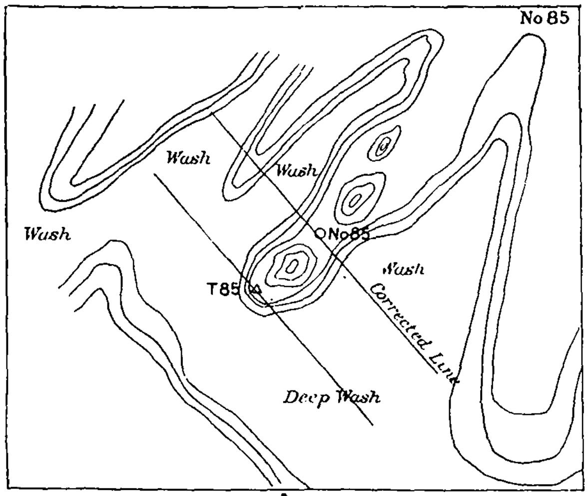


about 8 miles from Sand Springs, and can be seen from that place. Located on a bare, rocky ridge, with scattering sagebrush, greasewood, and cacti on it. Marked by drill hole in rock, pole, and cairn.

Point on corrected line, "No. 84," put in at right angles to line from old station, to eastward, distant 69·25 meters, thence southeast in direction of line 11·62 meters to place point on top of ridge. Marked by drill hole in a very large bowlder, a pine post 4-inches by 4-inches by 4-feet, marked "C. N. 84," and a large cairn around post and bowlder. Station is most easily reached from Sand Springs, where is to be found the only water within many miles.

T 85.

Looking along the line southeast from station T 82 there are seen two high, rounding, and prominent hills, some 9 miles distant, and beyond which nothing can be seen from this point. On the top of the highest and most eastern of these two is located station T 85 High. These hills form the divide between this part of Death Valley and a small valley to the southeast. This triangulation station is marked by drill hole, pole, and cairn.

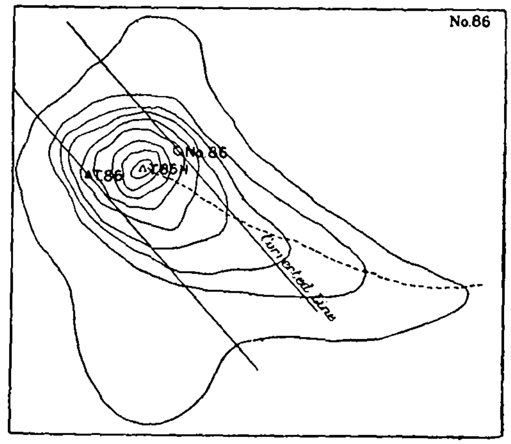


About three-fourths of a mile to the east, across a deep cañon and on the west slope of a small foothill, is located station T 85, visible from T 85 High. Hill bare, covered with small stones and some sagebrush. Marked by drill hole in rock, pole, and cairn.

Point on corrected line, "No. 85," put in at right angles to line, from old station, to eastward, distant 69·94 meters; thence 18·11 meters southeast in direction of line to place point on top of ridge. Station is now in saddle just east of the little sharp peak, and is marked by drill hole in stone, set in place, a pine post marked "C. N. 85," and a cairn of stones and gravel thrown up around post. Station most easily reached from Sand Springs.

T 86.

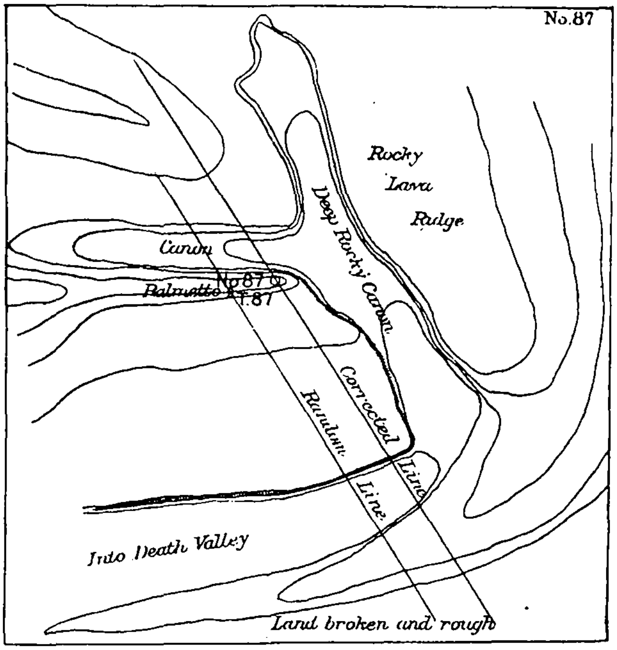
Station is on the west slope of a bare, sharp, and light-colored peak, 1 823 meters northwest of T 87, and easily reached from this station; some greasewood and large palmetto at the base of this peak. Station T 86 High is on the summit. Both stations were marked by drill holes in rocks, poles, and piles of stones.



Point on corrected line, "No 86," put in at right angles to line, from old station, to eastward, distant 71·55 meters; thence 16·22 meters to southeast in direction of line, in order to get station on top of ridge. Marked by drill hole in large rock; above this is a 4-inch by 4-inch by 4-foot pine post marked "C. N. 86," and a cairn around post. Station is on the northeast slope of peak, on a small flat, not much below nor far from the summit.

T 87.

Station is on the black lava foothills of the Grape Vine Mountains that are just north of the great wash through which the road goes that leads from Staininger's ranch to Thorpe's Mill, in the Ralston Desert. It is on the first high black ridge north of the road, is a very rough and rocky ridge, and difficult to get on. There are several deep, rocky cañons extending up to this ridge from the south and southwest side, one of which extends into Death Valley. Best way to reach the point is to follow out the road from Staininger to Thorpe Mill, some 5 miles, then strike across for the ridge. There

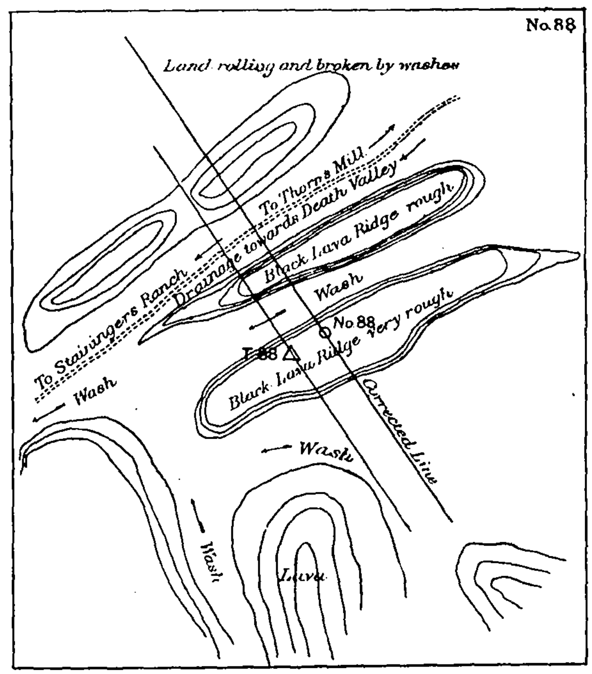


is a shorter way from Staininger's, but it is impossible to describe it. Station marked by drill hole in rock, pole, and pile of stones. It is about on highest point of ridge.

Point on corrected line, "No. 87," put in at right angles to line, from old point, to eastward, distant 71·98 meters; thence northwest in direction of line 29·18 meters, to place station on top of ridge. Marked by drill hole in rock; over this a 4-inch by 4-inch by 4-foot pine post marked "C. N. 87," and a cairn around post. To the north, east, and southeast of station there is a deep, rocky cañon around end of ridge.

T 88.

Station is on a black lava ridge, about 4 miles from Staininger's ranch, on the road to Thorpe's Mill and the Amargosa Desert. To the south of the road, and just before getting to the level desert, there is a long, level black-lava ridge, very rough and rocky, and some 400 feet high. One-half mile south of this ridge, across a deep cañon, is another similar ridge, and on this one is located station T 88, marked by drill hole in rock, pole, and cairn.

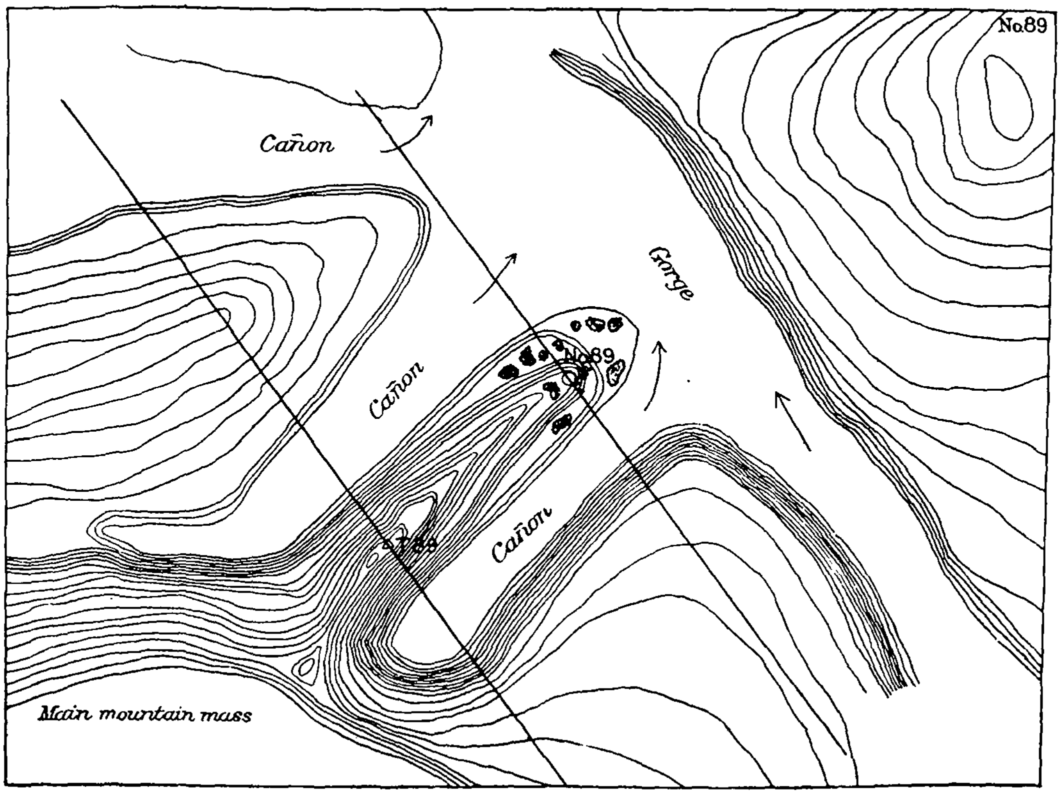


Point on corrected line, "No. 88," put in at right angles to line, from old point, to eastward, distant 74·04 meters. Marked by drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 88," and a cairn around post. A short distance west of station, on same ridge, there are two small lava peaks some 25 feet high. Station most easily reached from Staininger's ranch. Leave the road about 3 miles from the ranch, and turn up a big wash to the south. This wash heads up against the ridge on which station is located, and is about one hour's ride from ranch.

T 89.

Station is on the first prominent rocky ridge of the Grape Vine Mountains that the line crosses. The ridge is very steep and sharp, and the point can only be approached by going to the top of mountain of which ridge is part and descending down the point of ridge to station. Marked by drill hole in rock, pole, and small cairn.

Point on corrected line, "No. 89," was lined in from stations No. 86, No. 87, and No. 88, it being impossible to measure from the old point in any way. The station is about 15 feet back or west from the edge of a cliff that goes down perpendicularly for at



least 800 feet. Marked by drill hole in solid rock, a nut-pine pole, and a cairn; drill hole 3 feet north of pole. The only way to reach station is by coming down the spur of the ridge from old station, an extremely dangerous and hazardous undertaking, the spur being like a knife edge, composed of enormous granite rocks and cliffs, much cut up by cañons. It is at least seven hours' ride and climb to reach this point from Staininger's ranch, and is a very hard trip. On the summit of this ridge or mountain is located T 89 High station, marked by drill hole, pole, and pile of stones.

T 90.

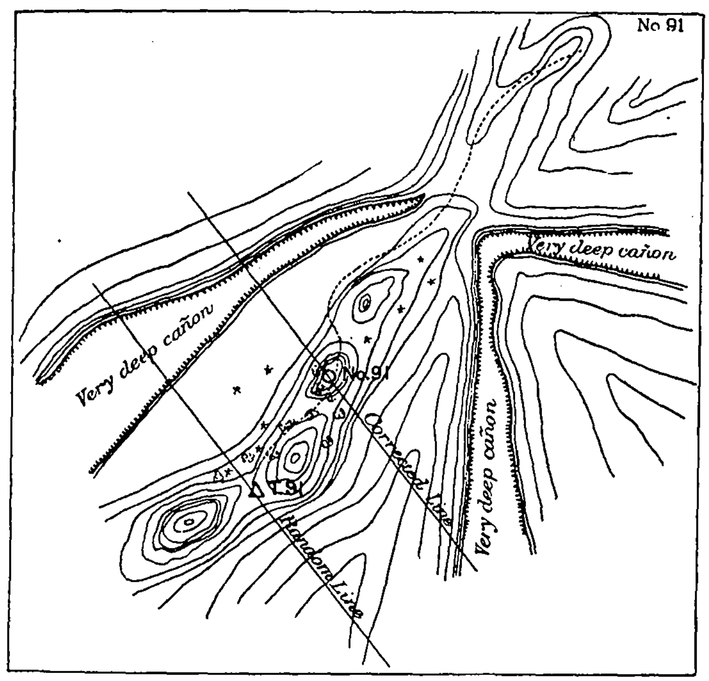
This station is on the southwestern slope of one of the main ridges of the Grape Vine Mountains. It is on a rocky bluff of the ridge, and from the point the mountain falls off nearly perpendicularly, 800 feet, into a cañon which opens into Death Valley. The

Sylvania Mountains can be seen from this point. The ridge is covered with a growth of nut pine, as are all of the mountains at the higher elevation. Station "Grape" is on the summit of this ridge.

The point on the corrected line, to be "No. 90," was omitted at this point, as it was found to be impossible to measure the offset, high, sharp, needle-like rocks and cliffs being to the northeast, with deep cuts between them, and there were no line points visible by which the station could be lined in, the stations to the northwest not being in at this time. The offset to the eastward to the line from old point is 77·70 meters. Old point marked by drill hole in solid rock.

T 91.

This station is on the third of the high ridges of the Grape Vine Mountains as the line crosses them, counting from the north. The point is on the summit of the ridge and on nearly the highest part. The ridge has a good growth of nut pine, and the



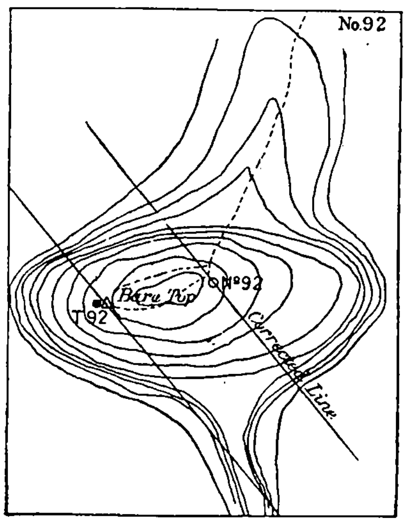
mountain is composed of shale rock, very loose and difficult to get animals over. The point is about one and three-fourths hours' ride from the Big Spring camp in the Grape Vine Mountains. Station marked by drill hole in solid rock and nut-pine pole.

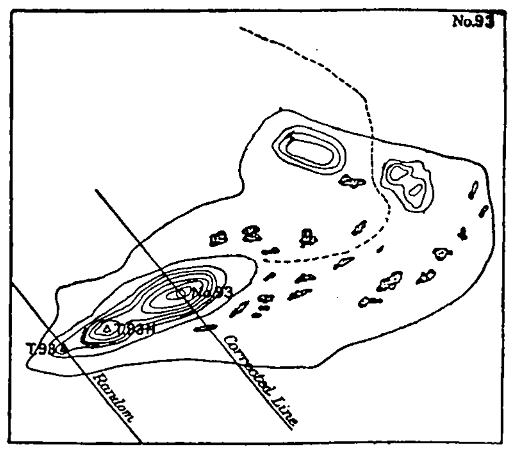
Point on corrected line, "No. 91," put in at right angles to line from old station, to eastward, distant 79·53 meters, thence 97·05 meters northwest in direction of line to place the point on top of ridge. It is on the eastern slope, about 50 feet west of the saddle, and just under a very rocky point of sharp, jagged rocks. Marked by drill hole in large rock; over this a 4-inch by 4-foot pine post and a large cairn around post. To reach this point, follow up the cañon at the mouth of which the Big Spring is to the top of ridge; then follow the ridge around to the south to the point. One of the deepest cañons in the Grape Vine Mountains is just west of this point.

T 92.

Station is about 20 feet lower than summit and on south slope of a bare mountain. Top is covered with loose, brownish sandstone. It is the most easterly of the main ridges of the Grape Vine Mountains, and commands the line for 60 miles to the southeast. It overlooks one reach of Death Valley running north and south, and also a portion of that part which runs northwest and southeast. It is just east of a very rough and deep cañon that runs south and bends slightly to the west to enter Death Valley. A small outcropping of stones is at the station, which is marked by a drill hole in rock, pole, and pile of stone.

Point on corrected line, "No. 92," put in at right angles to line from old station, to eastward, distant 81·00 meters, thence 24·00 meters southeast in direction of line to place point on top of ridge. Station is on eastern slope, about 75 feet from the top. Marked by drill hole in large stone set in position and a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 92," with a cairn of stone and gravel thrown up around post. Station is about four hours' ride from the Big Spring, but a very hard ride and a very rough one for both man and beast.





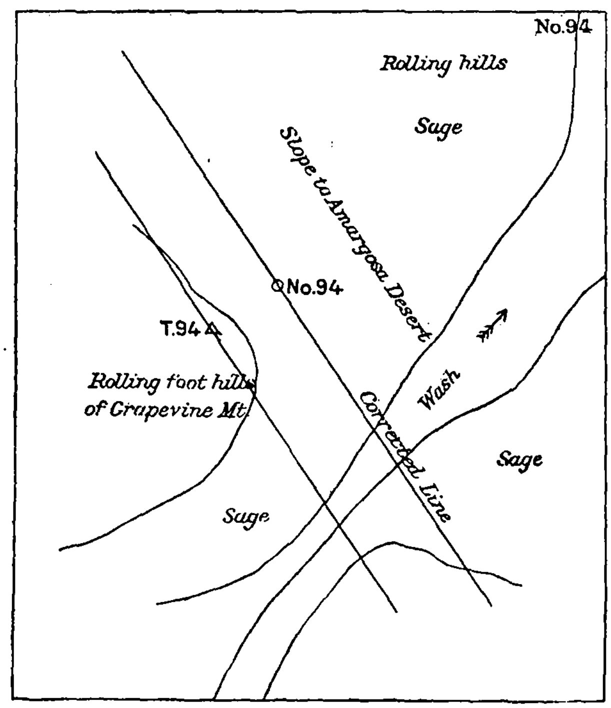
T 93.

This station is about 1 mile east from Daylight Spring, on the high, bare, rocky peak on the south side of the cañon that extends from Daylight Spring to the Amargosa Desert. The whole top of this peak is a black lava rock, very rough, and with cliffs on three sides. Station is on the west side of the mountain, about 200 feet below the summit, and on the edge of a bold rocky cliff, a difficult place to reach. Cliff from top to bottom is about 300 feet. Marked by drill hole in solid rock, pole, and cairn. Station T 93 High is on the same peak, about 150 feet east and about 100 feet higher, still not on the summit. Marked by drill hole, pole, and pile of stones. It is on the top and edge of another cliff.

Point on corrected line, "No. 93," lined in from back stations, is on the highest point of the rocky peak, about in the center, marked by drill hole in the solid rock, over which was put a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 93," and a large cairn built around post. This is a very prominent peak and mark, and the cairn can be seen for a long way out on the Amargosa Desert, and is plainly visible from Daylight Springs. This spring is on west side of Amargosa Desert, about 15 miles from Beatty's Ranch.

T 94.

This station is on the eastern slope of foothills of the Grape Vine Mountains, nearly down to the Amargosa Desert flat, and about 5½ miles southeast from Station T 93. The slope is bare, with the exception of some scattered grease-wood brush and very few



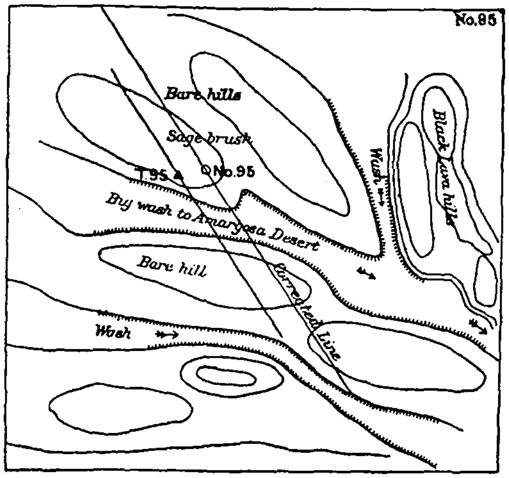
rocks. About three-fourths of a mile to the east there is a small white butte standing out in the desert. Detached hills 2 miles to southeast. Station marked by drill hole in rock and cairn.

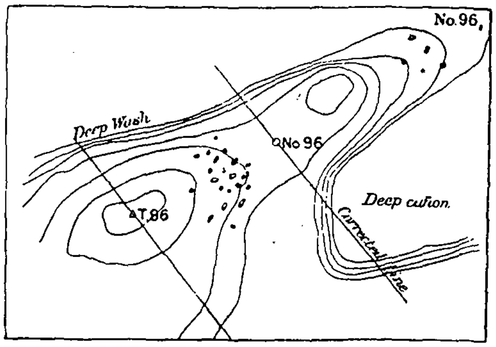
Point on corrected line, "No. 94," put in at right angles to line at old station to eastward, distant 86·55 meters. Marked by a 4-inch by 4-inch by 4-foot pine post marked "C. N. 94." Set firmly in the ground just southeast of post, and touching it, a large stone with drill hole in it, and a cairn of stone and gravel thrown up around post and stone. The little white butte, the mouth of the Little Amargosa River, and the station are all in line. Stations T 94, 95, 96, and 97 were all put in from a dry camp in the Amargosa Desert, all the water being hauled from the spring at the mouth of the Little Amargosa River, about 2 miles below the Beatty Ranch.

T 95.

Station is on the southeast slope of the ridge of the foothills of the Grape Vine Mountains, along which the line runs, the slope leading down to the Amargosa Desert. The slope is well cut up by dry washes, and this point is on the divide between two of these washes, which extend down and pass south of a mass of detached hills out in the desert to the east. Station marked by drill hole in rock, pole, and pile of stones.

Point on corrected line, "No. 95," put in at right angles to line from old station to eastward, distant 87·26 meters; thence southeast in direction of line 14·38 meters to place station on top of ridge. Marked by drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 95," and a cairn around post.





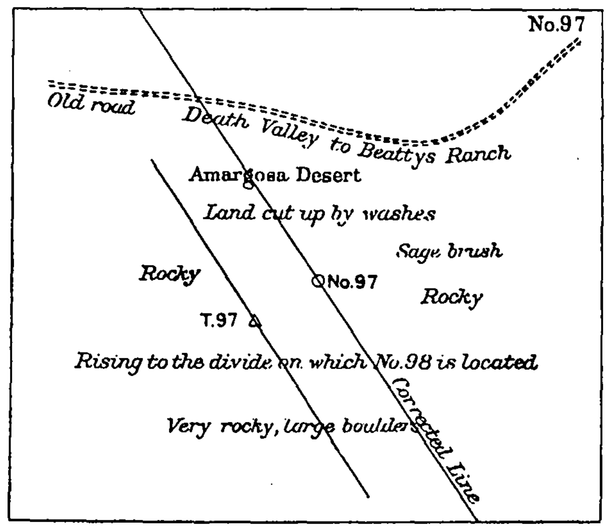
T 96.

This station is on the north slope of a prominent cone-shaped peak about the center of the group of low foothills of the Grape Vine Mountains, on the west side of Amargosa Desert; and the first prominent foothills north of the great wash between the Grape Vine and Funeral Mountains, up which a road goes from the desert over into Death Valley. Station is on the highest of this group of foothills, marked by drill hole in stone, pole, and pile of stones.

Point on corrected line was lined in from No. 95 and No. 98; it is on the same ridge as the old station, only some 40 feet lower, and is in a little saddle. Marked by drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 96," and a cairn around post. The road from the Little Amargosa River, across the desert to near T 97, passes to the east of this station about 2 miles.

T 97.

This station is on the open mesa. There is a pass between the Grape Vine and Funeral Mountains, through which a road goes from the mouth of the Little Amargosa River across the upper part of the Amargosa Desert and over into Death Valley, an old road not much used. The station is on the slope that rises from the Amargosa Desert up to this pass, is about 2 miles from the flat desert and some three-fourths of a mile



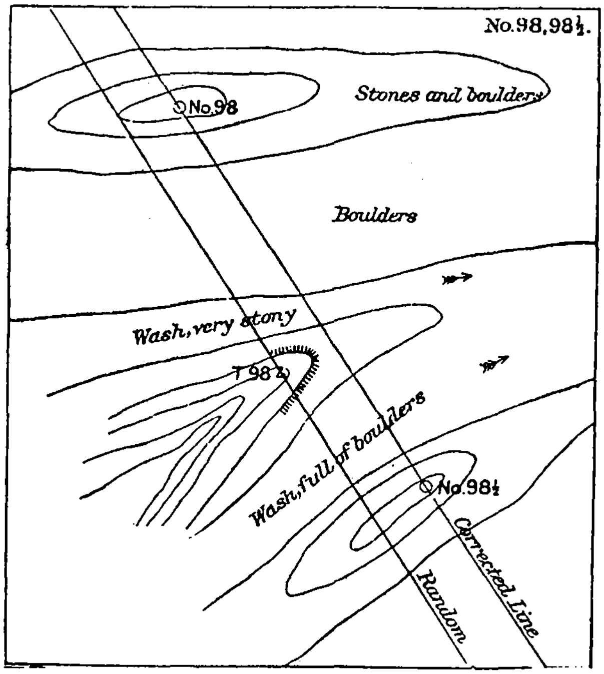
south of the road. Land at station rolling and rocky, cut up by many small washes and covered by sagebrush, grease wood, and cacti. Marked by drill hole in rock, pole, and cairn.

Point on corrected line, "No. 97," put in at right angles to line from old station to eastward, distant 90·94 meters; marked by a 4-inch by 4-inch by 4-foot pine post, set firmly in the ground and marked "C. N. 97." Around post there was thrown up a cairn of stone and gravel.

T 98.

Station is on a very rocky ridge (the extreme eastern slope and very near the end of the Funeral Mountains). This is the first and only place where the line touches the Funeral Mountains, and it enters just south on to the plain of the Amargosa Desert. About 1½ to 2 miles from point is a group of detached hills, on one of which the station Funeral is located. Point marked by drill hole, pole, and cairn.

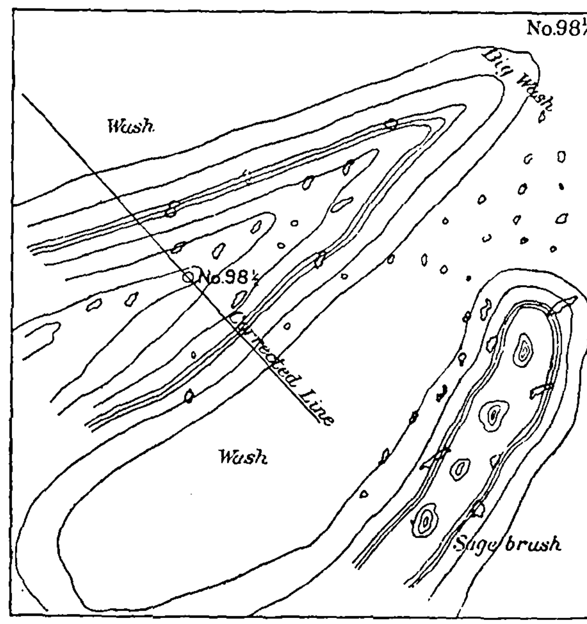
Point on corrected line, "No. 98," lined in from station No. 98½. It is about 300 meters northwest of where the point on the corrected line at right angles to the old



station would fall. It is on the highest part of the divide, between the Funeral Mountains and group of detached hills to the eastward, and just north of a big wash that leads down into the Amargosa Desert to the south. Ground rough, rocky, and very much cut up by washes, with some sagebrush and grease wood. Point marked by drill hole in large bowlder, a 4-inch by 4-inch by 4-foot pine post, marked "C. N. 98," and a cairn 6 feet high around post and bowlder. This cairn is very prominent from the south.

No. 98½.

This station is on the point of the Funeral Mountains, southeast, and next to the point on which T 98 was located, and is about 200 meters southeast of where the point on corrected line at right angles from old station would fall, and is on the second black rocky point south of the divide on which No. 98 is located, about 100 yards from the end of the point of the rocky incline. Station was lined in from stations No. 99 and No. 100. A big wash comes down from the Funeral Mountains between this station

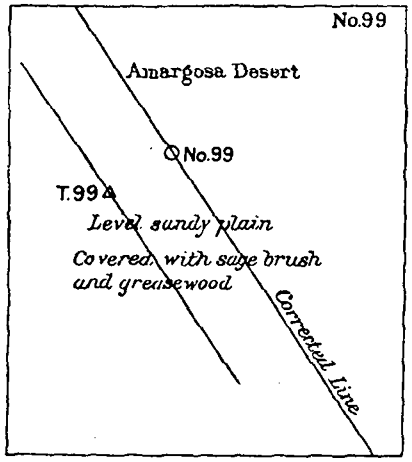


and the old station, T 98, and flows into the Amargosa Desert to the south. The rise from the desert to the top of the divide is very rough and rocky, cut up by numerous washes, all full of bowlders. Sagebrush, grease wood, and cacti cover the ground.

Station marked by drill hole in solid rock. Over this a 4-inch by 4-inch by 4-foot pine post marked "C. N. 98ª," and a large cairn around post. Just southeast of point are four small detached rocky knobs lower than No. 98½.

T 99.

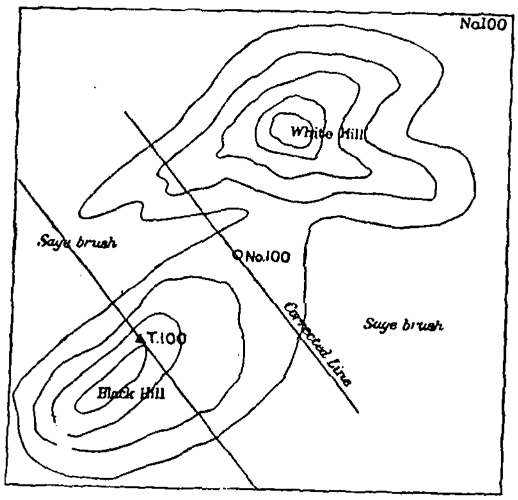
Point on corrected line, "No. 99," put in at right angles to line from old station to eastward, distant 94·17 meters, marked by a 4-inch by 4-inch by 4-foot pine post marked "C. N. 99," set firmly in the ground and a mound of sand thrown up around post. A



circular trench 12 feet in diameter was dug around mound. Land at station loose, sandy desert with scattering grease wood. This is the first station in the Amargosa Desert south of Funeral Mountains, and is about 9 400 meters from T 98.

T 100.

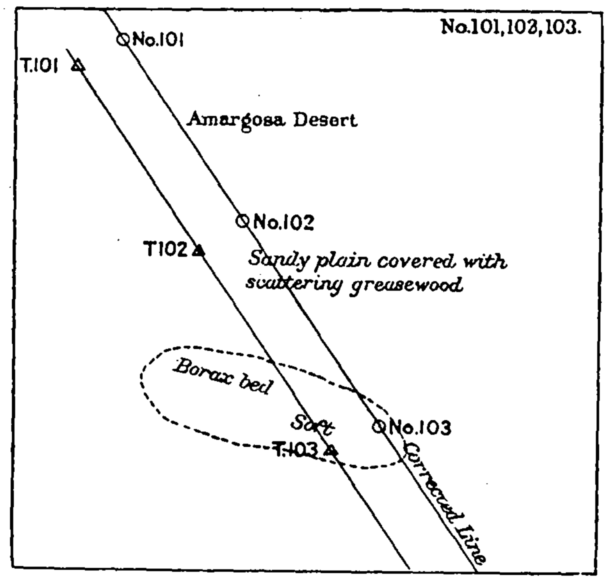
Station No. 100 is the second in the Amargosa Desert going southeast and is 7 589 meters from T 99. Put in at right angles to line from old station to eastward, distant 95·95 meters, marked by a nut-pine stick hewed roughly to about 1½ inches by 3 inches



by 6 feet long, marked "C. N. 100," a stone with drill hole in it placed southeast of pole and a cairn built around stone and pole. Station falls in a saddle between two low hills, the western one covered with dark colored lava rock and the eastern one rocky and light colored. Cairn shows well from both northwest and southeast.

No. 101.

Point on corrected line is at right angles to line from old station to eastward, distant 97·63 meters, marked by a 4-inch by 4-inch by 4-foot pine post marked "C. N. 101," and set firmly in the ground. A large stone with a drill hole in it was set just southeast of post, and a cairn of stone and sand built around post and stone. A circular trench was dug around cairn. Land is level, sandy desert, with scattered grease wood.



No. 102.

Point on corrected line put in at right angles to line from old station to eastward, distant 99·23 meters, marked by a 4-inch by 4-inch by 4-foot pine post marked "C. N. 102," firmly set in ground, and a mound of sand thrown up around post. A circular trench 12 feet in diameter dug around mound.

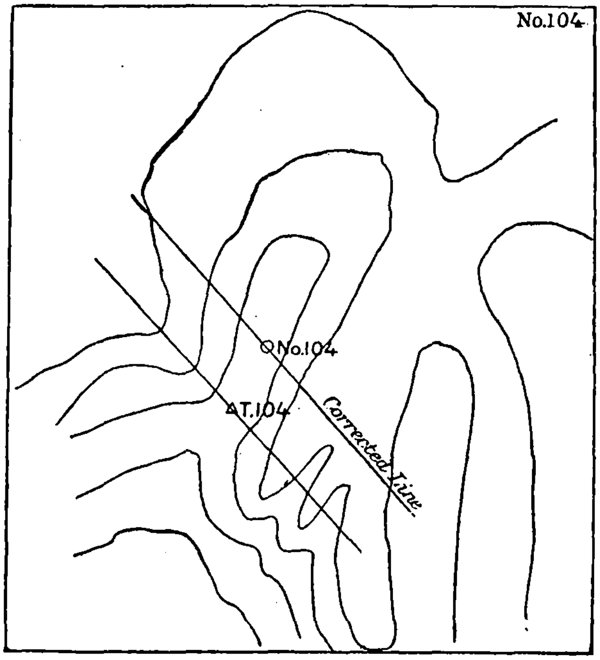
The old station was also the north end of the Amargosa Base Line, marked by a drill hole in stone. Ground level and sandy with some scattered grease wood.

No. 103.

Station on corrected line put in at right angles to line from old point to eastward, distant 100·68 meters, marked by a 4-inch by 4-inch by 4-foot fir post marked "C. N. 103," set firmly in the ground. Around the post was thrown up a mound of earth. This is the lowest line station in the Amargosa Desert, and is located on the eastern edge of a borax bed. Southeast side ground is soft and spongy.

No. 104.

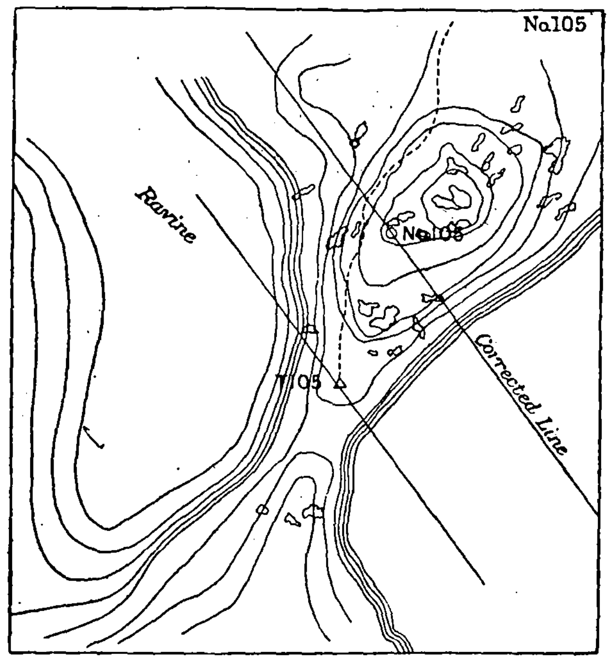
Station on corrected line put in at right angles to line from old point to eastward, distant 101·68 meters, thence northwest 50 meters in direction of line, marked by drill hole in stone set in position, over which was set a 4-inch by 4-inch by 4-foot fir post



marked "C. N. 104," and a cairn built around same. Station is on the rolling mesa, rising gently to the south. Gravel covered with sparse growth of sagebrush and grease wood. About 2 miles east from this station there is a range of bare hills, on the highest of which is located Station Hunch.

T 105.

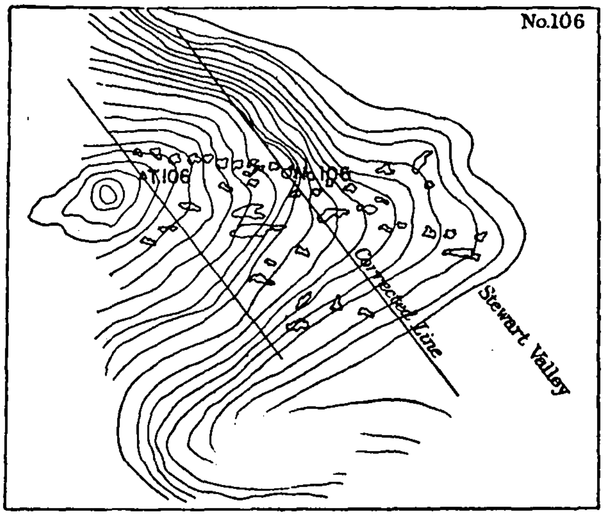
This station is on an eastern spur of the Chung Up Mountains, the dividing ridge between the Amargosa Desert on the north and Stewart and Pahrump valleys on the south. Station is well to the west, near to where the spur joins the main range of mountains, and in the first low sag east of the main summit. Station falls on eastern slope of sag 22 meters from the lowest part, marked by drill hole in solid rock and large cairn.



Point on corrected line, "No. 105," lined in from stations No. 106, No. 107, and No. 108. It is on the rocky peak, just east of low sag, about 1 mile east of the highest point of the northern part of the Chung Up Mountains. It is on the third rocky knob, on the first rise east of the sag and about 40 feet west of the summit, on a rocky ledge just west of some large projecting black rocks, marked by drill hole in solid rock. A 4-inch by 4-inch by 4-foot pine post marked "C. N. 105," with a large cairn around post. The whole of the Amargosa Desert and also Pahrump Valley are visible from this point. T 105 High is on the summit of the higher point, some 400 meters to the eastward, marked by a drill hole and cairn.

T 106.

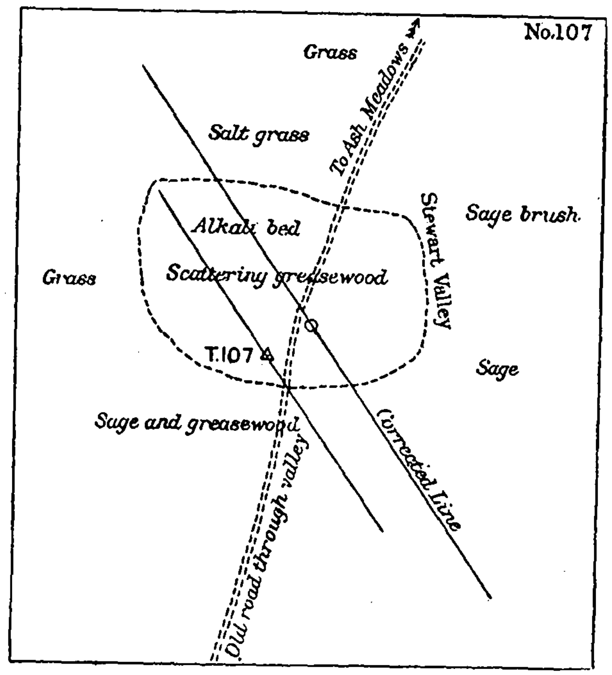
Station is on a rocky spur extending to the north from the Chung Up Mountains and about 3 miles southeast from "T 105." It is a sharp, black, very rocky ridge, rising abruptly from the west side of Stewart Valley. It is on the northeast slope, about one-third of the distance down from the summit.



Station "No. 106," lined in from stations No. 107, No. 108, No. 109, marked by drill hole in solid rock. Over this a 4-inch by 4-inch by 5-foot pine post marked "C. N. 106," and a cairn around post. This station overlooks the whole of Pahrump Valley clear to the State Line Mountains. This point can best be reached from the road going down through Stewart Valley, and is some 3 miles west of said road.

T 107.

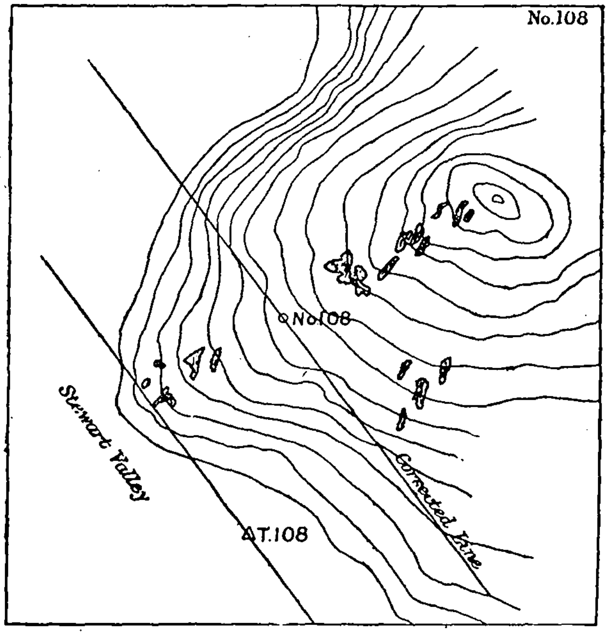
Station is about in the center of Stewart Valley, among the sagebrush on a hard, white alkali lake or flat, and about 1 mile south of the grassy part of the valley. It is about 300 feet west of the road that goes from the northeast end of this valley south to a pass, then over into Death Valley, marked by a mesquite stub 3 feet long set in the ground, a pole and mound of earth.



Point on corrected line, "No. 107," put in at right angles to line from old station to eastward, distant 105·59 meters, marked by a 4-inch by 4-inch by 5-foot pine post marked "C. N. 107," set in the ground, and a mound of earth thrown up around post. Station in hard, white alkali, and 50 feet east of road leading up valley. A deep trench encircles the mound.

No. 108.

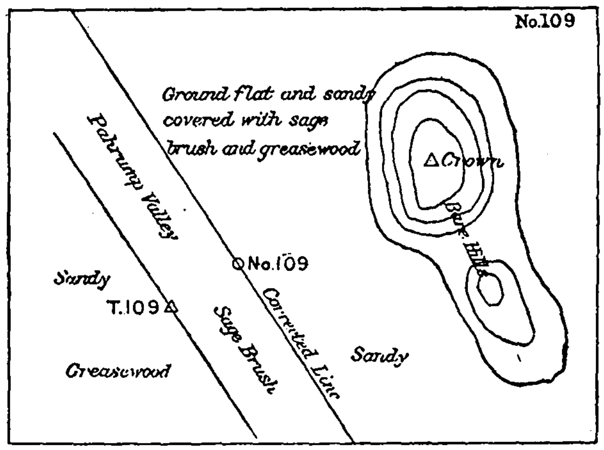
Station was lined in by the stations from No. 109 to No. 115, all of them falling exactly in line. Marked by drill hole in solid rock, over which was set a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 108." A cairn of stone was built around post. This station is on the extreme southern end of the range of hills that divides the Pahrump and Stewart valleys. This ridge is high and very rocky at the north end,



gradually getting lower to the south. It is about 10 miles long. Station is on a rocky spur that runs out in a westerly direction from the south end of ridge, projecting into the valley. It is about one-third of the way up to the first summit, about 50 feet higher than the old point, which was in the valley to the south. This point commands all points in the Pahrump Valley up to T 116.

T 109.

Station is in Pahrump Valley, about 5 miles south of the eastern end of the range of hills separating Pahrump and Stewart valleys. It is about one-fourth mile west of a low rolling hill, on the summit of which station Crown is located. Ground flat and sandy, covered with sagebrush and greasewood. Marked by drill hole in stone set in position, and a pole.

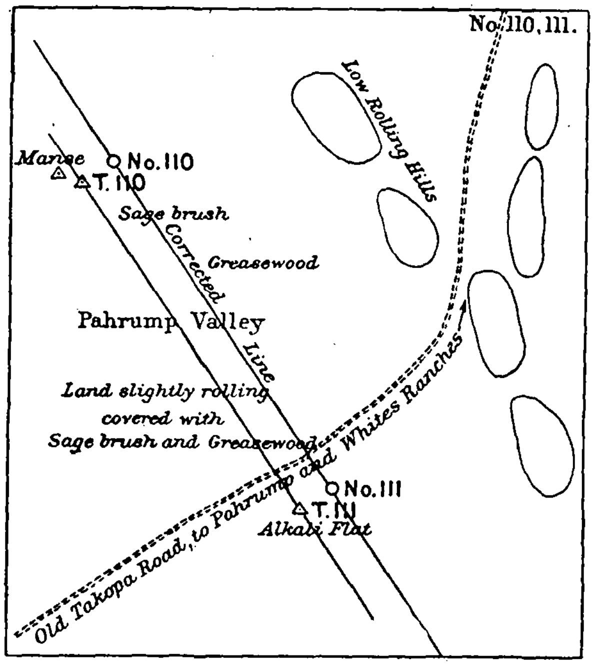


Point on corrected line, "No. 109," put in at right angles to line from old station to eastward, distant 108·35 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 109." A stone with drill hole in it just southeast of post and a mound of earth thrown up around post and stone. Station is best reached from White's ranch (Manse post-office) by following out an old wood road to the west, to the the low hill on which station Crown is located, thence down to T 109.

T 110.

Station is in Pahrump Valley, just west of the low, rolling hills extending through the valley northwest and southeast. Land slightly rolling and sandy, covered with sagebrush and greasewood. Marked by drill hole in rock, and pole. Station Manse is 51·7 meters to the west, marked by stub with nail in it, and pole.

Point on corrected line, "No. 110," put in at right angles to line from old station to eastward, distant 110·37 meters, marked by a 4-inch by 4-inch by 4-foot post,



marked "C. N. 110." A stone with drill hole in it placed just southeast of post, and a mound of earth thrown up around post and stone. Most easily reached from the White ranch, by following wood road to the west.

T 111.

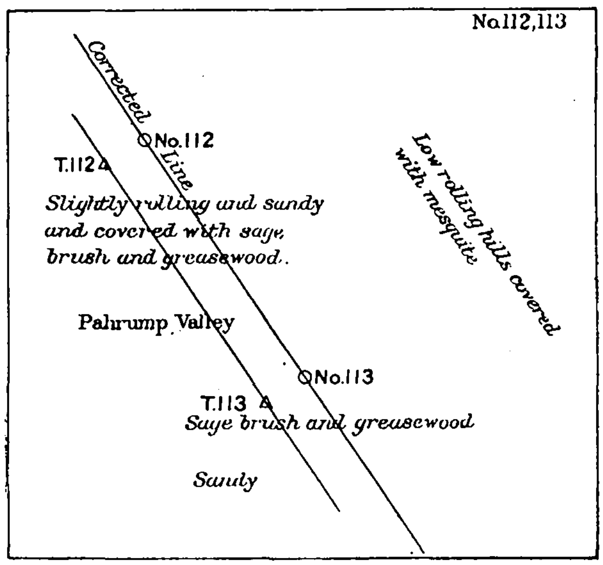
Station in Pahrump Valley, west of rolling hills in center of valley, on level alkali plain covered with sagebrush and greasewood and a few small stones. Station is about one-half of a mile south of the old Tekopa road, from White's ranch (Manse), to Tekopa mining camp, and about the same distance west from the low sand hills, reached from White's ranch by following the old Tekopa road through the sand hills to the Alkali Lake, thence southeast to station, marked by drill hole in rock and a pole.

Point on corrected line, "No. 111," put in at right angles to line from old station to eastward, distant 111·09 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 111." Set in the ground, just southeast of post, was placed a stone with drill hole in it, and a mound of earth thrown up around post and stone.

T 112.

Station in Pahrump Valley, just west of the rolling sand hills and 3·4 miles southeast from T 111. Land slightly rolling and sandy, covered with sagebrush and greasewood, and with a few stones scattered about. Marked with stone with drill hole, and pole.

Point on corrected line, "No. 112," put in at right angles to line from old station to eastward, distant 113·58 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 112," set in the ground. Just southeast of post was placed a stone with drill hole in it, and a mound of earth thrown up around post and stone.



T 113.

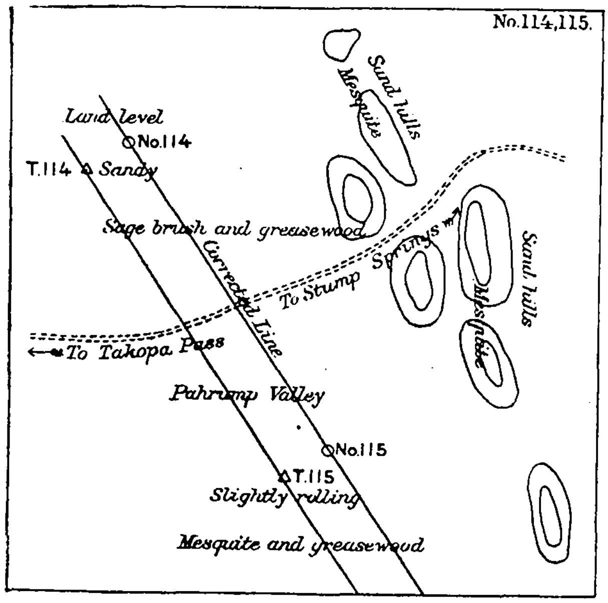
In Pahrump Valley, just west of rolling sand hills and 1 mile southeast from T 112, in hard, sandy plain, covered with sagebrush and greasewood. Marked by drill hole in stone set in position, and pole.

Point on corrected line, "No. 113," put in at right angles to line from old station to eastward, distant 111·22 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, set in the ground and marked "C. N. 113." A stone with drill hole in it placed just southeast, and mound of earth around post and stone. Station about 2¾ miles north of road leading from Stump Spring across valley to Tekopa Pass.

T 114.

In Pahrump Valley, and just west of rolling hills about 2¾ miles from Stump Springs, and about three-fourths of a mile north of the road from Stump Springs to Tekopa Pass, where the line crosses. Land level and sandy, covered with sagebrush and greasewood, marked by drill hole in set stone, and pole.

Point on corrected line, "No. 114," put in at right angles to line from old station to eastward, distant 113·57 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 114," set in the ground. A stone with drill hole in it placed just southeast, and a mound of earth then thrown up around post and stone.



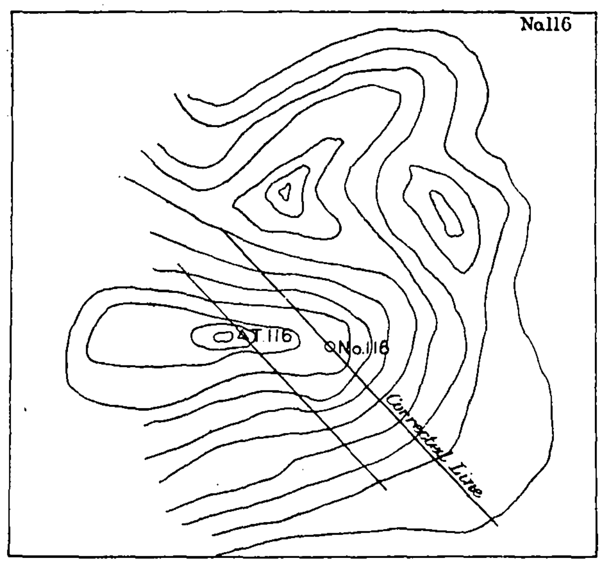
T 115.

This is the last station in Pahrump Valley before reaching the high, bare ridge upon which T 116 is situated. It is about three-fourths of a mile southeast of the Stump Spring and Tekopa Pass road where the line crosses, and some 2 miles from Stump Springs. Land level and sandy, with high sagebrush. Marked by drill hole and post.

Point on corrected line, "No. 115," put in at right angles to line from the old point to eastward, distant 112·40 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 115," set in the ground. Stone with drill hole, set southeast, and a mound of earth around post and stone.

T 116.

Station is on the highest one of a chain of bare hills about 4 miles south of Stump Springs, extending about east and west and nearly dividing Pahrump Valley. The part of the valley south of this chain of hills is sometimes called Mesquite Valley. Station is about south from Stump Springs, on the highest of the hills. It is in a sag just to the east of the highest point. Hill bare, with a few scattering sagebrush, and ground covered with small loose stones. Marked by drill hole in large rock, and signal pole.

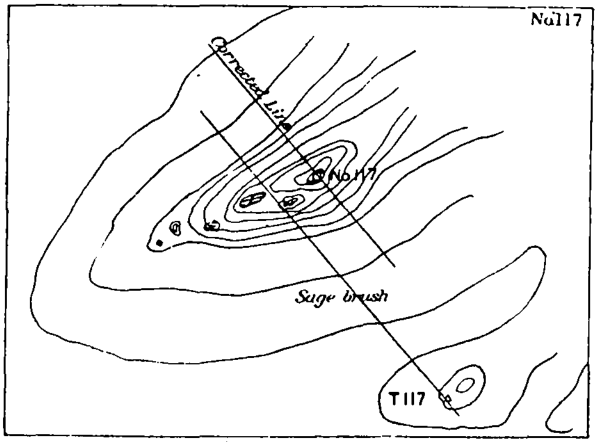


Point on corrected line, "No. 116," was lined in from No. 117, marked by drill hole in rock, over which was placed a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 116," surrounded by a cairn of rocks. This station is easily reached from Stump Springs, from which place it is visible. Ground at station is rocky. Station T 105, 34·8 miles to the northwest, and T 123, on the State Line Mountains, 26·3 miles southeast, are both visible from this station.

T 117.

Station is on a bare and very rocky black lava peak that juts out to the westward from the high black buttes that are in the center of Mesquite Valley. It is on the eastern slope and about 100 feet from summit, where is located station T 117 High. Both stations marked by drill holes in rocks, and poles.

Point on corrected line, "No. 117," was lined in by stations No. 118, No. 119, and No. 120, and is on the black, rocky point of the mass of Black Buttes that are in Mesquite Valley. The point is very rocky and rough, and full of holes and caves on



the south side. Station is on the third rocky knob from the northwest end, a great mass of black lava rock, and is on the highest part of knob, marked by drill hole in the solid rock. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 117," and a cairn built around post. This is a very conspicuous mark. About three-fourths of a mile south of station there is an isolated light-colored butte. T 117 High is about three-fourths of a mile southeast from station. Place best reached from Sandy post-office; leave Stump Springs road just before reaching the Black Butte; keep around it on south and west sides to T 117 High, and T 117, three-fourths mile northwest.

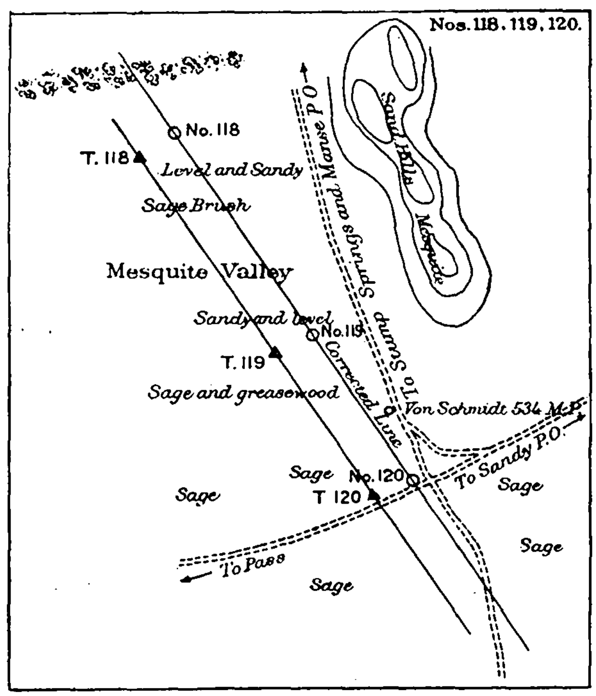
T 118.

Station is in Mesquite Valley, the first station southeast of the Black Butte. It is in a level, sandy plain covered with sagebrush and greasewood. Is about three-fourths of a mile southwest from the Pahrump and Manvel road, and about 300 yards south of a belt of greasewood and mesquite that extends nearly across the valley east and west. Marked by a stone with drill hole in it set in position, and a pole.

Point on corrected line, "No. 118," put in at right angles to old station, to eastward, distant 120·17 meters marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 118," set in the ground. A stone, with drill hole in it, placed just southeast of post, and two bottles, one northeast and one southwest of post. A mound of earth was then thrown up around post, stone, and bottles. Station most easily reached from Sandy post-office by following out the Pahrump road some 5 miles, thence to the west to station. T 118 is almost due north of the largest of a group of sand hills partially covered with mesquite, on which station Snow is located, and is distant from it about 1¼ miles or 2 146 meters.

T 119.

Station is in Mesquite Valley, about one-third of a mile southwest of the Pahrump and Manvel road, and some 3 miles from Sandy post-office, on level, sandy plain covered with heavy growth of sagebrush and greasewood. To reach station from Sandy follow out the Pahrump road 2½ miles, thence southwest through the sagebrush one-third of a mile to station. The mound can be seen from the road. Old station marked by rock with drill hole and a pole.



Point on corrected line, "No. 119," put in at right angles to line from old station, to eastward, distant 121·17 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 119," with a mound of earth thrown up around post. The mesquite-covered sand hill on which station Snow is located, is west 14° north from this station, distant 3 558 meters.

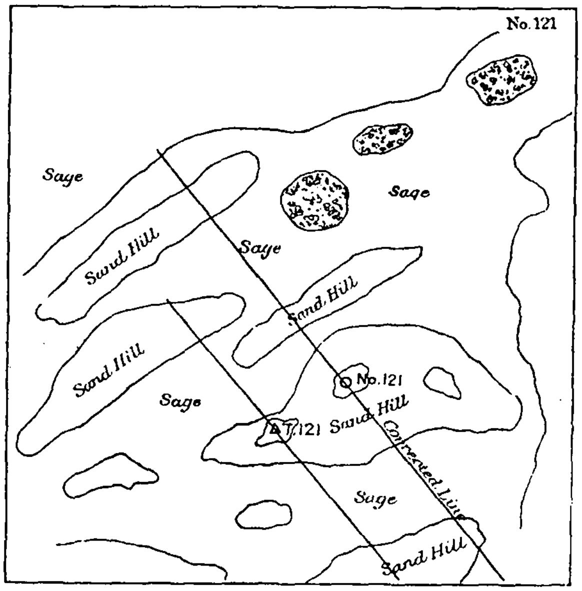
T 120.

Station is in Mesquite Valley, about 1⅓ miles from Sandy post-office, and some 50 feet northwest of the road from Sandy post-office west across the valley to a pass just south of the Kingston Pass, and about 100 yards west of the crossing of the above road with the one from Pahrump to Manvel. In level, sandy plain covered with sagebrush and greasewood. Marked by drill hole in stone and a pole.

Point on corrected line, "No. 120," put in at right angles to line from old station, to eastward, distant 122·01 meters, thence 6·0 meters southeast in direction of line. Station is 7·0 meters southeast from center of road running west from Sandy post-office and 37·0 meters westward from road running from Pahrump to Manvel through State Line Pass, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 120," set in the ground. A rock with drill hole in it was placed just southeast and a mound of earth thrown up around rock and post.

T 121.

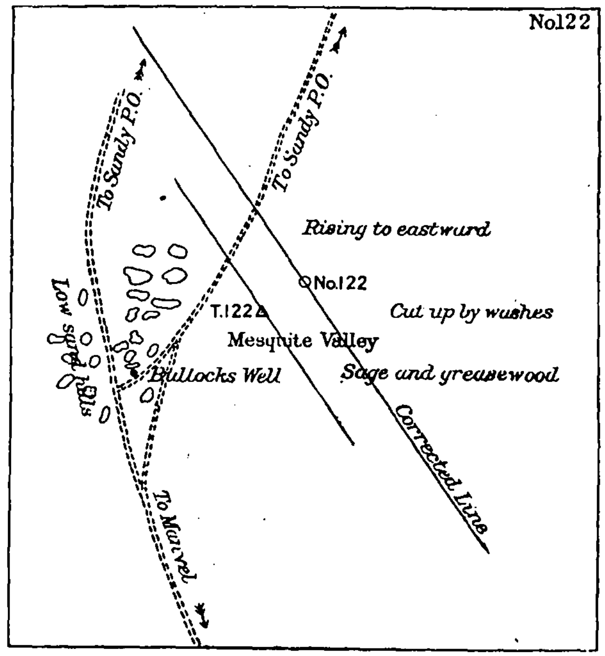
Station is on one of the group of sand hills, some bare and some covered with mesquite, that lie between the lower and upper roads from State Line Pass to Sandy post-office, and about half way from Bullock's well to Sandy, and about 1 mile east of the Oliver Rose Ranch. It is on one of the bare sand hills at the northeast end of the group. Marked by a stone with a drill hole in it and a pole.



Point on corrected line, "No. 121," was lined in from stations No. 119 and No. 120. It is on the highest part of the most northern of the clear sand hills, but to the north of it there are three separate sand hills, all higher and all covered with a mesquite growth. Only sagebrush covers the other hills of the group. Station is marked by a large stone with drill hole in it. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 121," and a large mound of sand thrown up around post and stone. Station is easily reached from the Oliver Rose Ranch, and is about 4 miles from Sandy post-office by the lower road.

T 122.

Station is in Mesquite Valley, about 1 mile above Bullock's well, on the upper road from State Line Pass to Sandy post-office. It is about one-half mile from this road on the slope leading up to the foot of the mountain bounding the eastern side of the valley. Marked by a stone with a drill hole and a small cairn of rocks.

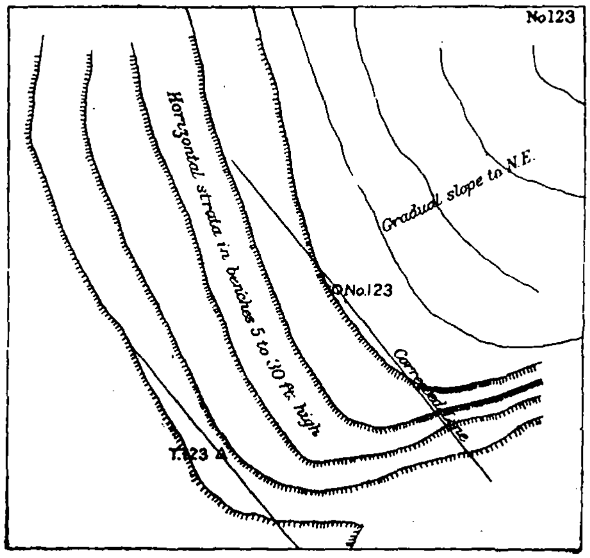


Point on corrected line, "No. 122," put in at right angles to line from old station, to eastward, distant 124·74 meters, marked by a drill hole in stone set level with surface of the ground. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 122." A cairn was built around post. Ground at station gently rising to eastward, cut up by washes and covered with sagebrush and greasewood.

T 123.

This station is on the west slope of the State Line Mountains, on east side of the pass high up near the first top. It is on the sharp saddle of a rock just above a ledge 10 feet high. Fifty feet southeast is a beetling rock, the under part having worn away, leaving a part projecting, under which the line passes. A cross cut on the rock and a pile of stones mark the point. A distinctive description on the slope is almost impossible.

Point on the corrected line, "No. 123," was lined in from the stations No. 126 and No. 127, marked by drill hole in the solid rock. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 123," and a cairn around post. Station is on the first



high point immediately northeast of the State Line Pass. It is on the top of the ridge on the western slope and about 150 feet from the summit. Very rough, rocky, and difficult to get up to this station from the pass.

T 124.

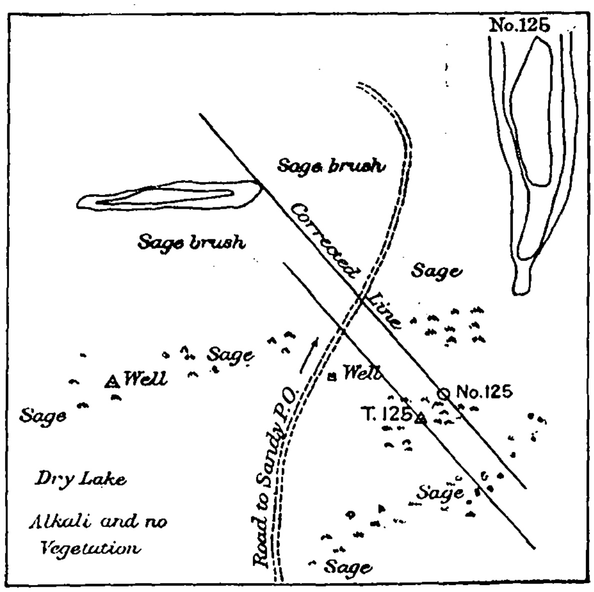
This station is situated on the fourth ledge from the top of the west side of a cliff that is just beyond the summit of the road leading to Ivanpah Valley through State Line Pass. Cliff is on the east side of the pass about one-half mile from where the road crosses. The vertical drop of the cliff is about 30 feet, succeeded by one of 50 feet. The stratification of this mountain was left nearly horizontal in the uplifting, and the weathering has formed a series of benches like the steps of a pyramid. Station is marked by ¾-inch drill hole in the solid rock, a pole, and cairn.

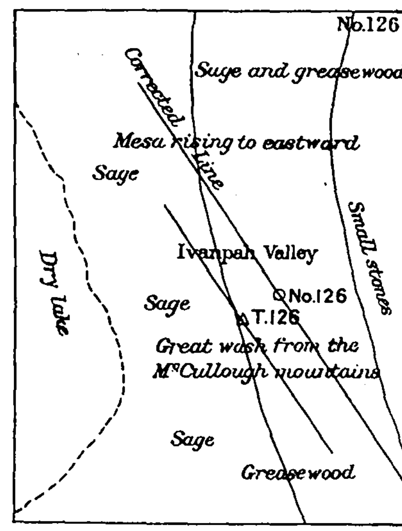
Point on corrected line "No. 124" was not put in at this station, but it would be at right angles to the line from the old station, to the eastward, distant 126·77 meters. Not considered necessary.

T 125.

Station is near the east edge of a lot of sand hummocks, on top of one of them. It is near the east end of Dry Lake, in Ivanpah Valley. These sand hummocks are only about 3 feet high and covered with sagebrush. It is about one-fourth of a mile southwest of the black ridge which terminates the range of mountains and three-fourths of a mile east of an old well near the edge of Dry Lake where the road comes in from State Line Pass. Marked by a stone with drill hole in it and a pole.

Point on corrected line "No. 125" put in at right angles to line from old station, to eastward, distant 128·73 meters, marked by a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 125," set in the ground with mound of earth thrown up around post. Three meters southeast of post in direction of line was placed a stone, top flush with surface of ground and drill hole in rock. The point is clear of the sand hills out in the Dry Lake.





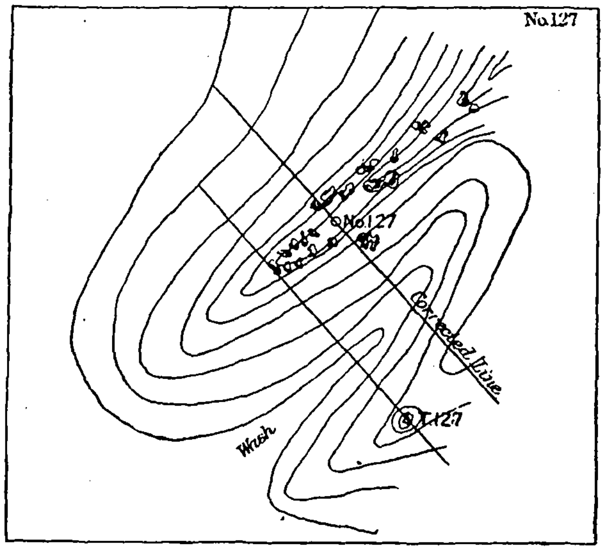
T 126.

Station is located in Ivanpah Valley, on the slope of the mesa, about 2 miles east of the Dry Lake and almost in line between the highest peak of the Mescal range on the west side of the valley and the highest peak of the range on the east side, on the great wash that comes down from the high peak on the east side. Land generally rising to the eastward, sandy, and covered with sagebrush, cut up by many washes with very rocky ridges between them. Marked by drill hole in large rock and a pole with pile of stone.

Point on corrected line, "No. 126," put in at right angles to line, from old station, to eastward, distant 130·09 meters, marked by drill hole in stone. Over this a 4-inch by 4-inch by 4-foot redwood post marked "C. N. 126," and around post a cairn.

T 127.

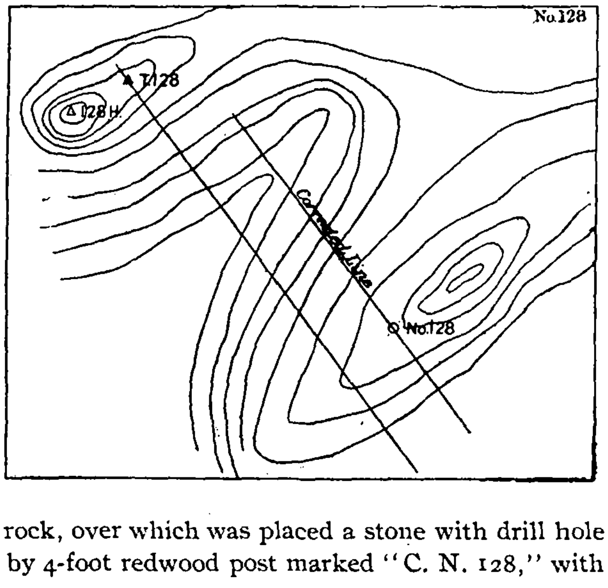
Station is on a rocky point, projecting from the foothills of the McCullough Mountains, extending along the east side of Ivanpah Valley. It is the first rocky point extending into the valley from these mountains, north of the road from the Dry Well to Crossman's Spring and also to Crescent Spring. Station is on the second point south of the most southerly of the two grassy washes in foot of hills, and the third point north of an outstanding black butte, and is between two large washes on west slope of ridge, which is very rocky. Marked by drill hole and pole.



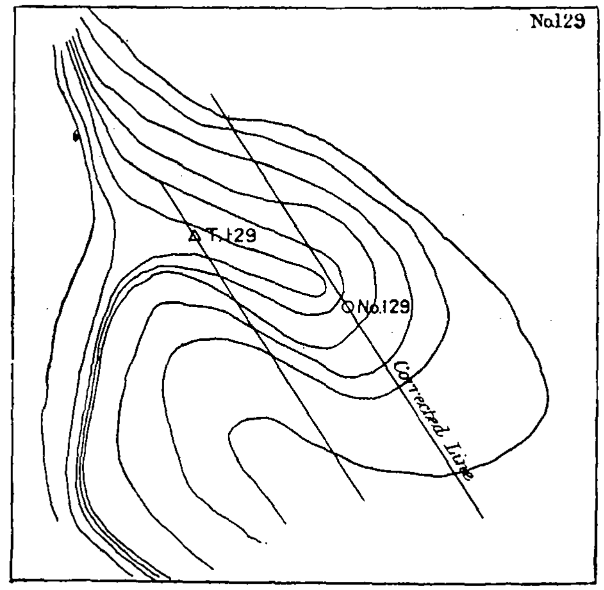
Point on corrected line, "No. 127," was lined in from stations No. 125 and No. 126. Is on the same ridge, but higher up. Marked by drill hole in solid rock. Over this a 4-inch by 4-inch by 4-foot redwood post marked "C. N. 127," with a cairn around post. This point is about 6 miles north of the Dry Well on the Alkali Lake in Ivanpah Valley.

T 128.

Station is on one of the bare peaks of the cluster of hills on the east side of Ivanpah Valley that lie south of the road leading from Dry Well in Ivanpah Valley to Crescent Spring, and also to Crossman's Spring. It is about one-half mile south of the road and about east from the junction of that road with one coming from Vanderbilt. It is in a small saddle on a peak about 150 feet east of the summit on which Station T 128 High is located. Both stations marked by drill holes in rocks, and poles with stones around them.



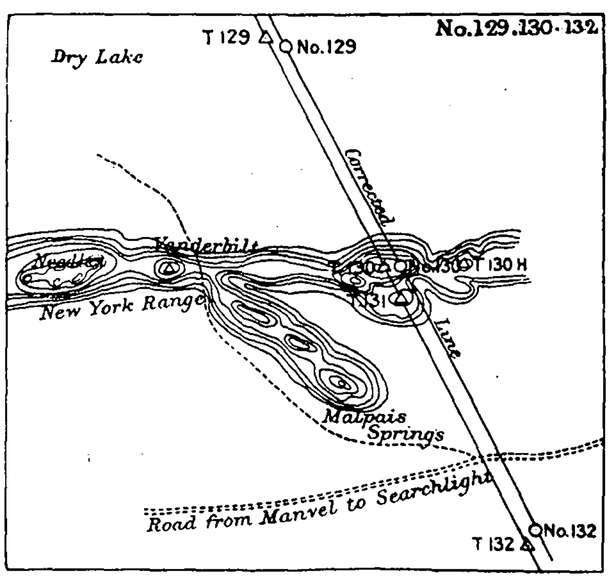
Point on corrected line, "No. 128," was lined in from stations No. 127 and No. 129. Station is on the west slope of the bare hill that is just southeast and across the head of a big wash from T 128, old point. Marked by a cut in solid rock, over which was placed a stone with drill hole in it. Above this a 4-inch by 4-inch by 4-foot redwood post marked "C. N. 128," with a cairn around post. To reach this station follow road from Dry Well to Crossman's Spring for about 7½ miles from the well; thence to the right to foot of hill, about one-half mile distant.



T 129.

Station is on the east slope of the first high ridge north of the New York range, on the southeast side of Ivanpah Valley, and is the first high peak up from the valley. Station T 129 High is on this same peak, to the northward and on the highest point. Both stations marked by drill hole in rock, and pole with stones around it.

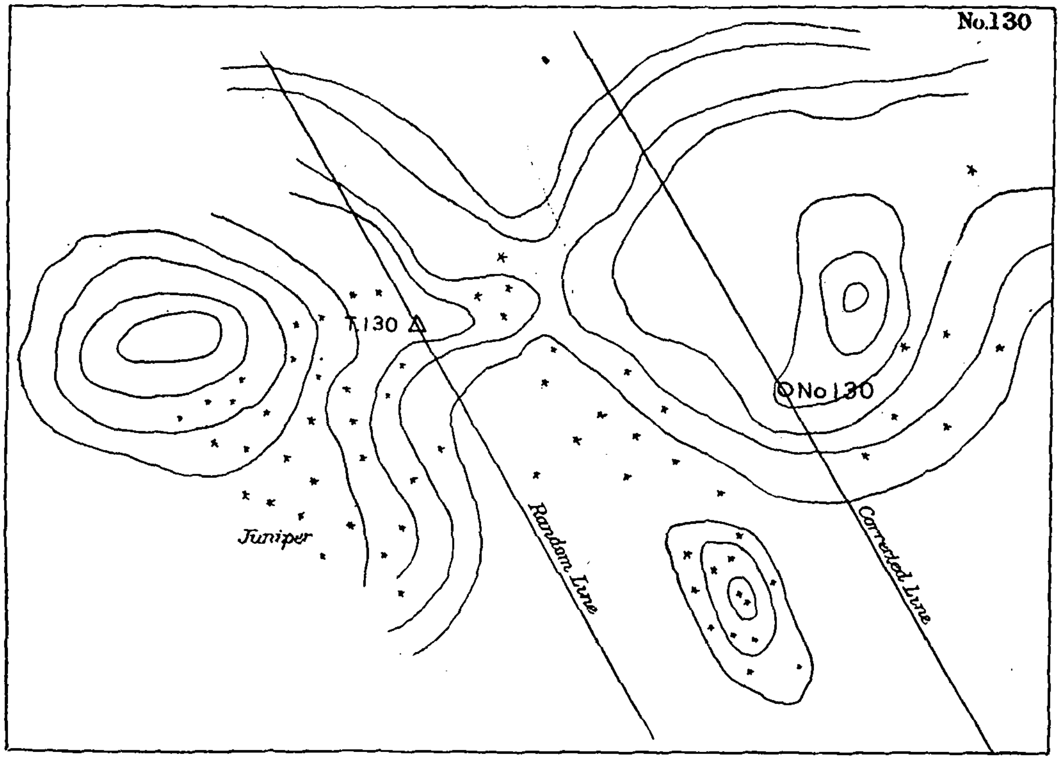
Point on corrected line, "No. 129," was lined in from No. 130. It is on the eastern slop, lower down, marked by drill hole in solid rock. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 129," and a cairn 5 feet in diameter at base and 4 feet high built around post. From Dry Well to foot of ridge is about 9 miles. To get there follow the Crossman's Spring road to the junction of the Vanderbilt road; then south on that road about three-fourths of a mile to the end of black, isolated lava peak; leave the road here and follow up the big wash on south side of peak. This wash heads up against the foot of ridge on which station is located. Can drive to foot of ridge in buckboard.



T 130.

Station is on the east slope of a high mountain in the New York range, about 2½ miles east of the Vanderbilt Needles. Hill covered with nut pine growth. Marked by drill hole in rock, a pole, and pile of stone. Station T 130 High is on the summit of a conical peak about one-third mile east of the station, marked by drill hole and pole.

Point on corrected line, "No 130," was lined in from No. 132. It is on the same ridge as old station, a little north and on opposite side of a wash that heads up against the ridge between the two stations. Marked by drill hole in rock set in position.



Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 130," and around post a cairn. Station is most easily reached from Malpais Springs.

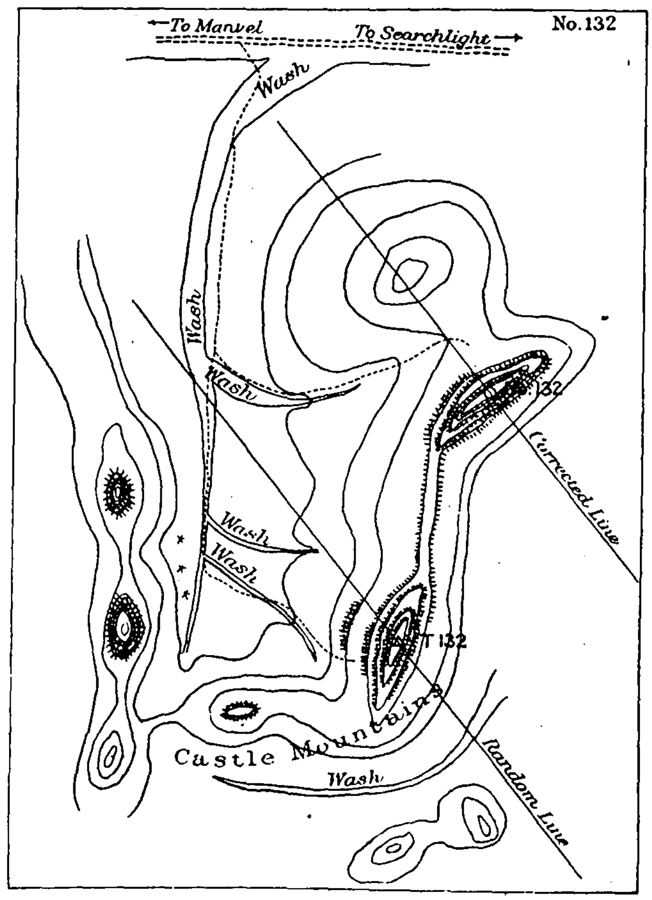
T 131.

Station is on the next ridge to the southeast, or rather a spur of the same ridge, as T 130 and only 237 meters from it. Marked by drill hole, pole, and pile of stones.

Point on corrected line, "No. 131," was not put in, as the station (new) No. 130 commands the line in both directions, northwest and southeast.

T 132.

Station is about 5 miles southeast of the New York range, on the most easterly of a number of high summits in the Castle Mountains. The summits are capped by vertical cliffs. To the west and south are very notable summits, higher than the station and rock capped. The summit on which station is has two ridges, and the station is on the southern and lowest one. Marked by a drill hole in solid rock in a little depression so as to give a place for the instrument. A pile of stone surrounds the pole.

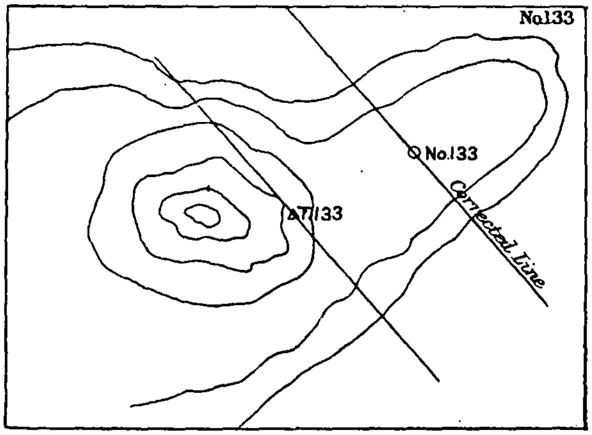


This mountain is south of the road from Manvel to the Search Light Mine and about 3½ miles south of Malpais Springs, where good water may be obtained in abundance.

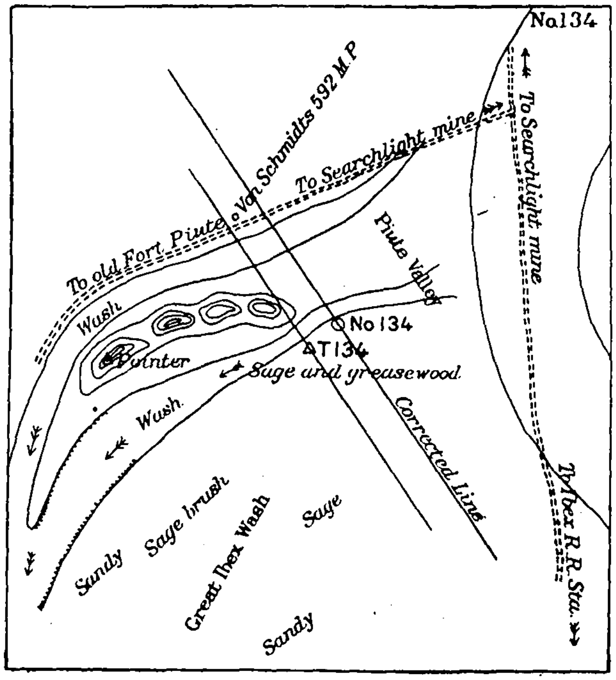
Point on corrected line, "No. 132," was lined in from No. 133. It is on the most northern and highest of the two summits, almost due north from the old station. Marked by drill hole in the rock. Over this a 4-inch by 4-foot redwood post, marked "C. N. 132," with a cairn around post.

T 133.

Station is on the Malpais Mountains, on the west side of Piute Valley and about one-half mile west of the two small black Malpais buttes that are at the southern end of the Castle Mountains. It is a black and very rough and rocky ridge extending to the eastward from the higher mountains to the west. There is a large, deep cañon on the north side, also one on the south side, and the best way up is by the point of ridge between these cañons. Very steep and rocky, this ridge terminates in a round, rough, very rocky knob, with a hogback running down to the eastward. Station is on the top of knob, marked by drill hole in rock, pole, and rock cairn.



Point on corrected line, "No. 133," lined in by stations No. 134 and No. 135. It falls on the hogback to eastward of old station and some 50 feet below it, marked by drill hole in solid rock. Over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 133," and a large cairn. To reach station from Malpais Springs, follow the big wash down Piute Valley for about 8 miles to the rocky, isolated butte in mid valley (has a great cliff on east side); thence across valley to westward to the south end of the two black buttes, and from there climb up ridge to station.



T 134.

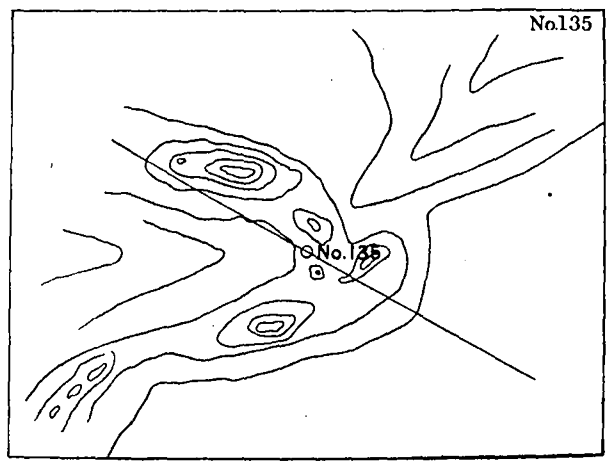
In Piute Valley, about 18 miles from Malpais Springs, and standing out in the great Ibex wash, are four isolated black buttes extending about north and south. The road from Searchlight mine to old Fort Piute, or Piute Springs, passes along the foot of these buttes on the north side, while the road from the Searchlight mine down Piute Valley to the railroad station of Ibex passes about 1½ miles to the east of said buttes.

T 134 is in Piute Valley, some 300 meters east of the eastern end of the four little buttes, on south side of a wash, marked by drill hole in stone set in position, a pole, and mound of sand.

Point on corrected line, "No. 134," put in at right angles to line from old station, to eastward, distant 143·19 meters, marked by a large stone with drill hole in it; over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 134," and a mound of sand and stones 3 feet high and 6 feet in diameter thrown up around post.

T 135.

Station is on the southwest end of a range of black buttes that lie in the middle of Piute Valley, and about 5 miles east of the great Ibex wash. The road from Searchlight mine to Ibex goes by these buttes, leaving them about one-half mile to eastward. On the southwest side of the western butte there are three small, rocky knobs, the upper two being close together. On the upper one is the station, marked by a drill hole



in solid rock, pole, and pile of stone. One-half mile west of station is a small light-colored butte standing out by itself. An old road goes up the wash between this butte and the station.

Point on corrected line, "No. 135," was lined in from No. 137. It is on the southwest butte, about 50 meters east from the top, and in a saddle just below and to the east of a little rocky knob. These buttes are all black, with the exception of the little saddle, which is formed of white granite rock. Station marked by a drill hole in solid rock; over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 135," and a cairn built around post. These buttes are about northeast from Piute Springs and some 10 miles distant.

T 136.

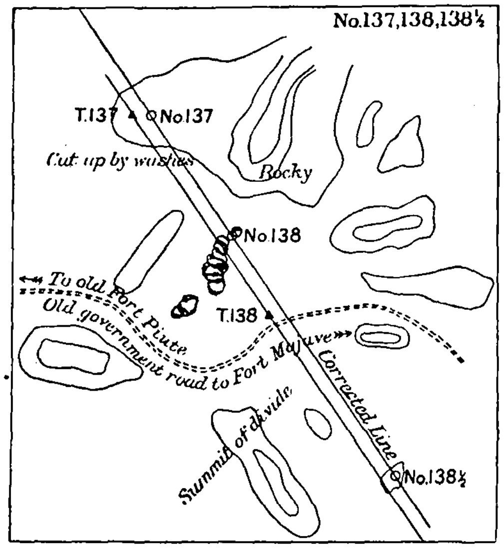
Station is on the first white, gravelly butte south of pass and west of the rough hills that extend from the pass to the north, on east side of Piute Valley. The butte is a white turtle backed one; entirely separated from the main range. On the top is located station T 136 High, marked by cross cut in the rock, pole and pile of stones.

Station T 136 is on the north slope of butte about 75 feet from T 136 High, marked by drill hole in solid rock, pole and pile of stones.

This point was omitted on the corrected line as it fell on a part of the line visible from no other station, and it was not practicable to measure from old station.

No. 137.

About 709 meters northwest of No. 138 on line, on a small rocky ridge on the south side of a large deep wash, is located station No. 137, which was lined in from No. 138. It is on the western edge of the summit of said ridge among some good sized bowlders.



Station is marked by a drill hole in one of these bowlders. Over this a 4-inch by 4-inch by 4-foot redwood post and a large cairn around same. Land rough and rocky, rising to the foothills to the east, covered with sage brush, greasewood, and cacti, and very much cut up by washes.

T 138.

Station is located on the summit of pass between Piute Valley and the Colorado River, and about 80 feet north of the old Government road at its highest point. It is a gravelly knoll and is marked by a drill hole in a large flat rock, pole, and pile of stones.

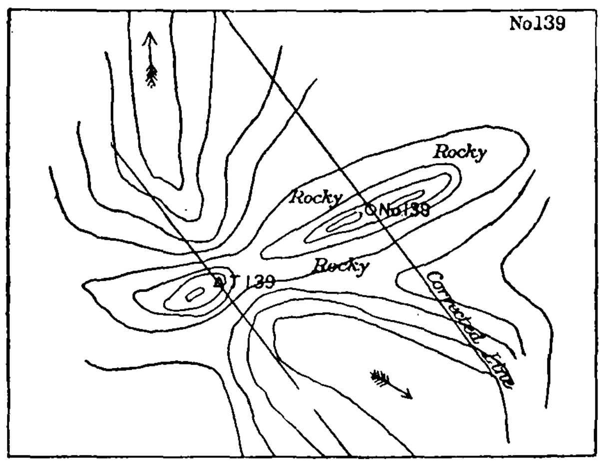
Point on corrected line, "No. 138," was lined in from No. 138½. It is on the northeast end of the large mass of white bowlders that extend down from the Newberry Mountains. These rocks are about 1 000 feet northwest of the old Government road where it crosses the summit, and are very prominent, as they stand up above the gravelly hill on which they are situated, some 25 feet. Station is at the northeast end, and is between two large bowlders which form a gap 10 feet deep and 8 feet wide, the last one to the northeast. Station marked by a drill hole 1½ inches deep in solid rock, and a 4-inch by 4-inch by 4-foot redwood post marked "C. N. 138. S." A cairn, 7 feet base and 7 feet high, built around post. The summit is 12·1 miles from Piute Springs by the old Government road.

No. 138½.

One thousand three hundred and twenty-three meters from No. 138 on the line there is a small rocky ridge that just cuts off the view from No. 138. No. 138½ is on the top of this ridge. The station was lined in from No. 139, marked by a drill hole in the rock, over this a 4-inch by 4-inch by 4-foot redwood post, marked "C. N. 138½" and with a large cairn around same. The random line ran to the west of this rocky peak or ridge and T 139 was visible from T 138, but the corrected line runs through the peak, therefore this extra station was put in. Land cut up by washes, with little rocky knolls and sand hills.

T 139.

Station is on the northeast slope of a rocky knoll about 700 meters east of station Vex, marked by a drill hole in the solid rock, a pole, and cairn around the pole.



Point on corrected line, "No. 139," falls on a rocky ridge just east of this peak and part of the same ridge. It is a saddle between two rocky little peaks, marked by drill hole in rock; over this a 4-inch by 4-inch by 4-foot redwood post with a large cairn around same. Land much cut up by washes, with little rocky ridges and peaks here and there.

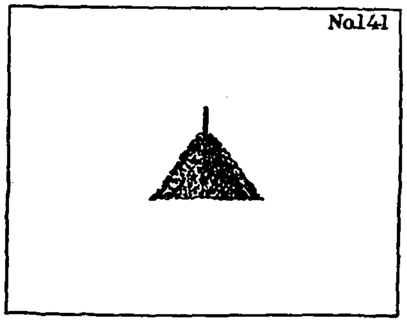
T 140 High and T 140.

Station T 140 High is on the summit of a sharp black cone, jutting up on the northeast end of a black mountain mass like the horn of a unicorn, just above a lot of white formation northwest of the spring in the cañon and 1½ miles from it. T 140 is on the northeast slope of the same cone. Both are marked by a drill hole in a rock with pole and pile of stones.

No. 140 was omitted from the corrected line.

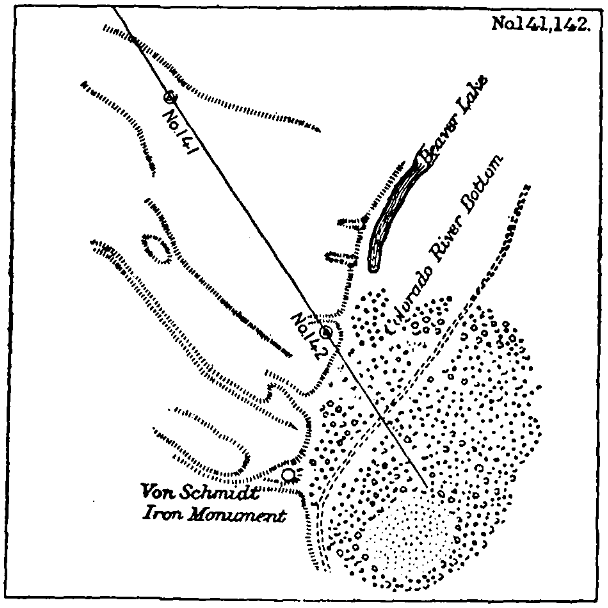
No. 141.

Station is on the mesa northwest of the last line point 2 334 meters, and nearly 184 meters south of the northwest line post of 1893, on the northwest side of the mesa not far from a ravine. The mesa is of sand and gravel with very few stones, covered



sparsely with greasewood. Marked by a drill hole in a stone set flush with the ground. A pile of stones is around foot of pole.

Point on corrected line, "No. 141" was lined in from Station No. 142, the first one on the line, by the azimuth. Marked by a stone with drill hole set in the ground.



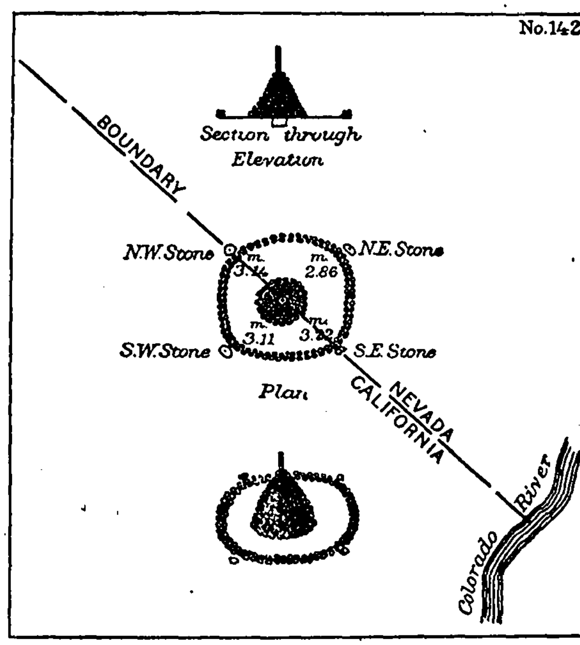
Over this a redwood post 4-inches by 4-inches by 6-feet, with "N. W. Line Post" and "C. & G. S." cut on it. Around post was built a large cairn.

Northwest line post of 1893 is a little west of north from new station, distant 12·75 meters. Marked by stone with drill hole in it. Cairn removed.

T 142.

On low mesa 159·4 meters southwest of the northeast line post set in 1893. It is just northeast of a wash and is marked by a drill hole in a stone, pole with pile of stone around it.

Point on the corrected line, "No. 142," or southeast line post, is 12·42 meters south of the other line post set in 1893 and was placed in February, 1899. It is marked by a mass of concrete 17 by 17 inches square and 18 inches long, sunk in the ground, with a drill hole in top to mark the center. On top of this was placed a redwood post, 6-inches by 6-inches by 6-feet, marked S. E. LINE POST. Around the post was built a cairn 10 feet in diameter at base and 6 feet high. An outer wall of stones nearly 20 feet in diameter and 1 foot high is outside the cairn. Four stones with drill holes were set in the ground just outside the outer wall, as shown in diagram, as reference marks. It stands on a sand ridge running east and west about 50 meters wide and about 100 meters west of the trees at the foot of the bluff.



Southeast line post of 1893 is 12·42 meters north of this station and is marked by a rock with drill hole in it. Cairn removed.

Station, East Post, 35° latitude, west side of river. C. H. Sinclair, 1893.

A redwood post 4-inches by 4-inches by 6-feet long was set over a drill hole in a stationary rock, and a pile of stones placed around it 7 feet in diameter and 5 feet high. On the west face was cut "Lat. 35°," on the north face was cut "1893," and on the east face was cut "C. G. S." This post is 100 meters west of the shore line of the lake, and 83 meters west of the foot line of the bluff. It stands on a sand ridge 42 feet high, and is 44·67 meters east of the meridian through Von Schmidt's 35° latitude post.

Station, West Post, 35° latitude, west side of river. C. H. Sinclair, 1893.

This post is similar to the one near the river, (East post), a drill hole in a stone, which was placed as a surface mark for this post. The post was set over this stone and a large stone and gravel mound, 7 feet in diameter and 5 feet high, built around it. On the east face was cut "Lat. 35°," on the north face was cut "1893," and on the west face was cut "C. G. S." This post is 440·068 meters west of east post. It stands a short distance south of a high sand plateau on a lower plateau, which is nearly one-half mile wide at this point.

Station Von Schmidt's 35° latitude posts.

In 1873 two posts were placed by Mr. Allexey W. Von Schmidt, United States Astronomer, to mark the thirty-fifth degree of north latitude on the west side of the Colorado River, about 12 miles north of the town of Needles, Cal. The post nearest the river is on a sand and gravel bluff, about 50 feet above the water and about 40 feet from the shore line.

At this time (1893) the water is a lake, the remains of an old river channel. The other post is 463 meters west. The post nearest the river was used as a point in triangulation and also as the azimuth station. A large mound of stone and sand surrounded this post, which was well preserved, with the original carvings in good condition. This post was temporarily moved, a stone with a drill hole was placed 2 feet beneath the surface, and a larger stone with a drill hole was set as a surface mark. After the observations were completed for azimuth and horizontal angles, the post was carefully centered over its old position and a large cairn was built around it. This point is also the north end of a meridian line, the south end of which is 468·69 meters distant, and marked by a concrete block 12 by 18 by 10 inches, with a small hole in it.

APPENDIX No 4.

REPORT 1900.

PROPORTIONS AND SPACING OF ROMAN LETTERS

AS ASCERTAINED FROM THE BEST EXAMPLES.

By WILLIAMS WELCH, Draftsman,
Coast and Geodetic Survey.

APPENDIX NO. 4. 1900.

PROPORTIONS AND SPACING OF ROMAN LETTERS AS ASCERTAINED FROM THE BEST EXAMPLES.

By WILLIAMS WELCH, *Draftsman, Coast and Geodetic Survey.*

Draftsmen and engravers agree very closely, in a general way, in regard to the width of the different Roman letters compared to their height, and they agree more closely still in regard to the relative spaces which are left between the different letters when they form words; but there are considerable differences of opinion among them in regard to the *exact* proportions and spacing of the letters.

From these facts it seems reasonable to believe that there may be geometric or æsthetic laws governing the proportions and spacing of letters, and that the differences of opinion may be caused by a lack of knowledge or appreciation of such laws, or by the unexplainable differences of taste which exist among different individuals. Or it is possible that the different lines forming the letters may produce optical deceptions or physiological illusions which affect different eyes or minds differently or to a different degree.

As each draftsman and engraver strives to form the letters and to space them in the way which gives the most pleasing appearance to himself, it is evident that, whether such laws are geometric or not, they must be as far as possible in conformity with those controlling ornamental art.

It is an easy matter to select and measure a large number of examples of first-class lettering done by different individuals, and then the average of these measurements can be taken. By doing this it is very evident that if such laws exist and are geometric, they may be discovered; if they are æsthetic, proportions will be found which will be pleasing to the greatest number of different individuals; and if optical or mental aberrations affect the matter to any degree, results will be obtained which will be satisfying to the greatest number of eyes or minds.

The examples which are given in the following table are about the best that could be obtained, although they may not be the best in existence. The height of the letters is taken as the unit of measurement, and the widest part of each letter is given, regardless of the fine horizontal lines which are at the tops and bottoms, as is shown in the upper line of the words PENOBSCOT BAY, on page 490.

Comparison of the widths of capital letters with their height.

Specimens.	A	B	C	D	E	F	G	H	I	J	K	L	M
United States Coast and Geodetic Survey standard	0·75	0·75	0·88	0·85	0·75	0·75	0·85	0·75	0·17	0·60	0·80	0·75	0·85
A United States Coast and Geo-Survey engraver	·75	·80	·90	·90	·78	·70	·90	·78	·16	·60	·80	·73	·90
A United States Coast and Geodetic Survey draftsman	·80	·80	·95	·95	·75	·70	·95	·80	·17	·60	·80	·70	·95
United States Geological Survey standard	·81	·80	·90	·85	·78	·75	·89	·75	·14	·63	·78	·75	·90
J. Enthoffer's Manual, Plate I.	·90	·82	·88	·88	·83	·78	·93	·82	·18	·63	·88	·77	·90
J. Enthoffer's Manual, Plate II.	·85	·85	·90	·87	·80	·78	·90	·85	·19	·65	·85	·75	·90
H. S. Jacoby's text-book	·92	·83	·92	·92	·83	·79	·92	·83	·17	·67	·92	·75	1·00
H. S. Jacoby's type specimens	·80	·80	·90	·85	·80	·80	·90	·82	·12	·53	·80	·75	·85
C. E. Sherman's type specimens	·80	·85	·90	·90	·80	·80	·90	·80	·16	·60	·85	·80	·90
American Type Foundry Co.	·75	·75	·85	·90	·75	·70	·90	·80	·16	·62	·75	·75	·85
Average	·813	·805	·898	·887	·787	·755	·904	·800	·162	·613	·813	·750	·900

Specimens.	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
United States Coast and Geodetic Survey standard	0·70	0·88	0·75	0·88	0·75	0·80	0·90	0·70	0·75	1·15	0·80	0·75	0·80
A United States Coast and Geodetic Survey engraver	·70	·95	·75	·95	·80	·82	·87	·75	·80	1·25	·80	·80	·80
A United States Coast and Geodetic Survey draftsman	·70	·95	·75	·95	·80	·80	·95	·70	·80	1·20	·80	·80	·80
United States Geological Survey standard	·73	·92	·78	·92	·76	·75	·93	·73	·84	1·20	·92	·91	·88
J. Enthoffer's Manual, Plate I.	·72	·92	·75	·92	·79	·83	·83	·72	·76	1·27	·79	·79	·86
J. Enthoffer's Manual, Plate II.	·70	·95	·80	·95	·80	·85	·85	·70	·80	1·15	·80	·80	·90
H. S. Jacoby's text-book	·75	1·0	·79	1·0	·92	·83	·92	·75	·83	1·33	·92	·92	·83
H. S. Jacoby's type specimens	·70	·95	·78	·95	·80	·75	·90	·75	·80	1·15	·80	·80	·85
C. E. Sherman's type specimens	·65	1·0	·80	1·0	·80	·80	·95	·70	·75	1·25	·90	·80	·85
American Type Foundry Co.	·65	1·0	·75	1·0	·75	·75	·90	·75	·75	1·25	·85	·80	·80
Average	·700	·952	·770	·952	·797	·798	·900	·725	·788	1·200	·838	·817	·837

The foregoing table gives the mean width of all the letters compared with their height as 4 to 5.

It is well known that the most pleasing proportions are simple multiples of some unit which it is difficult for the eye to detect; therefore the letter I and the stems of the other letters, compared with their height, should be 1:6 or 1:7 instead of the mean of several different proportions, as given by the above table.

In order to obtain the average spacing between the letters, 40 titles were selected from charts of the United States Coast and Geodetic Survey which ranged in date from 1856 to 1896, and as far as could be ascertained were drawn free-hand, without any rule or other guide than the eye, and were made by trained engravers and draftsmen of a number of different nationalities.

First the spaces between all straight-stemmed letters, like I, and all round letters, like O, were measured. The height of the letters was taken as the unit of measurement.

Between I and I 20 were measured. They varied from ·45 to ·67, the average being ·60—.

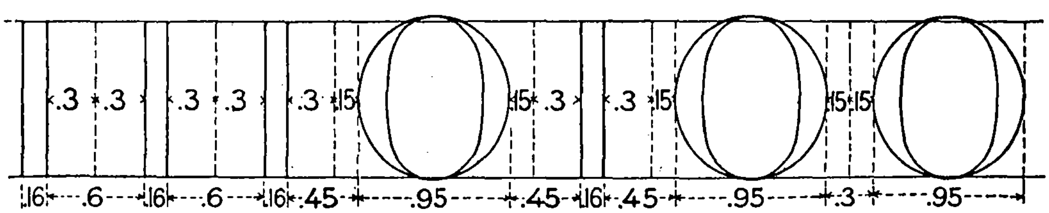
Between I and O 40 were measured. They varied from ·37 to ·53, the average being ·45+.

Between O and O 6 were measured. They varied from ·29 to ·33, the average being ·30+.

From these values the space on either side of I may be called a, and that on either side of O called b, and the following equations written;

$$2a = {}^{\cdot}60 \qquad a + b = {}^{\cdot}45 \qquad 2b = {}^{\cdot}30$$

From these equations the space on either side of a straight stem is found to be ·30, while that on either side of a round letter is ·15. The following example shows the method and the result of spacing straight and round letters, in accordance with these measurements.*



The average space found between the straight stems compared with the height of the letters is the pleasing proportion of 3 to 5.

As there are 26 capital letters, and each one has two sides, there are in all 52 spaces to be ascertained. The above measurements give just 20 of these spaces.

By taking the space on either side of the straight stems as ·30, and those on either side of the round letters as ·15, the other spaces were ascertained as follows:

On the left side of A 20 spaces were measured from straight-stemmed letters. These spaces varied from ·37 to ·50, the average being ·437. On the same side of the letter 20 spaces were also measured from round letters. These varied from ·23 to ·35, the average being ·284. Subtracting ·30 (the space on either side of I) from ·437, and subtracting ·15 (the space on either side of O) from ·284, gives ·135 as the average space on the left side of A. On the right side of A 48 spaces between the straight stems and round letters were measured, and ·30 subtracted from the spaces between the straight stems, while ·15 was subtracted from those between the round letters. The average was found to be ·137.

---

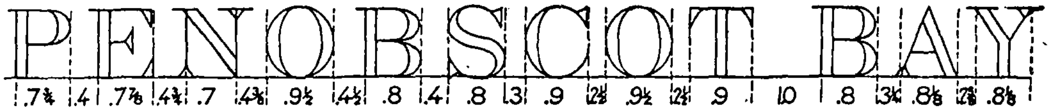
*Letters reproduced by photo-mechanical processes are subject to very slight variations from the measurements of the original.

A great many measurements were made from the other letters and the averages found in the same way. These measurements are rather too numerous to be given in detail, but the following table gives the result. The mean width of all the spaces given in the table, compared with the height of the letters, is the proportion of 2 to 5.

$1\frac{3}{8}$ **A** $1\frac{3}{8}$	3 **B** $1\frac{7}{8}$	$1\frac{4}{8}$ **C** 1	3 **D** $1\frac{4}{8}$	3 **E** $1\frac{6}{8}$	3 **F** 1	$1\frac{4}{8}$ **G** $1\frac{5}{8}$	3 **H** 3	3 **I** 3
$\frac{5}{8}$ **J** 3	3 **K** $1\frac{3}{8}$	3 **L** $\frac{5}{8}$	3 **M** 3	3 **N** 3	$1\frac{4}{8}$ **O** $1\frac{4}{8}$	3 **P** 1	$1\frac{4}{8}$ **Q** $1\frac{4}{8}$	3 **R** $2\frac{1}{8}$
$2\frac{1}{8}$ **S** $1\frac{1}{8}$	1 **T** 1	3 **U** $2\frac{5}{8}$	$1\frac{2}{8}$ **V** $1\frac{3}{8}$	$1\frac{3}{8}$ **W** $1\frac{3}{8}$	$1\frac{6}{8}$ **X** $1\frac{6}{8}$	$1\frac{3}{8}$ **Y** $1\frac{3}{8}$	$1\frac{6}{8}$ **Z** $1\frac{5}{8}$	0 **.** 0

To avoid the decimal point the height of the letters in this table is taken as 10. On each side of each letter is given its spacing. The spacing between any two letters is found by adding the spacing on the right of the first letter to the spacing on the left of the second. For example: The spacing for AB is $4\frac{3}{8}$; for CD is 4; for HI is 6, and for LA is 2.

In the example below the name PENOBSCOT BAY is shown laid off according to the values given in the preceding tables.



PENOBSCOT BAY

For the spacing between two words, lay them off as though the letter I were in the middle of the space between them. A period or comma adds its width to the space, and its distance from the preceding letter is equal to the spacing which is on the right of that letter.

The following examples show the result of spacing about the worst combinations of letters, exactly according to the values given.

ALASKA STRAIT

FTWAVLJ PJ LTTN

In the upper line the stems are one-sixth, while in the lower line they are one-seventh, the height of the letters.

"A Text Book on Plain Lettering," by Prof. H. S. Jacoby, of Cornell University, is a very excellent and carefully prepared work of 48 pages, about 12 of which are devoted to the spacing of letters. The two lines below show words spaced by the two methods. The upper line is made exactly according to Professor Jacoby's proportions and spacing. It can be noticed that in it the masses of white between the letters are approximately equalized, while in the lower line the letters themselves are so evenly distributed that no two appear to stand closer together or farther apart than any other two.

SIDE ELEVATION

SIDE ELEVATION

By knowing the exact widths of the letters and the exact spaces between them, a draftsman, engraver, sign painter, sculptor, or designer can lay off words precisely the length desired and know they will be all right without spending time and effort in sketching them in beforehand and changing them. This is especially desirable in lettering maps.

In practice the measurements may be laid off on a piece of stiff, thin paper, very close to its edge. It can then be moved about until the word occupies the right position on the drawing. These marks can be projected from the edge of the paper or pricked through to the drawing.

A very close rule for determining the length of a word before laying it off is: Multiply all the letters by 8 and all the spaces by 4.

The relations between the widths and spacing of the letters being determined throughout the alphabet, they may be varied in many ways, provided the variations are uniform. When it is desired to spread out the letters and make the words longer, any unit may be added to the spaces given in the table. The idea is the same as that of printers in spacing type when they insert blanks of equal width between the letters. If it is desired to make a word shorter, the letters can be crowded more closely by measuring their widths by one scale and the spaces between them by a scale with slightly closer divisions.

There is another method, which is derived from the previous table and which avoids the trouble of adding the spacing as given in it. By this second method the spacing between all the letters is laid off exactly equal. The measurements, however, are not taken from the extreme widths of the letters, but are laid off from points near the left of each letter (except J). The alphabet given below shows the points from which the spacing is measured, and under each letter is given its width between these equidistant measurements. The extreme width of each letter is the same as that given in the previous table. This uniform spacing may be any distance which is not less than three-sevenths the height of the letters.

A	B	C	D	E	F	G	H	I	J	K	L	M
$4\frac{7}{8}$	$6\frac{7}{8}$	$5\frac{1}{2}$	$7\frac{3}{8}$	$6\frac{5}{8}$	$5\frac{1}{2}$	$6\frac{1}{4}$	8	$1\frac{5}{8}$	4	$6\frac{3}{4}$	$5\frac{1}{8}$	9

N	O	P	Q	R	S	T	U	V	W	X	Y	Z
7	$6\frac{1}{2}$	$5\frac{3}{4}$	$6\frac{1}{2}$	$7\frac{1}{8}$	$5\frac{5}{8}$	5	7	$4\frac{3}{8}$	$8\frac{3}{4}$	$5\frac{7}{8}$	$4\frac{5}{8}$	$5\frac{7}{8}$

This method is best for very wide spacing on account of the rapidity with which the words can be laid off; and as slight defects in wide spacing are not very apparent, the width of the letters between the spacing may be measured by the eye and only their extreme widths measured accurately.

From numerous specimens measured and tests made, it was found that the spacing is most pleasing in appearance when the uniform distance is some fractional part of the height of the letters, as one-half for close spacing; four-sevenths, three-fifths, or five-eighths for medium; and two-thirds, five-sevenths, or three-fourths for wide. In the following examples the stems of the letters are one-seventh of their height; the spacing in the upper line is three-sevenths, in the lower line five-sevenths, and in all the examples shown elsewhere it is three-fifths the height of the letters.

CLOSEST SPACING

W I D E   S P A C I N G

When a definite length is given for a word, the spacing between the letters can be found by multiplying all the letters by 6 and dividing the remaining distance by the number of spaces.

The roman small (lower case) letters were investigated by the same method—i. e., quite a number of the best examples were selected, and every detail of each letter was carefully measured and averages found. The results are shown in the alphabet which is given on page 493. Under each letter is given its width between the equidistant spaces, as explained in the last table of capital letters.

The extreme width of each letter was found to be as follows: i, l $= 1\frac{3}{4}$; t $= 4\frac{5}{8}$; f, j, r $= 6\frac{1}{2}$; g, n, h, s, u $= 8$ (g has width of top, including ball, $11\frac{1}{4}$; width of bottom, 10); a, v, y, x, z, k $= 8\frac{1}{2}$; b, d, p, q $= 9\frac{1}{8}$; e, c $= 9\frac{1}{2}$; o $= 10$; w $= 13\frac{1}{2}$, and m $= 14\frac{3}{8}$.

The height of the short letters is taken as 10, and the tall ones was found to be 16, which is the pleasing proportion of 5 to 3 between the lower and upper parts of the tall letters.

In slanting letters, the average slant was found to be the proportion of 2 to 5 between the sine and the cosine of the angle of slant. The proportion of 3 to 8 gives a slightly less slant, while 3 to 7 gives one which is slightly greater.

There are numerous optical deceptions in the alphabet which must be overcome in order to make the letters appear correct. They are as follows:

A, and all letters with round tops, like O and S, must be about one-fortieth higher than the other letters, or they will appear to be too low.

C, G, O, Q, S, and the curved parts of B, D, P, and R, must have the widest part of the curve about one-eighth greater than the straight stems, or it will appear too narrow.

B, E, F, H, R, and S must have the middle part slightly above the center, or it will appear too low.

B, C, E, K, S, X, and Z must be narrower at the top than at the bottom, or they will appear wider.

E, N, S, and X must have the bottom spur slightly larger than the top one, or it will appear too small.

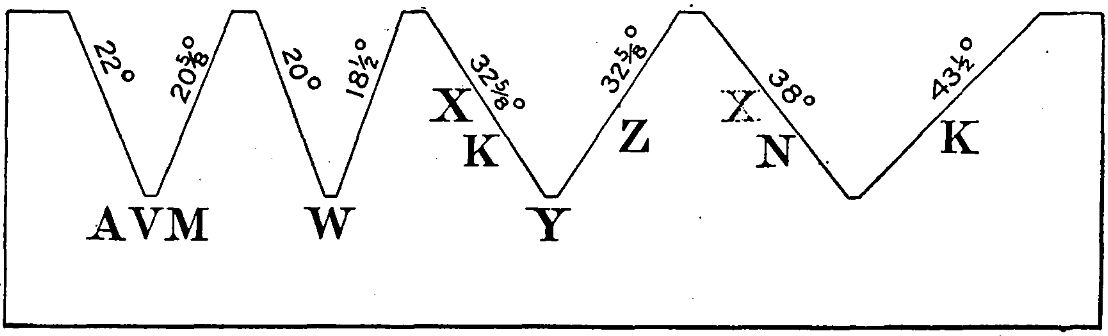
The fine horizontal lines at the bottom of the letters must be slightly heavier and longer than those at the top, or they will appear lighter and shorter, and the little curved lines which fill in the angles at the bottom of the letters must be almost horizontal, while those at the top must be very small and almost vertical.

A, N, V, W, and the left half of M, must lean about three-fourths of a degree to the left, or they will appear to lean to the right, and they must have the pointed ends of the oblique stems swelled slightly, or they will appear sunken.

X must have a slight offset in the fine cross line, or the line will not appear straight.

K must have the lower part of the fine oblique line bent down very slightly, or it will not appear straight.

A piece of transparent celluloid, about one-twentieth of an inch in thickness, can be cut in the shape shown below. It not only facilitates the work, but it greatly lessens the effort required to make the letters acourate. These angles were found by carefully measuring about two hundred well formed letters with a protractor and taking the mean of these measurements for each angle. They are given from a vertical line. In the corresponding small letters (except y) the angles were found to be slightly greater.



Similar devices are sold by manufacturers of drawing instruments, but in them the angles have not been accurately determined and they do not give good results.

APPENDIX No. 5.

REPORT 1900.

THE INTERNATIONAL LATITUDE SERVICE AT GAITHERSBURG, MD., AND UKIAH, CAL., UNDER THE AUSPICES OF THE INTERNATIONAL GEODETIC ASSOCIATION.

BY

EDWIN SMITH, ASSISTANT, COAST AND GEODETIC SURVEY,

AND

MR. F. SCHLESINGER, SPECIAL OBSERVER.

PREFACE.

Observations for the variation of latitude have been made from the middle of October to the close of the fiscal year at Gaithersburg, Md., and at Ukiah, Cal. This work has been carried on under the general direction of the International Geodetic Association, of which the United States is a member. The central bureau of the association is located at Pottsdam, Germany.

In view of the fact that the results of these observations are of interest and value in all geodetic work of precision, the Superintendent of the Coast and Geodetic Survey was invited by the association to assume supervision of the work as far as the acquisition of sites, the disbursement of funds, and the selection of observers were concerned.

It was thought well, therefore, to give in an Appendix to the Annual Report of the Coast and Geodetic Survey a popular exposition of the theoretical side of the subject, and also a brief statement of the methods of observation. The former has been written by Mr. Frank Schlesinger, who has charge at Ukiah, and the latter by Mr. Edwin Smith, Assistant, Coast and Geodetic Survey, in charge of the Gaithersburg Observatory.

Still another station has been established in the United States, at Cincinnati, Ohio. The astronomical observatory at that place happens to lie on the parallel of latitude chosen for the other stations. This favorable circumstance has led to the inauguration of a series of observations with the same object in view, and the work is being carried out by Mr. J. G. Porter, the director, using an instrument loaned by the Coast and Geodetic Survey.


PAHRUMP VALLEY
MESQUITE VALLEY
MESQUITE VAL.
SPRING MOUNTAINS
STATE LINE
MOUNTAINS
Sage brush, greasewood and Spanish bayonet
Sage brush
Von Schmidt 505
Von Schmidt 512
Von Schmidt 521
V.S. 524
V.S. 528
V.S. 529
No. 109
No. 110
No. 111
No. 112
No. 113
No. 114
No. 115
No. 116
No. 117
No. 118
No. 127
No. 128
No. 126
Crown 2592
2494
Manse 2515
2527
2586
2610
2647
2689
3089
2621
High 2924
Hard 2820
Dell 2760
Old lake bed white alkali
Gap 2541
Ring 2617
Blow 3221
Belle 2984
Mag 2870
Jumbo 2643
2835 Martin
2893 Move
Stump Spring
From Manse Post Office
To Sandy
Spanish bayonet
Sandy P.O.
Sage brush Adobe soil
White alkali Flat
2537 Taylor
2561 Bullock
Bullocks Well
Sage brush Greasewood Spanish bayonet
Shenandoah Peak
Copper Mines
To Good Springs
2592 Well
2693 Link
Sage brush, greasewood
To Sandy

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LIST OF ILLUSTRATIONS.

APPENDIX No. 5. 1900.

THE INTERNATIONAL LATITUDE SERVICE AT GAITHERSBURG, MD., AND UKIAH, CAL., UNDER THE AUSPICES OF THE INTERNATIONAL GEODETIC ASSOCIATION.

I. VARIATIONS OF LATITUDE CONSIDERED WITH SPECIAL REFERENCE TO THE PROGRAMME OF THE INTERNATIONAL GEODETIC ASSOCIATION.

By Frank Schlesinger, Ph. D., *Special Observer.*

The chief object of this paper is to give a short account of the latitude work now being carried out by the International Geodetic Association, especially in this country. The purpose and difficulties of this work will, however, be better understood if we first glance briefly over what has already been done on this important problem.

A. EULER'S THEORY.

The history of the subject properly begins as early as 1765, with Euler's memoir on The Theory of the Motion of Solid and Rigid Bodies. We are to imagine with Euler that the earth is a perfectly rigid body, and that its mass is so distributed that its equatorial moments of inertia are equal. Two polar axes may now be defined: First, *the axis of figure*, that is, the polar principal axis of inertia, and second, the *axis of rotation*, or that about which the earth performs its diurnal revolutions. We may consider the latter axis as being fixed in space, for though this is by no means the case, its motions are completely defined in the theory of precession and nutation. We are here concerned merely with the motions of points on the earth's surface as referred to the axis of rotation.

Euler showed that under these suppositions the axis of figure would describe a right cone about the axis of rotation; or, what is the same thing, that the pole of figure would describe a circle about the rotation pole. Now, as latitudes are based upon the position of the rotation pole on the earth's surface, it will be seen that every point upon the latter must suffer a periodic change in latitude amounting to twice the radius of this circle. The period of this oscillation depends only upon the ratio of the polar moment of inertia to the equatorial, and this is known very accurately from precession and nutation. The Eulerian period, therefore, destined to play so important a part in the history of latitude variation, was known to be very nearly three hundred and five days. What the radius of the polar motion might be could not, however, be determined from theory, except that it must be small. Its actual value was a matter for observation to decide.

B. *EARLY OBSERVATIONS.*

The first astronomer to accept the invitation thus implied was Bessell. In 1842, examining his own observations, he could find no trace of an oscillation with a period of three hundred and five days. The only conclusion that could be drawn was the negative one that the variation was too small to be detected by the astronomical methods then available. As instruments and methods improved we find successive attempts being made by various observers to detect Euler's variation. Thus the following results for the radius of the polar motion were published:

	″
By Peters, at Pulkowa	0·08
By Nyrén, at Pulkowa	0·09
By Downing, at Greenwich	0·08
By Newcomb, at Washington	0·03

These results seem fairly accordant, but there is another condition which must be fulfilled. The *phases* of the oscillation, as derived from each of these four series separately and reduced to one epoch and to one longitude, must be the same. To this condition the results did not at all conform, so that astronomers were again constrained to believe that variations of latitude, if they existed at all, were insensible even to the refined methods then attained in practical astronomy. This view was almost universally accepted until less than fifteen years ago.

C. *RECENT INVESTIGATIONS.*

It is a significant fact that the observations from which a variation of latitude was first revealed and announced were undertaken with an entirely different purpose in view, and without any suspicion of a change in latitude. In 1884 Küstner, of Berlin, began a short series of observations for the purpose of testing a method devised by him for determining the constant of aberration. The method employed involved the measurement of small differences of zenith distances in the manner devised by Talcott, of the Corps of Engineers, United States Army. Although there was every reason to believe that this method would lead to precise results Küstner found that his separate values of the aberration constant agreed neither among themselves nor with the best previous determinations. By a nice chain of logic Küstner was able to exclude one possible explanation after another till only a latitude variation was left to account for these discrepancies. His next step was to examine other nearly contemporaneous series of observations, and when he found that several puzzling anomalies could thus be accounted for he no longer hesitated to announce a variation of latitude. He stated that the latitudes of Gotha, Berlin, and Pulkowa had each fluctuated to the extent of a few tenths of a second of arc.

This announcement at once awoke the liveliest interest, and the matter was promptly taken up by the International Geodetic Association. Observations were set on foot at Berlin, Prague, Strassburg, and Potsdam, and these showed an agreement that left few doubting the reality of latitude variations. There were a few, however. Indeed, as recently as 1892 we find the Director of the Paris Observatory pronouncing against variations. The crucial test was made in 1891 by the International Geodetic Association and the United States Coast and Geodetic Survey. Observations for latitude were made by the former at Berlin, Strassburg, and Prague, and at Waikiki, in the Sandwich Islands; and by the Coast and Geodetic Survey at Rockville (in Maryland), San Francisco, and also at Waikiki. The last station was especially important because its longitude is about 180° different from those of the German stations. Consequently, if the latitudes of the latter are found to increase during a certain period then that of Waikiki must be expected to simultaneously decrease by the same amount. As this was found to be the case, we may say that the two independent series of Marcuse and Preston, at Waikiki, firmly established the fact that the earth's axis of figure was slowly revolving around its axis of rotation.

Meanwhile Chandler, of Cambridge, Mass., had already begun his investigations upon the law of variation. The results obtained by him mark an epoch not only in this subject, but in the whole progress of precise astronomy. For he was able to trace variations of latitude as far back as the time of Bradley (1750), and to show that many of the discouraging discrepancies encountered since that time were due to fluctuations in the latitude.

Chandler's first announcement, and the most important, was to the effect that all recent observations showed a period of about four hundred and twenty-eight days, or 40 per cent more than Euler's classic period. Although Chandler's evidence on this point was most conclusive his period was hesitatingly received until Newcomb pointed out a serious defect in Euler's theory—the neglect of the effect of the earth's plasticity upon the polar motion. Newcomb showed that if the earth were assumed to be slightly more rigid than steel, instead of absolutely rigid, the Eulerian period would be increased to agree with that of Chandler. It seems strange that this oversight on Euler's part should have remained so long unnoticed by the many master minds that concerned themselves with the mechanics of the earth's motion. Had it not been for this oversight on the part of theory there can be little doubt, it must be confessed, that observers would long since have detected the variation, for it now appears that many of these had noticed that a change in the latitude would make their results more accordant, but none had the boldness to announce such a change before Küstner did so.

Chandler's further researches indicate a law of variation which is by no means simple. The motions of the pole of figure are composed of two separate motions; *first*, (what is now accepted as the modified Eulerian motion), uniform motion in circle with a radius slowly variable between $0''.08$ and $0''.17$, and with a period of about four hundred and twenty-eight days; *second*, an elliptical motion with an annual period; the semiaxes being $0''.11$ and $0''.03$, respectively, and the rate of motion being such that the radius vector from the center describes equal areas in equal times.

D. DISCUSSION OF CHANDLER'S LAW.

Much difficulty has been encountered in attempting to assign physical causes that would lead to such a polar motion as is indicated by Chandler's empirical law. However, it may be said that these difficulties are for the most part quantitative only. Newcomb's explanation of the lengthening of the Eulerian period to four hundred and twenty-eight days (namely that based upon the nonrigidity of the earth), is not the only one admissible. The mobility of the earth's envelopes of water and air, as well as properly directed currents in them, would tend to increase the period. Moreover, Woodward has shown that if the equatorial moments of inertia of the earth be not equal, as Euler had assumed them to be, the resulting period would be more than three hundred and five days; however, it does not seem probable that the increase from this cause can exceed two or three days. The annual part of the polar motion is due no doubt to meteorological causes, such as deposits of snow and ice, and atmospheric and oceanic currents. But it must be remarked that it is only differential effects of this class that can give rise to an annual term. For example, equal deposits of snow upon the Western and upon the Eastern hemispheres would leave the polar motion undisturbed; or, again, an ocean current flowing with constant velocity in a fixed path might affect the four hundred and twenty-eight day motion, but not the annual. If, however, the current flows in one direction during one-half the year, and in the opposite direction during the other half of the year, this might produce the observed effect. Another class of causes is to be found in the changes going on in the interior of the earth, and still another has been quite recently implied in the researches of Halm, who has established, on evidence that leaves little room for doubt, a connection between latitude variations and the intensity of the earth's magnetism.

It seems clear that the problem of latitude variation is not yet in sight of complete solution. Indeed, it may be that the causes of the polar motion are such as to preclude the possibility of predicting them for more than a few years in advance. At any rate, all are agreed upon the necessity of further observation, for it must be remembered that only during the present decade have we precise knowledge of the motions of the pole. Our knowledge of them prior to 1890 is derived from observations made for very different purposes, and indeed, as we have seen, before the existence of such a motion was suspected.

E. THE WORK OF THE INTERNATIONAL GEODETIC ASSOCIATION.

For almost ten years the International Geodetic Association has had under consideration a plan for observing variations of latitude which finally came into operation in the fall of 1899. The zenith telescopes employed in this work and the method of using them will be found described elsewhere. It is my purpose here to outline only the general plan of the work.

The distinguishing feature in this plan is the establishment of a number of stations upon the same parallel of latitude, and as widely separated in longitude as possible. The selection of suitable sites was far from easy, as many other conditions besides the above had to be kept in view. It was desirable to have a good average of clear nights, to have the character of the country the same on the north as on the south of each station, and to have good seismological, hygienic, and social conditions.

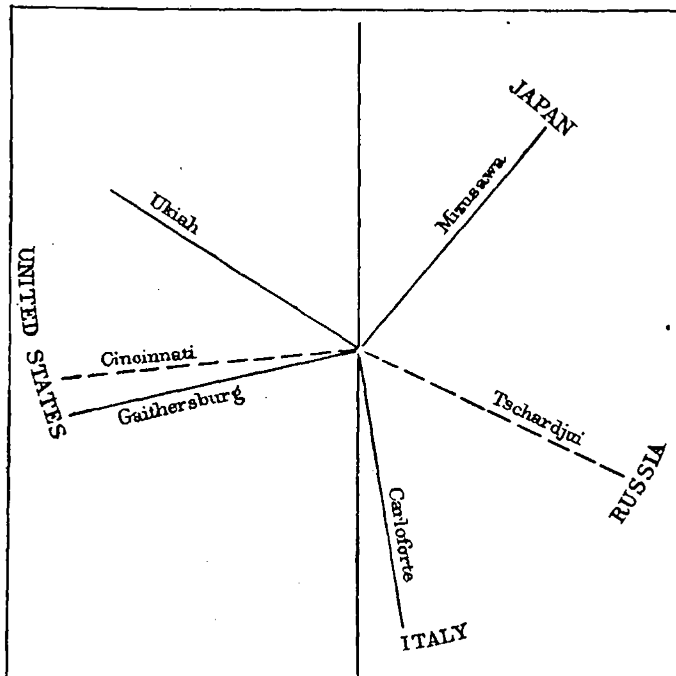
After discussing many possible combinations, the following stations were finally fixed upon:

	Longitude west of Greenwich.
	°
Mizusawa, Japan	−141
Tschardjui, Russia	−64
Carloforte, Italy	−9
Gaithersburg, United States	+77
Cincinnati, United States	+84
Ukiah, United States	+123

All these stations are within a few seconds of latitude $+39^\circ\ 8'\ 10''$.

Recognizing the efficiency with which such work has been performed in the past by the United States Coast and Geodetic Survey, the Superintendent of the latter has been intrusted by the International Association with the surveillance of the work in this country.

No. 1.



DISTRIBUTION OF THE STATIONS

The vertical line represents the Meridian of Greenwich

F. PROGRAMME OF OBSERVATIONS.

In arranging the programme for observing, the controlling desideratum has been to obtain the most accurate results for the variation of latitude solely, and not to attempt to use the observations for deducing the value of the constant of aberration. Following Küstner's lead, in which he obtained the first conclusive observational evidence of a change in latitude, most other latitude observers have also sought to determine the aberration constant. Such a plan necessitates a limited number of groups, of which one at least must be observed during nearly the whole of the period in which it transits at night. The central bureau of the Association has decided to use no less than twelve groups, each extending over two hours of right ascension. Two consecutive groups are to be observed on each night, as follows:

Group.	R. A.	To be observed.		Duration of—	
		From—	To—	Group.	Group connection.
	h. h.			*Days.*	*Days.*
I	0– 2	Sept. 23	Dec. 6	75	35
II	2– 4	Nov. 2	Jan. 4	64	29
III	4– 6	Dec. 7	Jan. 30	55	26
IV	6– 8	Jan. 5	Feb. 24	51	25
V	8–10	Jan. 31	Mar. 21	50	25
VI	10–12	Feb. 25	Apr. 15	50	25
VII	12–14	Mar. 22	May 11	51	26
VIII	14–16	Apr. 16	June 8	54	28
IX	16–18	May 12	July 9	59	31
X	18–20	June 9	Aug. 13	66	35
XI	20–22	July 10	Sept. 22	75	40
XII	22–24	Aug. 14	Nov. 1	80	40

By "duration of group connection" is meant the period in which the same two groups are observed; thus, Groups I and II are observed together during a period of thirty-five days, Groups II and III during twenty-nine days, etc. It will be noticed that these periods are short in the spring and long in the fall. This arrangement was adopted principally for the convenience of the observer, as the night's work is thus brought as nearly after sunset as was deemed safe. In midwinter observing will begin not less than two and a half hours after sunset, while in midsummer this minimum interval is reduced to one and a half hours.

Each group contains 8 pairs, only 6 of which, however, are to be used directly in determining the latitude. The two others are of very large zenith distances and were introduced, upon the suggestion of Professor Helmert, in order to detect anomalous refraction. In the discussion of previous latitude observations such anomalies have often been appealed to in order to account for some puzzling systematic discrepancies in the results. It has happened, for example, that the values of the latitudes from all the pairs on a certain night were greater than the true value. This result would be brought about if the index of refraction were greater to the south of the station than to the north. In the present programme such a condition of affairs will be revealed in the observations themselves for any single night, since there will be 4 pairs at about 60° zenith distance, while the latitude pairs exceed 20° zenith distance in only five cases in all twelve groups.

The observing list therefore requires the selection of 96 suitable pairs, a greater number than has usually been employed. Nevertheless it has not been a very difficult task to make the selection, because the instruments are of large enough aperture to permit the use of stars down to the seventh magnitude; and, besides, accurate knowledge of proper motions, or even positions, of the stars is by no means necessary in the present case. A proper-motion effect can not be confused with a variation of latitude, for the latter at any station has its counterpart, or rather its intaglio, at a station on the opposite meridian. For example, if the latitude of Ukiah should increase, then that of Tschardjui must decrease by practically the same amount, since these two stations differ nearly 180° in longitude. On the other hand, if the increase in the latitude of Ukiah should be only apparent and due to ignorance of proper motions, then the latitudes of all the other stations would be increased by the same amount. Similarly an incorrect value of the constant of aberration, or any other cause that would render the apparent places of the stars inexact, is practically without effect upon the results. Another advantage which arises from having all the stations on one parallel is that it will never be necessary to compute the apparent places of more than 16 stars for any date, as the same stars are observed simultaneously at all the stations. Considerable computing is thus saved.

From the results thus far obtained it appears that expectations of accuracy are likely to be realized. A preliminary discussion by Dr. Albrecht, of the central bureau of the association, has shown that the probable error of a single determination of latitude is about $0''.12$ on the average, and that the place of the pole may be defined with a probable error of less than $0''.02$.

II. DESCRIPTION OF STATION, INSTRUMENTS, METHODS, ETC., AT GAITHERSBURG, MD.

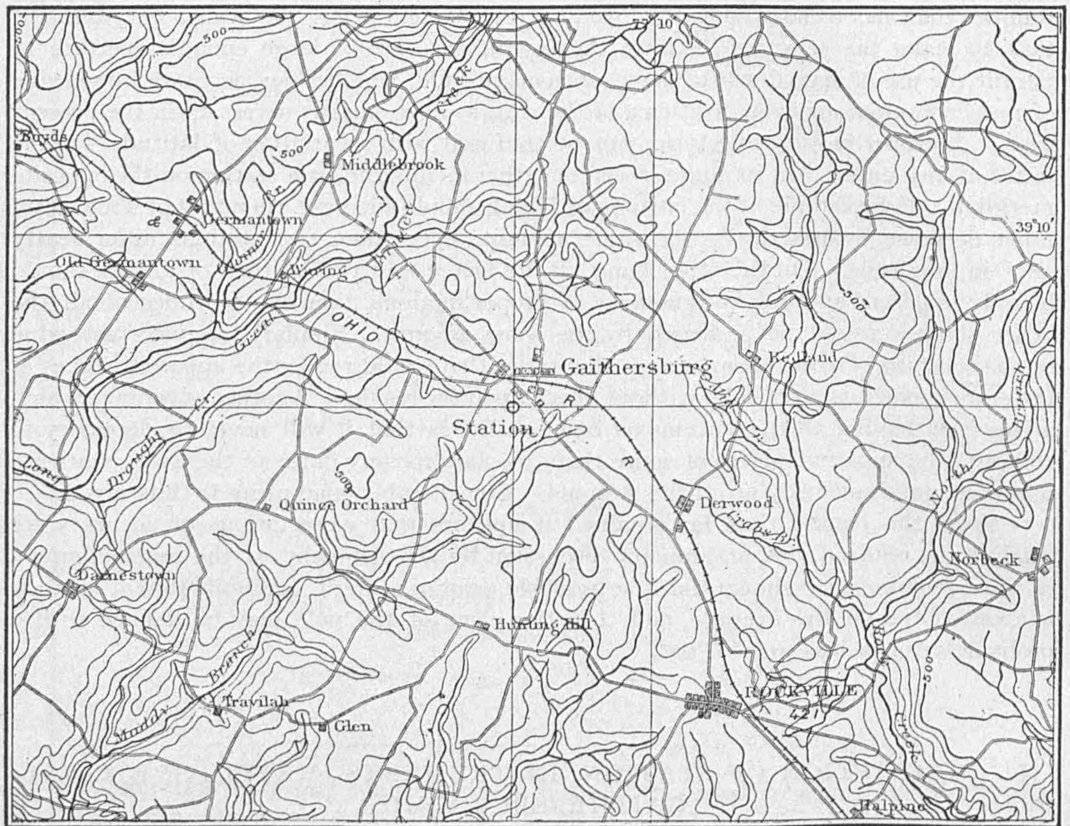
By EDWIN SMITH, *Assistant, Coast and Geodetic Survey.*

A. LOCATION OF STATION.

On July 1, 1899, the Superintendent of the United States Coast and Geodetic Survey assigned the writer to take charge of the International Geodetic Association Latitude Station at Gaithersburg, Md. At various times previous to this date he had assisted the Superintendent in selecting the station. On April 1, 1899, a lot containing 2.3 acres was leased for a term of ninety-nine years. This lot is in a corner of the north part of a farm belonging to Mr. I. T. Fulks. It is about half a mile from the Baltimore and Ohio Railroad station. Gaithersburg is 21 miles northwest of Washington. The sketches show the location of the lot and the plans of the buildings.

The observatory is on a summit about 540 feet above tide water. It is some 1 500 feet northwest of the site originally selected, and, though a few feet lower, is in every other respect a better location. The buildings were begun soon after July 1, 1899, and in the early part of August the observatory was in a condition to be used for the determination of longitude. The observations were made with the Coast and Geodetic

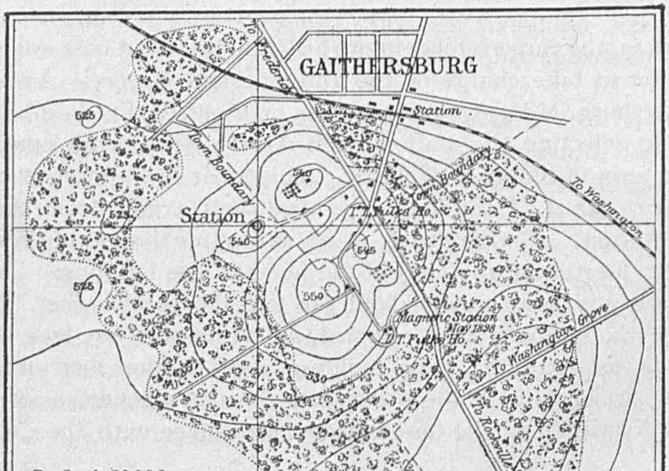
No. 2.

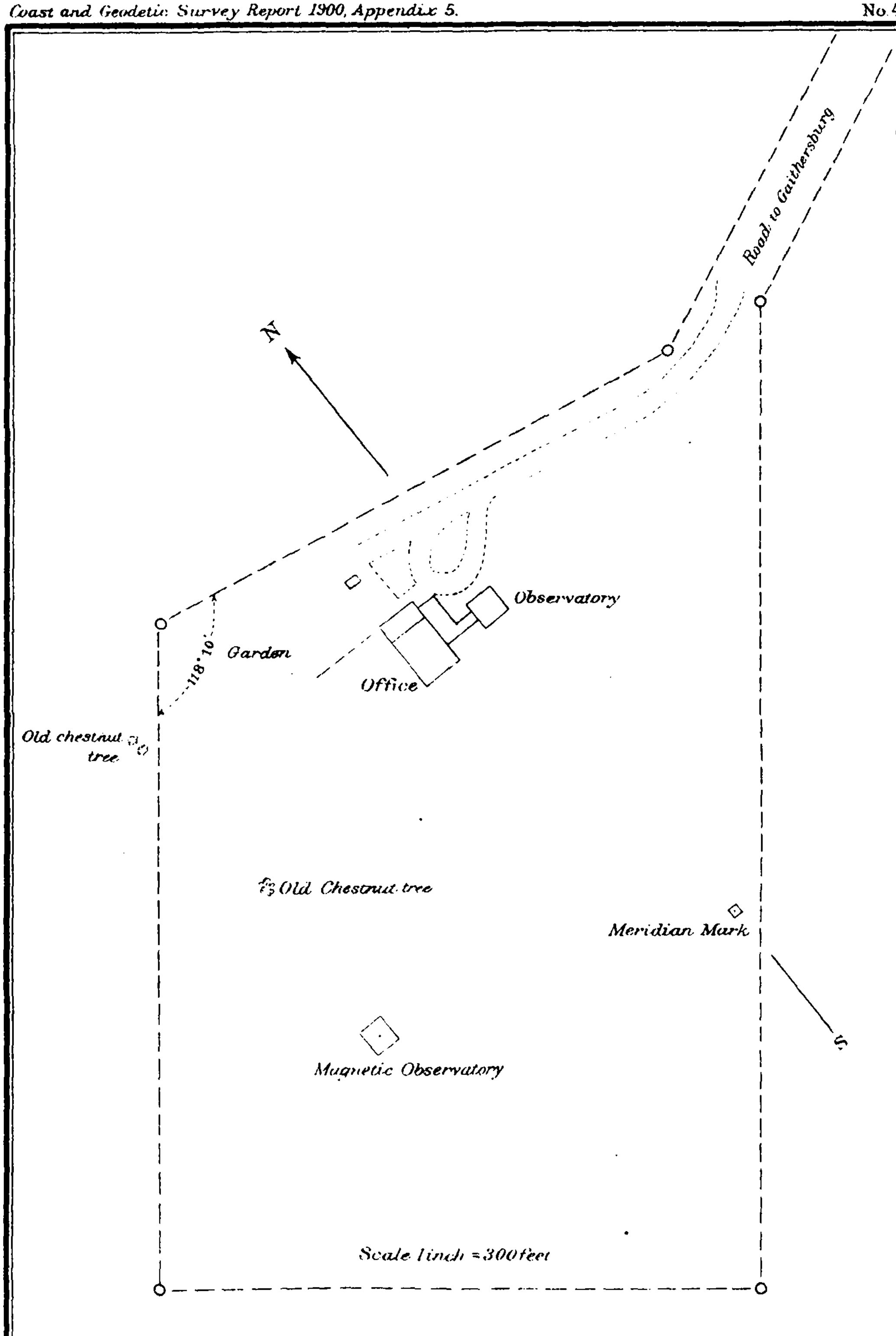


0 1 2 3 4 5 6 Miles

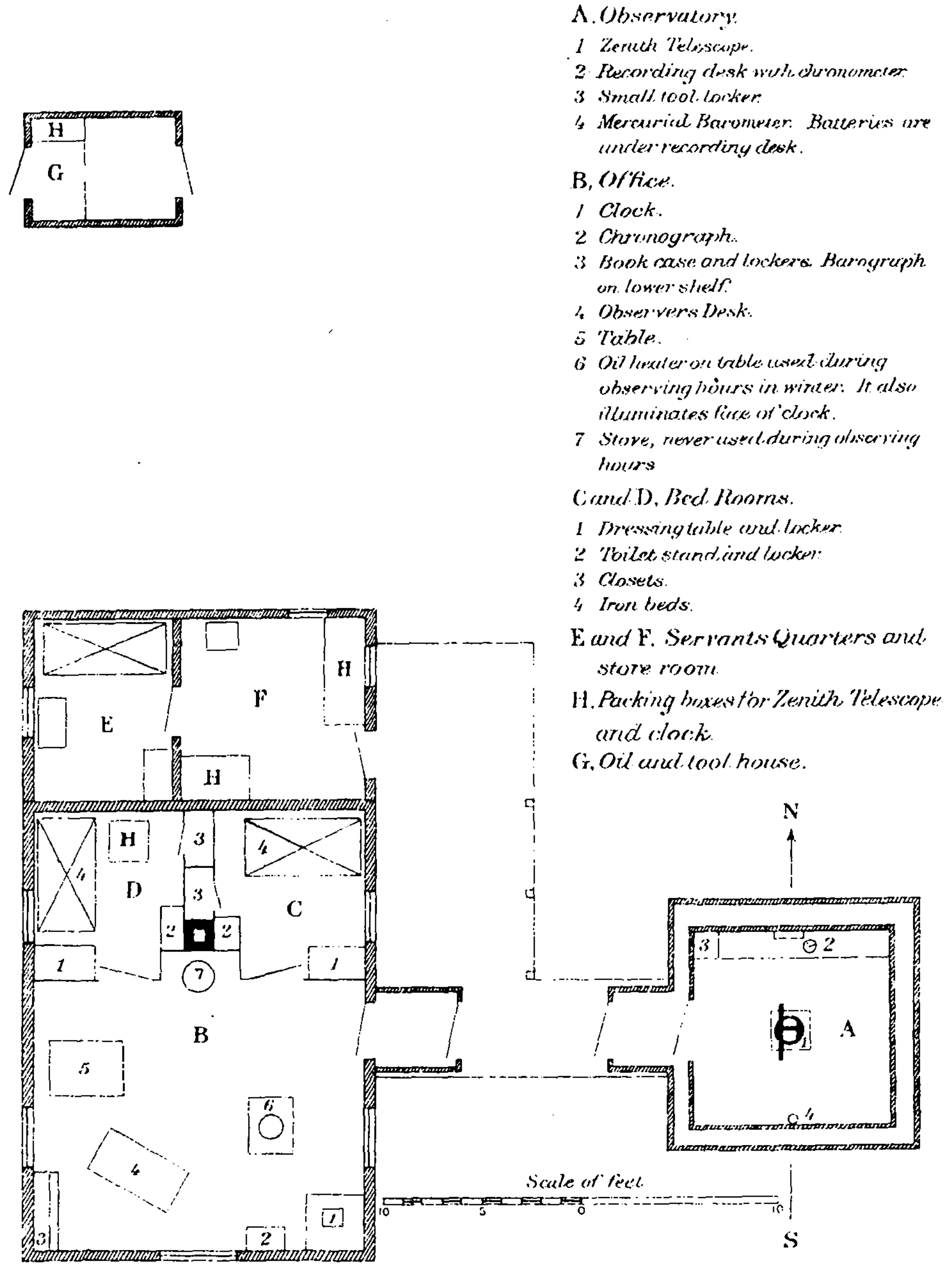
Contour Interval 50 feet

No. 3.





PLAT OF THE STATION



PLANS OF BUILDINGS

THE NORRIS PETERS CO. PHOTO-LITHO. WASHINGTON, D.C.

Survey instruments by the writer and Mr. John E. McGrath, of the Coast and Geodetic Survey. The results are as follows:

Date 1899.	Gaithersburg Observatory west of Coast and Geodetic Survey station at Washington, D. C.
	h. m. s.
August 19	0 00 46·00
August 22	46·02
August 25	46·03
August 29	46·06
August 31	46·03
September 1	46·00
September 4	45·98
Mean	0 00 46·02 ±0^s·007
Washington station west of Greenwich	5 08 01·71
Gaithersburg Observatory west of Greenwich	5 08 47·73

The observatory was then prepared for the latitude instruments, which reached Gaithersburg September 20. They were at once set up, and by October 1 were ready for the regular observations.

B. THE BUILDINGS.

Plans for an observatory, to be built of iron, were received from the Central Bureau of the International Geodetic Association. It was found, however, that the observatories of the American stations could not be built of iron from the available funds. New plans for observatories, to be built of wood, were therefore made by the writer. These plans conform as nearly as practicable to the original ones. The observatory at Gaithersburg is built of Georgia and Virginia pine, the roof being covered with heavy tin.

The zenith-telescope pier is in the center of the observatory. It is of brick, 22 inches square, with a white marble cap 24 inches square. The brick pier rests on a stone foundation (a cube of 5 feet), the top of which is 6 inches below the surface of the ground. The foundation of the observatory is of stone, 2 feet wide, projecting 6 inches above the surface of the ground, and of the same depth as the foundation of the zenith-telescope pier. The space between the foundations of pier and observatory is about half filled with loose earth.

The observatory is 10 feet square inside, and the walls are 7 feet 4 inches high above the floor. These walls rest on the inner edge of the stone foundation. On the outer edge of the stone foundation rests a wooden lattice 12 feet square, the top of which is a few inches lower than the walls of the observatory. This lattice keeps the sun from the walls of the observatory and leaves a well-ventilated space all round them. The door is in the center of the west wall, to be convenient to the office. There are two ventilators in each of the four walls near the roof east and west and near the floor north and south. These ventilators are always open, except during observatory hours, when they are closed tight. In the south wall are two openings through which to view the meridian mark. These openings are always kept closed, except during the few minutes necessary for setting the instrument on the meridian mark.

The roof is in two parts, which move east and west on iron wheels. The north wheels run on an iron track and the south wheels in an iron groove. The roof is double, and open to the air north and south, so there is a free circulation of air through it. There is a ventilator in each half of the roof, under which is a hood so arranged that no water can get on the instrument, even if the ventilator should be blown off. The roof is easily opened and closed by the observer inside the observatory by ropes running over pulleys. The full opening is 6 feet 6 inches, and the full opening is always used at Gaithersburg.

The interior of the observatory is painted a pale, dull blue, and the exterior is painted white.

Extending across the north side of the observatory is a shelf 1 foot 6 inches wide, which serves as a recording desk, etc. On the west end of this shelf is a locker for tools, and below the west and east ends are other shelves for the batteries used for electric illumination. The chronometer is set into the shelf and can be wound from below without moving it. On the north wall, over the chronometer, is a tin hood which throws the electric light onto the chronometer and recording desk and protects the observer's eyes.

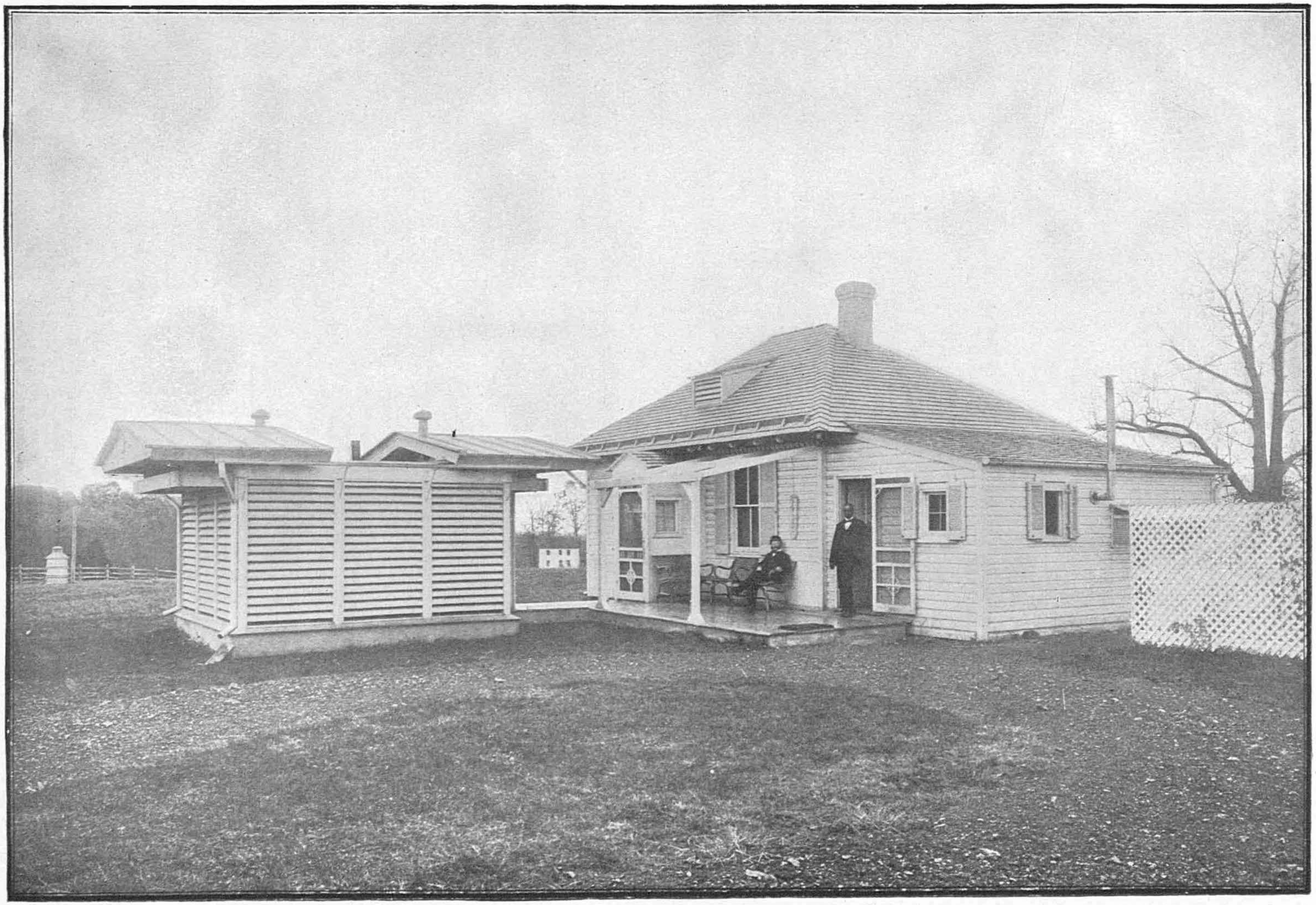
Around the pier, just below the marble cap, is a band of wood, to which are fastened the switches and rheostats for control of the electric lights. At the center of the south wall is suspended the mercurial barometer. A thermometer is suspended from the axis of the zenith telescope. During the warmest part of the summer days this thermometer, as well as the one attached to the barometer, indicated temperatures from 1° to 3° C. below the temperature of the outside air. During observing hours the temperatures inside and outside the observatory have been determined by swinging a thermometer. In general the inside temperature has been found 0°·1 to 0°·2 C. higher, occasionally 0°·5 C. higher, and in a few cases slightly lower than the outside temperature. This indicates that the observatory is well planned to secure nearly equal temperatures of the air inside and outside.

The zenith telescope is so high that the tube has to be brought to a nearly horizontal position in order to close the roof of the observatory.

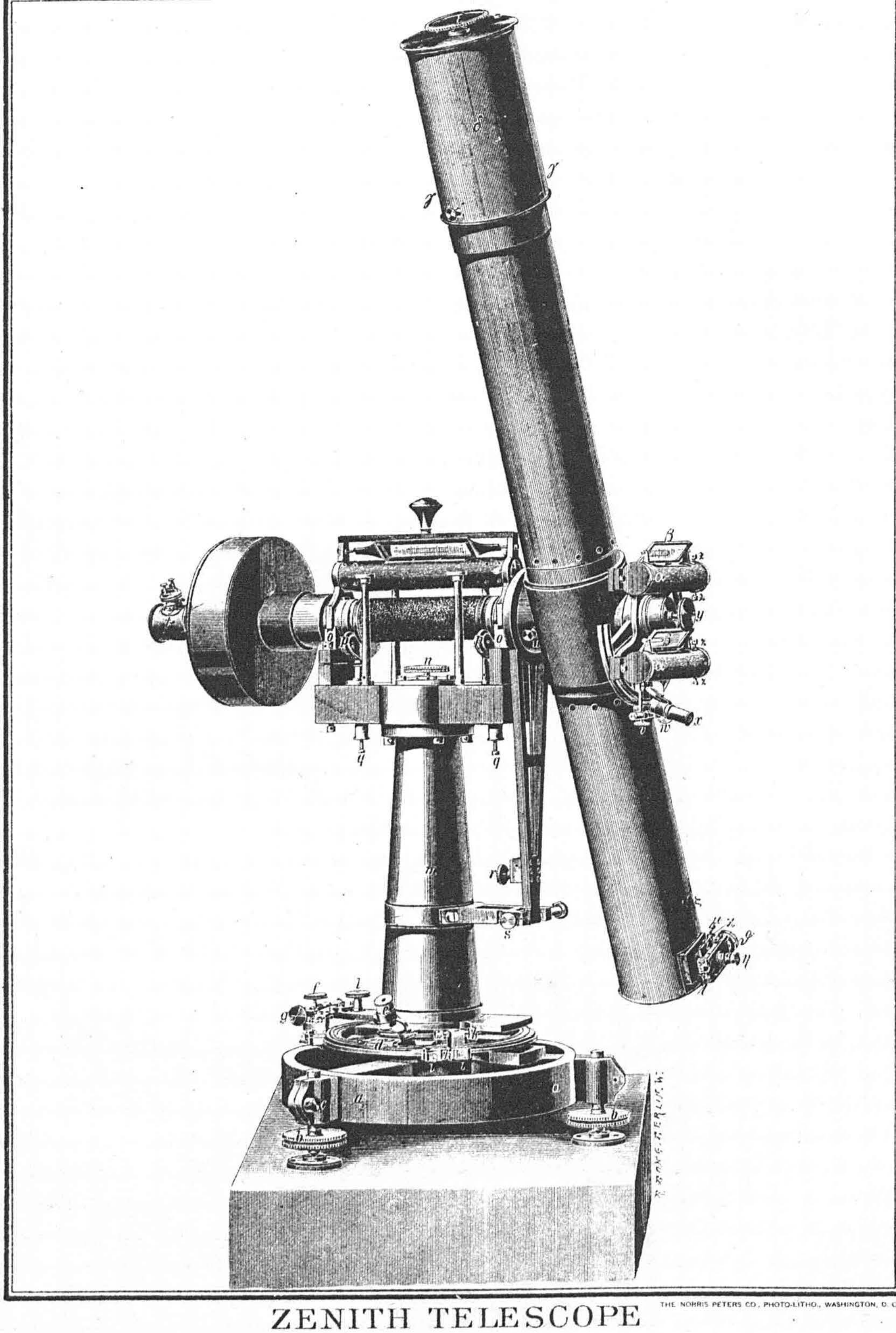
At a distance of 53·85 meters south of the center of the zenith-telescope pier is the meridian mark, mounted in a brick pier resting on a stone foundation, similar to the zenith-telescope pier. This pier and meridian mark are protected by a double casing of galvanized iron painted white.

From the door of the observatory is a platform extending 15 feet to the door of the office. The office building is 18 feet by 24 feet, with an extension of 10 feet at the north end for servants' quarters. This building is not intended as a residence, but the Gaithersburg station is so isolated that it was necessary to provide the observer with a place to sleep on observing nights, as well as a place to retire for a few minutes on cold winter nights and to work in during the hours he would necessarily be at the station and not observing.

The clock, chronograph, and barograph are kept in the office, as indicated on the plans.



VIEW OF BUILDINGS AT GAITHERSBURG STATION.



ZENITH TELESCOPE

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

C. THE INSTRUMENTS.

The instruments furnished by the International Geodetic Association are a zenith telescope and accessories, a sidereal clock, a sidereal watch, and a Richard barograph. The Coast and Geodetic Survey has furnished a cylinder chronograph, a sidereal break-circuit chronometer, a mercurial barometer, and several thermometers. The clock and zenith telescope only need special mention.

The clock is by Strosser & Rohde, Glashütte i. S., and has a Riefler pendulum. It is mounted in the office on a post which extends 5 feet into the ground, and is isolated from the building. During the past year the range of the temperature in the office has been not less than 50° C., and in the winter there were times when the range was as great as 30° in twenty-four hours, as no fire was allowed there except when the observer was present. The intervals between time observations have frequently been ten days. Even under these unfavorable conditions the uncertainty of the clock correction has at no time been greater than $\pm 0^{s}.3$, a matter of no importance in the latitude work.

The zenith telescope is one of four made by Julius Wanschaff, in Berlin, for the International Geodetic Association latitude service. The "Anleitung zum Gebrauch des Zenitteleskops auf den Internationalen Breitenstationen," by Th. Albrecht, gives a detailed description of these instruments, the methods of installation and observing, and the programme to be followed in the latitude work. The accompanying illustration of the instrument is a reproduction of that in the "Anleitung."

The zenith telescope is an altazimuth, or universal instrument. The vertical axis and horizontal circle are attached to a heavy circular base, supported by three leveling screws on point, line, and plane. The horizontal circle is 28^{cm} in diameter, graduated to 10′, and reads to 10″ by two verniers. The movable part of the instrument may be clamped to the horizontal circle by the screw *f*, and the verniers set by the tangent screw *g*. When the approximate circle reading of the meridian has been determined the stops *h* are fastened to the circle by the screws *i*. The clamp *f* is then loosened and the movable part of the instrument clamped to the stop by a clutch worked by the screw *l*, and the final adjustment in the meridian is made by the stop screws *k*. The instrument may then be quickly reversed 180° and clamped to either stop by *l*.

The weight of all the movable parts upon the bearings of the vertical axis is regulated by the screw *n*. This requires very nice adjustment in order that the instrument may be easily reversed without disturbing the instrumental constants. At Gaithersburg it has been necessary to readjust this for every change of temperature of 4° to 5° C.

The weight carried by the horizontal axis upon the bearings of the wyes *o* is regulated by the friction rollers *p*, supported on springs adjusted by screws *q*.

The optical parts of the instrument were made by Carl Zeiss, in Jena. The objective has an aperture of 108^{mm} and a focal length of 130^{cm}. With the eyepiece used in the latitude work, the telescope has a power of 104. Near the eye is a prism which reflects the cone of light at right angles, so the micrometer and eyepiece are placed in a most convenient position for observing.

On the side of the telescope tube opposite the eyepiece is a focus scale, and the focus is clamped by the screw ζ. The telescope tube is inclosed by another tube open at the eye end and pierced by a double row of holes near the horizontal axis. The dew cap γ is 24^{cm} long.

The setting circle is attached to the telescope tube opposite the horizontal axis. It has a diameter of 24^{cm}, is graduated at 10′, and reads to 10″ by a vernier. The levels are by Carl Reichel, in Berlin. The scale divisions are a little over 2^{mm}. The arc value of 1 division of the striding level is about 2″·5, and of the latitude levels about 1″. The scale of the upper latitude level is 0 to 40, and of the lower one 50 to 90. These levels are mounted in double tubes, and the two latitude levels are attached to a solid frame, one above and one below the center of axis of setting circle. They are adjusted parallel to each other by the screws z. They are chambered and the bubbles can be adjusted to the desired length and equal to each other without removing the levels from the instrument. The levels being above the observer's eyes, the scales are read in the mirrors β. By means of the clamp v and tangent screw w the circle is set to zenith distances, and when set the clamp y, at axis of circle, is applied and the clamp v loosened.* The telescope is then set approximately to the zenith distance and clamped at s, and the level bubbles brought to the middle of the scale by the tangent screw s.

The micrometer head is at δ, and by an ingenious device the whole revolutions and fractions are read by the same index. The micrometer head is divided into 100 parts. One revolution of the screw is 40″; so the smallest direct reading is 0″·40, and by estimation 0″·04. The working field is limited by two fixed threads parallel to the micrometer thread to 30 revolutions of the screw, or 20′, and the eyepiece can be centered over any position of the micrometer thread by the screw λ. At right angles to the micrometer thread is a system of 11 transit threads with equatorial intervals from the middle thread O, $2\frac{2}{3}^s$, $10\frac{2}{3}^s$, $13\frac{1}{3}^s$, 16^s, and 24^s. The collimation of the middle transit thread and the verticality of the micrometer thread are adjusted by opposing screws ι and κ.

In front of the eyepiece is a reversion prism. This is mounted in a tube which can be turned just 90° against a stop on the tube of the eyepiece. When the eyepiece with the prism attached is adjusted to distinct vision of the micrometer thread, the eyepiece is clamped in its adapter, and the eyepiece and prism can be revolved without danger of changing the focus, and the threads made to appear at any desired angle, whatever the inclination of the telescope may be.

Between the micrometer box and the large prism is another box containing the auxiliary lens, which by means of the rod μ may be shunted into the optical axis of the telescope. When this is done an object at the distance of 53·85 meters (meridian mark) is at distinct vision at the focal plane of the objective. This lens changes the collimation, but as it works against a stop the change of collimation is always so nearly the same that it makes no difference in the control of the azimuth by setting on the meridian mark.

The field of the telescope may be illuminated by oil or electric lamps, and the brightness of the illumination may be controlled by the screw u. At Gaithersburg only electric lights are used, and they are controlled by a rheostat. The illustration shows the instrument fitted for electrical illumination at t.

*In 1892–93, while the writer was in charge of the instrument division of the Coast and Geodetic Survey Office, designs were made for a special latitude instrument. In the drawings mentioned will be found the design for a clamp at the axis of the setting circle with an improvement over the above-mentioned clamp y, in that the same motion that applied the clamp at the axis loosened the clamp at the circle without disturbing the setting. The design is by Mr. E. G. Fischer. E. S

D. INSTALLATION AND METHODS OF OBSERVING

The zenith telescope was tested at Berlin, and the following data was received with the instrument:

Zenith telescope No. 4 for Gaithersburg.

Micrometer screw 1 R=39″·777. Screw errors not greater than 0^R·0006.
Latitude level I (0 — 40) 1d=0^R·02261 (by level tape=0″·947).
Latitude level II (50 — 90) 1d=0^R·02189 (by level tape=0″·963).
Stride level, 1d=2″·327=0^s·1551.
Equatorial intervals of transit threads, Tel. W., upper culmination: I, +23^s·789; II, +15^s·871; III, +13^s·204; IV, +10^s·540; V, +2^s·630; VI, 0^s·0; VII, −2^s·621; VIII, −10^s·392; IX, −13^s·209; X, −15^s·864; XI, −23^s·787.

Side flexure $b = + 1^s{\cdot}74$.
Collimation $c = + 0^s{\cdot}81$.
Distance from vertical axis of zenith telescope to meridian mark $53{\cdot}8^m$ to $53{\cdot}9^m$.
Reading of focus scale $6^{mm}{\cdot}0$.

The instrument was first set up and adjusted in September, 1899, using the value of $b = + 1^s{\cdot}74$, and reducing the transit observations by Mayer's formula. In October a series of seven nights' observations were made and reduced by the method given in the "Anleitung," from which was found $b = + 1^s{\cdot}69$. During this series of observations the meridian mark was established. The method given in the "Anleitung" for reducing the transit observations is briefly as follows. The notation is preserved.

Let u = clock correction, c = collimation constant, b = side flexure, k_e and k_w = azimuth constants for telescope east and west. These five quantities must be determined from the transit observations. Let U = mean of observed threads reduced to the middle thread and corrected for aberration and rate of clock, α and δ the right ascension and declination of zenith and south stars, and let U', α', and δ' be like quantities for the pole stars and i the level error of horizontal axis referred to west end. Then each zenith and south star will give an observation equation.

$$0 = \alpha - U + \frac{x-m}{15} - i \sec \varphi - u \pm c \sec \varphi \frac{\cos \frac{1}{2}(z'-z)}{\cos \frac{1}{2}(z'+z)} \mp b \sec \varphi \left\{ \begin{array}{l} \text{Tel } E. \\ \text{Tel } W. \end{array} \right.$$

in which

$$\frac{x-m}{15} = \mp \frac{\tan \varphi - \tan \delta}{\tan \delta' \mp \tan \delta} \left[\begin{array}{c} (U' - \alpha') - (U - \alpha) \\ (U' - \alpha' - 12^h) - (U - \alpha) \end{array} \right] \text{Pole star } \begin{array}{l} \text{upper culm.} \\ \text{lower culm.} \end{array}$$

Put,

$$\left(\alpha - U + \frac{x-m}{15} - i \sec \varphi\right) = S$$

$$\sec \varphi \frac{\cos \frac{1}{2}(z'-z)}{\cos \frac{1}{2}(z'+z)} = Z$$

$$\text{and } \sec \varphi = W$$

Let u_1 = assumed clock correction, δu its correction, and $d = S - u_1$. Then each observation equation will give the conditional equation,

$$0 = d - \delta u \pm Zc \mp Wb \left\{ \text{Tel } \begin{array}{l} E. \\ W. \end{array} \right.$$

The normal equations will be,

$$0 = \Sigma d - \Sigma \delta u + \Sigma Zc$$
$$0 = \Sigma Zd - \Sigma Z\delta u + \Sigma Z^2 c + \Sigma ZWb$$
$$0 = \Sigma Wd \quad . \quad . \quad . \quad + \Sigma ZWc + \Sigma W^2 b$$

from which δu, c, and b become known. k_e and k_w are then determined as follows: Correct U_e' and U_w' for level, side flexure, and collimation,
Upper culmination

$$+ (i \pm b) J' \mp c \sec \delta' \quad \text{Tel} \frac{E.}{W.}$$

Lower culmination

$$+ (i \pm b) J' \pm c \sec \delta' \quad \text{Tel} \frac{E.}{W.}$$

in which

$$J' = \frac{\cos (\varphi \mp \delta')}{\cos \delta'} \quad \begin{matrix}\text{upper culm.}\\ \text{lower culm.}\end{matrix}$$

Then.

$$k_e = \frac{\alpha' - U_e' - u}{K'} \text{ and } k_w = \frac{\alpha' - U_w' - u}{K'}$$

in which for lower culmination $\alpha' + 12^h - U'$ must be substituted for $\alpha' - U'$, and where

$$K' = \frac{\sin (\varphi \mp \delta)}{\cos \delta} \quad \begin{matrix}\text{upper culm.}\\ \text{lower culm.}\end{matrix}$$

To facilitate this computation the "Anleitung" gives tables of the coefficients $\frac{\tan \varphi - \tan \delta}{\tan \delta' \mp \tan \delta}$ and $\sec \varphi \frac{\cos \frac{1}{2} (z' - z)}{\cos \frac{1}{2} (z' + z)}$ for $\delta = 39° \ 8'$ and for pole stars with δ greater than $+ 80°$ and zenith stars $\delta = +25°$ to $50°$ and south stars $\delta = -10°$ to $-30°$.

The best conditions for this method will be found in a set of two polar stars, upper and lower culmination, four zenith stars, and four south stars, arranged as in the example given below:

Determination of clock correction and instrumental constants, Gaithersburg, Md., October 29, 1900.—Observer, Edwin Smith.

Position of telescope and star.	Number of threads.	U and U'	α and α'	δ and δ'	i
		h. m. s.	h. m. s.	° ′	s.
Tel W. Zenith star γ Cygni	5	20 18 41·99	20 18 40·78	+39 56·7	−0·024
South star δ Capricor.	5	34 25·76	34 25·20	−18 29·1	−0·004
Pole star u. c. 79 Draco.	4	49 47·59	49 47·93	+82 10·2	−0·032
E. Pole star u. c. 79 Draco.	4	49 50·84			0·000
Zenith star δ Cygni	5	53 30·51	53 29·47	+40 47·5	+0·004
South star θ Capricor.	5	21 00 25·36	00 23·58	−17 38·0	+0·048
E. South star δ Aquarii	5	21 04 14·33	21 04 12·59	−11 46·2	+0·020
Zenith star τ Cygni	5	10 51·97	10 50·98	+37 37·7	+0·016
Pole star l. c. ι Draco.	4	22 56·31	22 57·43	+81 45·6	−0·012
W. Pole star l. c. ι Draco.	4	23 01·48			−0·048
Zenith star 74 Cygni	5	33 00·96	32 59·68	−39 58·4	−0·020
South star δ Capricor.	5	41 35·86	41 35·33	−16 34·5	−0·020

$U'-\alpha'$	$(U'-\alpha')-(U-\alpha)$			$\alpha-U+\frac{x-m}{15}-i\sec\varphi=S.$		
s.						
−0.34	−1.55	+0.0037	$-\frac{\tan\varphi-\tan\delta}{\tan\delta'-\tan\delta}$	−1.21	−0.01	+0.03
	−0.90	−0.1514		−0.56	+0.14	0.00
+2.91	+1.87	+0.0078		−1.04	+0.01	0.00
	+1.13	−0.1491		−1.78	−0.17	−0.06
−1.12	−2.86	+0.1626	$+\frac{\tan\varphi-\tan\delta}{\tan\delta'+\tan\delta}$	−1.74	−0.46	−0.03
	−2.11	+0.0060		−0.99	−0.01	−0.02
+4.05	+2.77	−0.0034		−1.28	−0.01	+0.03
	+3.52	+0.1794		−0.53	+0.63	+0.03

	S	$-u$	$\pm Zc$	$\pm Wb$	d	Zd	Wd	Z^2	ZW	Zc	Wb	u	Δ
	s.									s.	s.	s.	
0=	−1.19	$-u$	$-1.28c$	$+1.29b$	−0.07	+0.09	−0.09	1.64	− 1.65	−1.62	+1.72	−1.09	−0.06
0=	−0.42	$-u$	$-2.00c$	$+1.29b$	+0.70	−1.40	+0.90	4.00	− 2.58	−2.52	+1.72	−1.22	+0.07
0=	−1.03	$-u$	$+1.27c$	$-1.29b$	+0.09	+0.11	−0.12	1.61	− 1.64	+1.60	−1.72	−1.15	0.00
0=	−2.01	$-u$	$+1.99c$	$-1.29b$	−0.89	−1.77	+1.15	3.96	− 2.57	+2.51	−1.72	−1.22	+0.07
0=	−2.23	$-u$	$+2.24c$	$-1.29b$	−1.11	−2.49	+1.43	5.02	− 2.89	+2.83	−1.72	−1.12	−0.03
0=	−1.02	$-u$	$+1.31c$	$-1.29b$	+0.10	+0.13	−0.13	1.72	− 1.69	+1.65	−1.72	−1.09	−0.06
0=	−1.26	$-u$	$-1.28c$	$+1.29b$	−0.14	+0.18	−0.18	1.64	− 1.65	−1.62	+1.72	−1.16	+0.01
0=	+0.16	$-u$	$-2.39c$	$+1.29b$	+1.28	−3.05	+1.65	5.71	− 3.08	−3.02	+1.72	−1.14	−0.01
$(u_1=$	$-1.12)$	$-8u$	$-0.14c$	$0.00b$	−0.04	−8.20	+4.61	25.30	−17.75			−1.15	

$$
\begin{array}{l|l}
0=-0.04-8.00\,\delta u-0.14c & c=+1.262^{s} \\
0=-8.20+0.14\,\delta u+25.30c-17.75b & b=+1.336 \\
0=+4.61\qquad\qquad -17.75c+13.31b & \delta u=-0.027
\end{array}
$$

$$u_1+\delta u=u=-1.15^{s}$$

79 Draconis u. c.	$J'=+5.36$	$c'=7.34$	$K'=-5.01$
1 Draconis l. c.	-4.57	6.98	$+5.27$

	79 Draconis u. c.		1 Draconis l. c.	
	W	E	E	W
	h m s	h m s	h m s	h m s
U'	20 49 47.59	20 49 50.84	21 22 56.31	21 23 01.48
Level	− 0.16	0.00	+ 0.05	+ 0.22
Flexure	− 7.17	+ 7.17	− 6.10	+ 6.10
Coll.	+ 9.26	− 9.26	+ 8.80	− 8.80
U' corrected	20 49 49.52	20 49 48.75	21 22 59.06	21 22 59.00
α'	20 49 47.93	20 49 47.93	21 22 57.43	21 22 57.43
$\alpha'-U'$	− 1.59	− 0.82	− 1.63	− 1.57
u	− 1.15	− 1.15	− 1.15	− 1.15
$(\alpha'-U')-u$	− 0.44	+ 0.33	− 0.48	− 0.42
k	+ 0.09	− 0.07	− 0.09	− 0.08

The time observations at Gaithersburg are always made before the latitude observations, at intervals of five to ten days. It is not often that such a complete set of stars can be selected without interfering with the latitude work. Frequently two or more zenith and two or more south stars have been combined with one polar star at upper culmination, with good results. When no polar star above 80° declination is available, the value of b is assumed as known and the observations reduced by

Mayer's formula. Five nights' observations in September and October, 1900, give $b = +1^{s}\cdot37$, or $0^{s}\cdot32$ less than the value from the same set of stars a year ago. The observations throughout the year seem to indicate that this is a real change in the value of b.

The instrumental constants must be kept within such limits that the latitude results will not be affected so much as $0''\cdot01$. On a latitude determination the effect of

Collimation c is $d\varphi = +\frac{1}{2} c^2 \sin 1'' \tan \delta$
Azimuth k is $d\varphi = -\frac{1}{2} k^2 \sin 1'' K \cos \varphi$
Level, i is $d\varphi = + i^2 \sin 1'' J \sin \varphi$

For a latitude pair (z not greater than 20°) c or k may be 50″, and i 40″. For a refraction pair ($z = 60°$) c or k may be 30″ and i 25″. The displacement of the middle thread from the meridian on account of the side flexure b is $b \cos z$, a maximum in the zenith, and the combined effect of collimation and flexure is $c - b \cos Z$. If now c is adjusted to the condition $c - b = 0$, the combined effect will be zero for the zenith and $\frac{1}{2} b$ at 60° zenith distance. This condition will entirely eliminate the effect of collimation and flexure on the latitude pairs, and the error $\frac{1}{2} b$ or less than 12″ on the refraction pairs will be inappreciable.

The latitude levels are frequently tested by aid of the meridian mark. The auxiliary lens, which must be used in these tests, changes the value of micrometer, and a special determination of a revolution of the micrometer screw with the auxiliary lens in optical axis has to be made before the absolute value of the level divisions becomes known from these tests. This has yet to be done at Gaithersburg. The level tests, however, serve to show the condition of the levels, and if any change has taken place in them.

The value of one revolution of the micrometer screw and its progressive and periodic errors are determined by observing the transits of a polar star near its elongation, over progressive readings of the micrometer. This has conveniently been done at Gaithersburg four times during the year without interfering with the latitude observations:

December, 1899, on δ Urs. Min., 51 Cephei, and λ Urs. Min.
March, 1900, on α Urs. Min.
May and June, 1900, on δ Urs. Min., 51 Cephei, and λ Urs. Min.
August and September, 1900, on α Urs. Min.

The resulting mean value of one revolution of the micrometer is very nearly the same as determined in Berlin. There seems to be no appreciable periodic error, but there seem to be some greater errors in different parts of the screw than indicated in the statement received with the instrument.

E. THE METHOD OF OBSERVING LATITUDE.

The roof of the observatory at Gaithersburg has always been open at least two hours before beginning the latitude observations. About half an hour before time for the first latitude pair the side ventilators have been closed, the instrument carefully leveled, and the middle transit thread set on the meridian mark, telescope east and west. Temperature inside and outside the observatory and the state of the barometer have been recorded at the beginning, middle, and end of each night's work, and more frequently in case of sudden changes.

The telescope is set to the mean zenith distance of the two stars of the first pair, being careful to securely set the clamp y and loosen the clamp v. The instrument is clamped by l to the E. or W. stop. The micrometer head is then set to the approximate reading for the first star, from the approximately known difference of zenith distance and the eyepiece is centered over the micrometer thread. The reversion prism is then turned against its stop, and the eyepiece and prism turned until the micrometer thread appears vertical. About half a minute before the star enters the field the state of the two latitude levels are read and recorded. As the star crosses the field, four bisections are made with the micrometer thread at points in the field corresponding to equatorial intervals 20^s, $6\frac{2}{3}^s$, $6\frac{2}{3}^s$, and 20^s (if a lower culmination star $6\frac{2}{3}^s$, $2\frac{2}{3}^s$, $2\frac{2}{3}^s$, $6\frac{2}{3}^s$). The reversion prism is turned 90° against its stop between the second and third bisection, so that if the star enters the field moving up it will leave the field moving down.*

The four micrometer readings are then recorded, a note of the sharpness and steadiness of the star is made, and the state of the two levels again read and recorded. The instrument is then reversed 180° and clamped by l against the other stop, and the micrometer and eyepiece are set for the second star. By means of the tangent screw s, the levels are brought to the same reading, as nearly as practicable, as for the first star. The second star is then observed as the first. The instrument remaining clamped to the stop, the telescope is set for the second pair, etc. If the first pair begins telescope W, the second pair will begin telescope E, the third pair W, etc., during the night's work. On the following night the first pair will begin E, the second pair W, etc.

The following is a specimen of the record:

Date (astronomic), October 6, 1900.

Group.	Pair.	Tele-scope.	Level I before. Level II before. Level I after. Level II after.	Micrometer readings.	Tele-scope.	Level I before. Level II before. Level I after. Level II after.	Micrometer readings.	Remarks.
			At 21^h 53^m ta 22°·0 ti 22°·1 b 754^{mm}·60 + 22·4 Party cloudy, light wind, S. Inst. 22·2					
XII	89	W	9·8 29·9	16·562	E	10·3 30·5	14·349	
			60·2 80·2	57		60·5 80·7	52	
			B_1 R_1	65		B_1 R_1	58	
			9·8 29·9	60		10·3 30·5	55	
			60·2 80·3			60·5 80·7		
	90	E	9·4 29·7	15·355	W	9·5 29·8	14·115	
			59·9 80·1	51		59·9 80·2	16	
			B_2 R_1	45		B_2 R_2	32	
			9·4 29·7	54		9·5 29·8	30	
			59·8 80·1			59·8 80·1		

ta = temperature outside observatory.
ti = temperature inside observatory.
Inst. = temperature at instrument.
b = reading of mercurial barometer.

* The keeping of the micrometer thread apparently vertical will correct for errors of the observer's eye (astigmatism), and the inverting of the field eliminates personal equation of always setting too far to right or left.

B refers to the sharpness and brightness of the star, and *R* to its steadiness. A scale of 4 is used, 1 indicating the best possible conditions and 4 such conditions that observations are scarcely possible. At Gaithersburg the conditions have been rather above B_2 R_2, many nights having been B_1 R_1, comparatively few B_3 R_3, and the condition B_4 R_4 has been exceptional.

F. THE PROGRAMME OF OBSERVING.

Twelve groups of stars, each covering two hours of right ascension, have been selected by the Central Bureau.

Two groups are observed each night, covering four hours, in summer between the hours of 9 p. m. and 3 a. m., and in winter between 7 p. m. and 1 a. m. The duration of the groups is from fifty to eighty days, and the duration of the group combinations is from twenty-five to forty days. It is expected that from eight to twelve good nights will be obtained in each group combination.

Each group has eight pairs, six latitude pairs with zenith distances less than 20° and difference of zenith distance less than 15′, and two refraction pairs of about 60° zenith distance and difference of zenith distance less than 5′. The stars are between the fourth and seventh magnitudes. An eighth magnitude star can be observed with the instrument.

To facilitate the reduction of the observations the "Anleitung" gives tables for the correction for curvature of the parallels and for refraction. The Central Bureau has furnished the apparent declinations for the mean of the two stars of each pair for every two days. Convenient tables for the level corrections and the value of micrometer have been formed, so that the computation of a night's latitude observations is not a great matter.

The record of each month's latitude observations is kept in a separate book, a duplicate of which is kept at the station. The original record is sent to the Coast and Geodetic Survey Office, and thence to the Central Bureau, at Potsdam. With each monthly record book are also sent the results of the time observations, the record of the level tests, the record of the observations for value of micrometer screw, and the barograph sheets.

In addition to making the latitude and other observations, the observer has to make all the computations, duplicate the records, and look after the maintenance of the station. The results of the year's work can not be given, as the observations will be finally reduced and published by the Central Bureau. It may be stated, however, that the probable error of one observation for latitude from all the observations at Gaithersburg is about $\pm 0''.09$ for the latitude pairs and about $\pm 0''.16$ for the refraction pairs. A recent report of the Central Bureau, giving the results from January 5 to May 11, 1900, confirms this statement.

G. THE WORK ACCOMPLISHED.

The following is an exhibit of the observations made at Gaithersburg October 1, 1899, to October 31, 1900. All the observations were by Edwin Smith, assistant, Coast and Geodetic Survey:

Month.	Observations for latitude.		Observations for time and instrumental constants. Number of nights.	Observations for value of micrometer.		Number of level tests.
	Number of pairs.	Number of nights.		Number of sets.	Number of nights.	
October, 1899	142	11	9	....	....	....
November	176	13	5	....	....	....
December	182	16	5	4	2	....
January, 1900	202	15	5	....	....	....
February	164	13	4	....	....	1
March	157	15	3	4	4	2
April	168	13	4	....	....	....
May	168	15	5	9	5	....
June	228	18	3	3	3	4
July	225	16	4	....	....	....
August	201	15	3	5	5	....
September	133	12	5	3	3	5
October	196	15	4	....	....	....
13 months	2 342	187	59	28	22	12

APPENDIX No. 6.

REPORT 1900.

DESCRIPTION OF PRECISE LEVELS NOS. 7 AND 8, COAST AND GEODETIC SURVEY, 1900.

BY E. G. FISCHER,
Chief of the Instrument Division.

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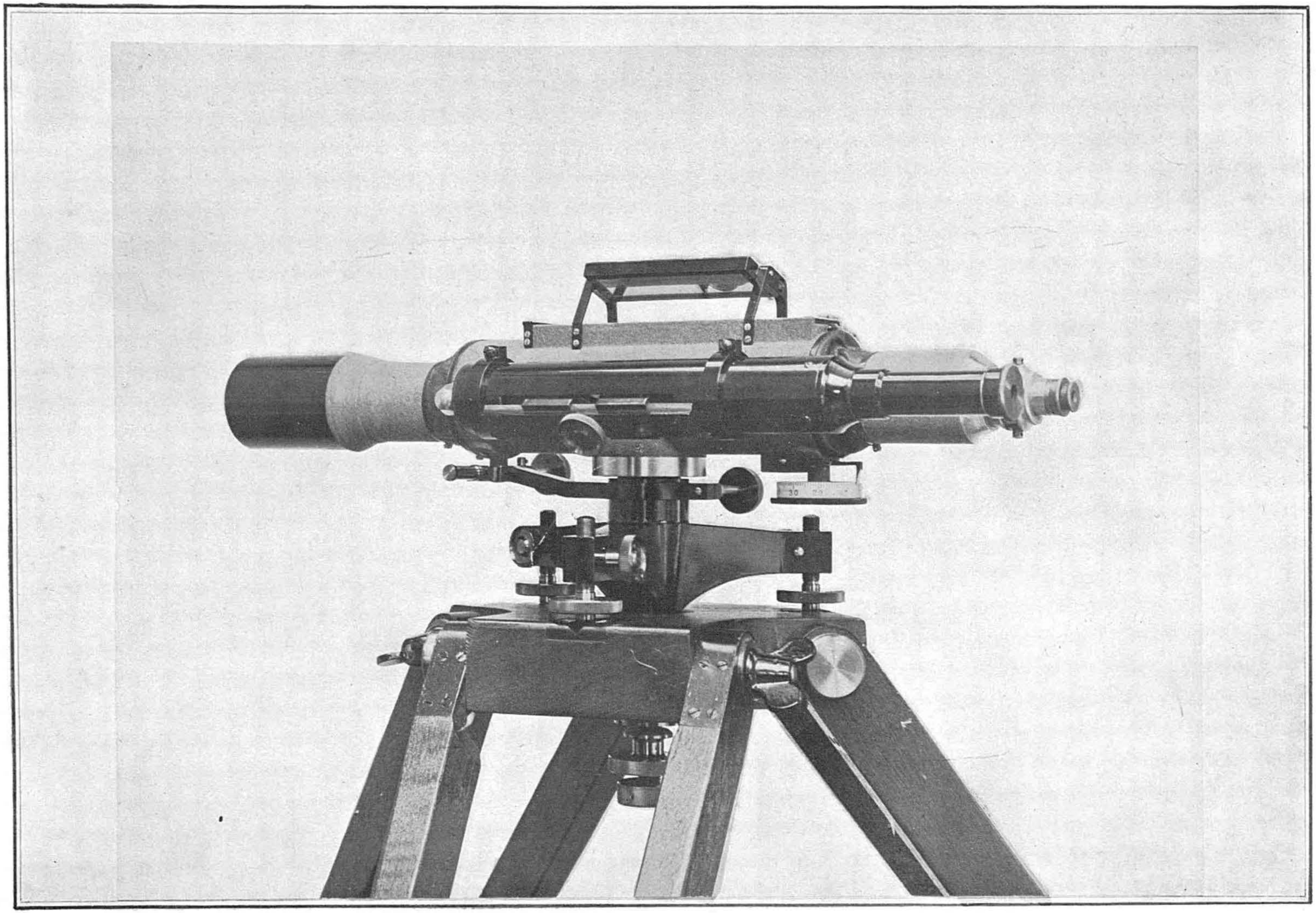
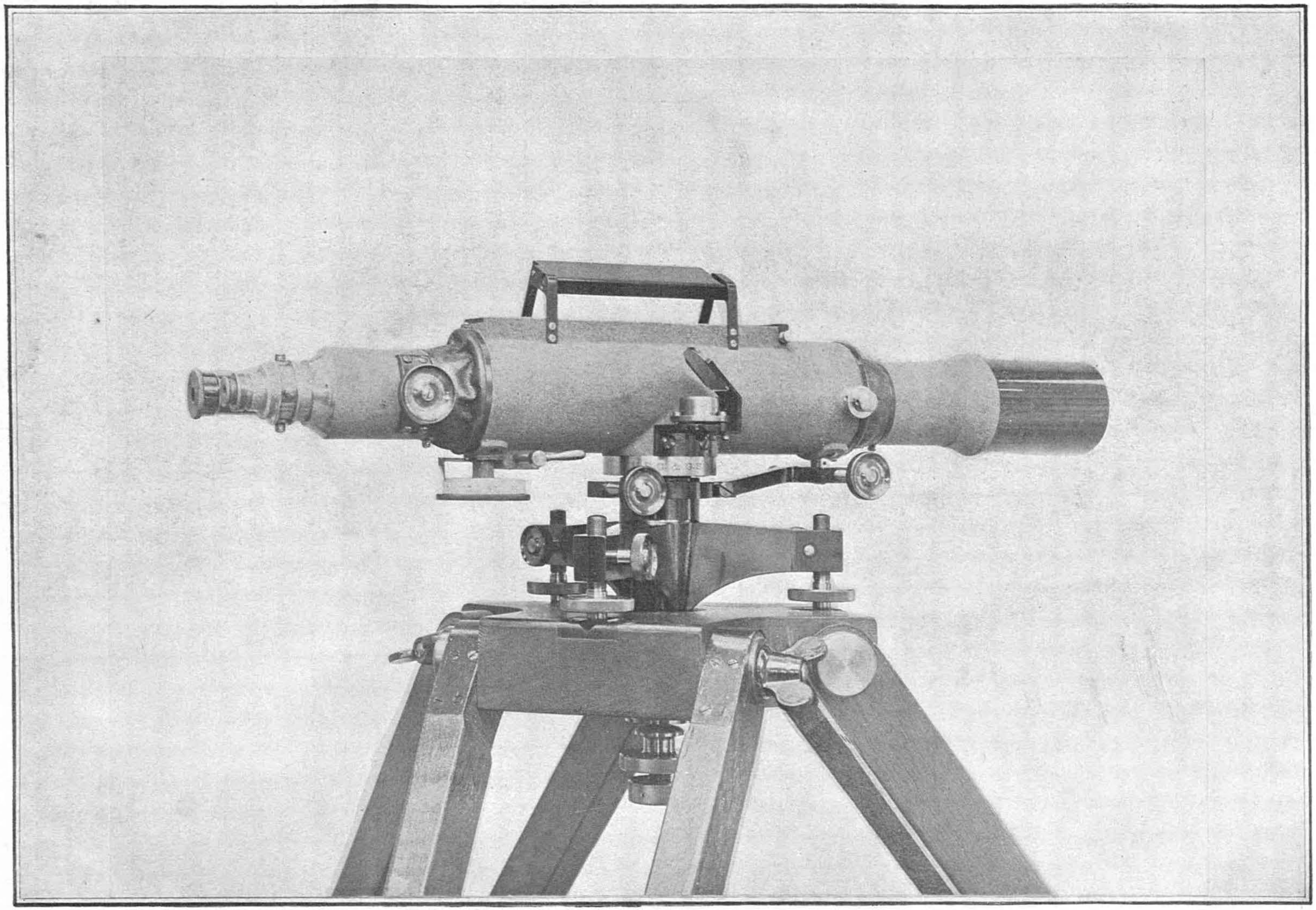


PRECISE LEVEL OF 1900.



PRECISE LEVEL OF 1900.

APPENDIX NO. 6. 1900.

DESCRIPTION OF PRECISE LEVELS NOS. 7 AND 8, COAST AND GEODETIC SURVEY, 1900.

By E. G. FISCHER, *Chief of the Instrument Division.*

A. INTRODUCTION.

When it became necessary to provide additional instruments for carrying out the geodetic leveling planned for the season of 1900, opportunity arose to embody in a new design the fruits of the deliberations of the committee on precise leveling of 1898–99,* whose conclusions had been tried and proven with the three geodetic levels Nos. 1, 5, and 6, remodeled in the instrument shop of the Survey in the spring of 1899 and used in the field during the whole of that season. A careful study of the results obtained with these instruments proved conclusively that the use of the new alloy of iron and nickel, which was first applied in their reconstruction, and the reduction of the distance between the level and the line of collimation were decided improvements and practically eliminated errors due to temperature effects.

These facts were kept in view by the writer in designing the new instruments. As the newly adopted method of observation obviated the use of the reversible stride level and the rotating telescope, the distance between the level and the line of collimation could be reduced to a minimum by placing the former in an opening cut into the telescope and the latter could be placed within a tube-shaped support, at one end of which two pivot screws provide a horizontal axis around which the telescope can be rotated and the line of collimation put into the horizon by means of a fine motion or micrometer screw mounted at the other end. By making the support for the telescope tubular, it was not only given the strongest and lightest form, but it could be made to serve at the same time as a protection to the level mounted in the telescope. The level-reading device, in principle the same as that used in the reconstruction of levels Nos. 1, 5, and 6, being mounted at the side of the telescope at binocular distance from it, offers, with the exception of a small mirror, which is almost horizontal and fastened neither to the level nor the telescope, no additional surface to wind pressure and enables the observer to stand with head and body erect while observing the rod with one eye and the level with the other.

* See page 352 of the Report of 1898–99.

As has been done in designs of other instruments made by the writer for the Survey, the legs of the instrument were put as high up on the center bearing as possible and the lower part of the latter disposed of within the head of the tripod; thus not only affording room for an unusually long and therefore more durable and rigid center, but also bringing the center of gravity of the instrument much nearer to the plane of support.

B. THE MATERIAL.

For all those parts upon which depend the constancy of the relation between the line of collimation and the level—the telescope, the tube incasing the level vial, the draw tube, reticle ring, and the supporting cylinder—the material selected is the same as that used in the reconstruction of geodetic levels Nos. 1, 5, and 6 in the spring of 1899.

The nickel-steel alloys brought out by Dr. Ch. Ed. Guillaume,* of the International Bureau of Standard Weights and Measures, had attracted considerable attention by reason of their low expansion coefficients (down to 0·000001 per degree centigrade). Inquiry established the fact that tubing and castings, almost indispensable in the construction of instruments, could not be obtained, because attempts to produce them had not yet been successful. Mr. George T. Ennis, of this city, who furnishes the brass castings required in the shops of the Survey, was pursuaded to undertake a series of trials in 1899 of alloying various kinds of steel and iron with nickel. A quantity of what in the trade is called "machinery steel" and commercially pure nickel were weighed off in the proportion of 64 of steel to 36 of nickel, the same from which Dr. Guillaume obtains a coefficient of less than one-millionth per degree centigrade. The furnaces of brass founders being supplied with air only by natural draught, it was with considerable difficulty that sufficient heat could be developed to melt the steel, and when mixture with the nickel was finally accomplished the temperature was still too low to allow impurities to rise freely to the surface and leave the casting sound and solid.

In another attempt steel turnings from the large gun forgings being assembled at the Washington ordnance yard were used, but the trial castings also proved porous.

The coefficients of these specimens, as determined from the temperatures of 0° and about 60° C., were, however, quite low, namely, three-millionths, nearly. The melting point of cast iron being much lower than that of wrought iron or steel, a trial was made with it, using the same proportion. But while the castings were now sound and free from pores the coefficient had increased to nearly five-millionths. The results of Dr. Guillaume's investigations showing that but a slight variation from the above given proportion caused a change of several units in the sixth place of the coefficient, it was thought likely that a loss of one or the other of the two metals by oxidation during the melting and mixing was the cause of this increase. For this reason a number of alloys were made of different proportions, of which one of 66⅔ parts of a medium-grained cast iron, furnished by the Brown & Sharpe Manufacturing Company, and 33⅓ parts of what is called "grain nickel" was finally adopted. It can be cast, free from sand and blowholes, and has a coefficient of 0·000004.

No thorough tests as to strength, etc., were made of this alloy, but so far as shop practice reveals its physical properties it can be said to be rather brittle, easily worked

* These alloys are protected by patents.

in the lathe and with the file, entirely malleable, and behaving practically like the better and softer grades of cast iron. It can readily be brazed and soldered, and, unlike cast iron, very easily takes an exceptionally fine polish, resembling that of nickel. The smoothness with which it wears against itself, even under considerable pressure, should be particularly mentioned. For instance, the nickel-iron drawtubes of the three remodeled instruments of 1899, though moving in bearings of the same metal, do not show the slightest wear or looseness, though they were used in running 200, 300, and 600 miles of leveling line, respectively.

None of the acids except aqua regia will readily attack it. A rectangular piece submerged in water for twelve days showed formation of what resembled iron oxide, but only along the sharp corners and without pitting, while the surfaces remained bright. A rough test proved the specific gravity of the alloy to be between that of iron and of nickel, but below that theoretically deduced from their proportions. The nickel used in these experiments was purchased at a cost of 42 cents and the iron at 6 cents a pound, making the cost of the two-to-one alloy 18 cents per pound, which is 2 cents less than that of good brass.

The pointed screws pivoting the telescope, the screws holding in place the level tube and by which the level is adjusted, the screws holding and adjusting the reticle ring, and the fine-motion micrometer screw, upon all of which depends the constancy of the relation between the line of sight and the plane tangent to the middle point of the level vial, and which require to be of a material much harder than the casting above described, are made of nickel steel, with a coefficient of ·000001, obtained from the Société Anonyme de Commentry Fourchambault, 26 Place Vendôme, Paris. This alloy is well adapted for screws of all kinds, and should now entirely replace steel in the manufacture of all measuring screws, such as micrometer screws for astronomic and surveying instruments, micrometer calipers, gauges, etc., used in mechanical engineering, provided, of course, that the nuts into which such screws are threaded are made of the same material, for it is obvious that a screw with a coefficient of ·000001 could be made to fit closely in a nut of brass whose coefficient is ·000018 only at one certain temperature.

The material used in the construction of other portions of the instrument will be named in the description of those parts.

C. THE TRIPOD.

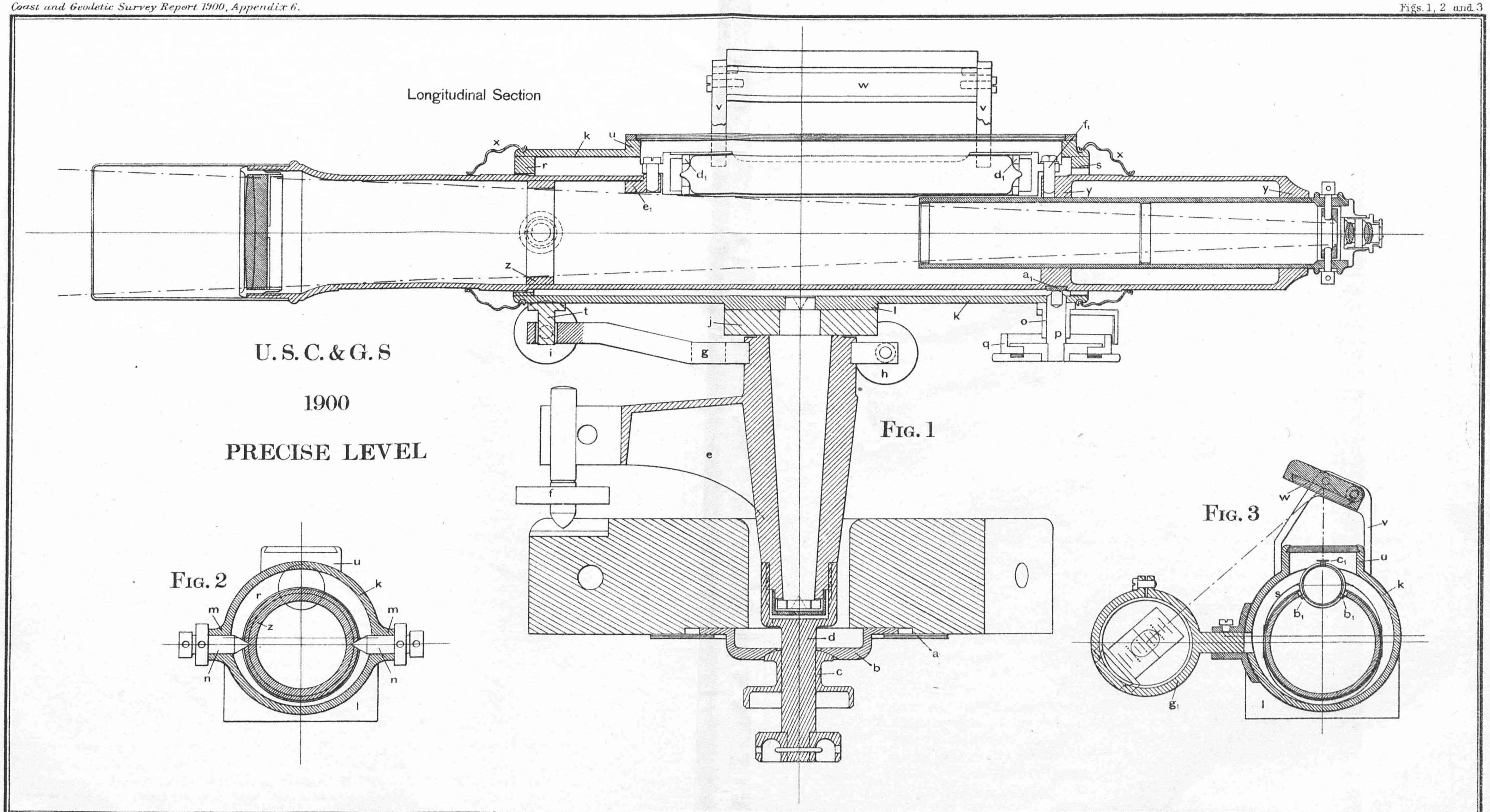
The tripod is of the usual form. The three legs, separating some distance above the feet into two rectangular rods, pivot in the head by means of bolts about 1^{cm} diameter at points forming a regular hexagon. The feet consist of pointed hollow sockets about 14^{cm} long and $3\frac{1}{2}^{cm}$ diameter at the top, fitted and fastened by screws to the legs. They are made of 10 per cent aluminum bronze, an alloy but little inferior to steel in hardness and toughness. The two rods forming the leg are made of black walnut, 2^{cm} by $3\frac{1}{2}^{cm}$, and fastened together at two points by walnut braces which are screwed between them. The tops of the legs are brass bound to guard against the splitting out of the bolt holes. In obtaining the length of the legs, which should be made to suit the observer's height, their normal angle with the ground was taken to be 60°, the vertical distance between the bolt holes in the head of the stand and the line of collimation being 13^{cm}. The head of the stand, also of black walnut, is $4\frac{1}{2}^{cm}$ thick and carries sunk into its upper surface the three V-grooved plates forming the supports for the foot screws of the instrument. In a circular recess in the lower surface is held by a ring-shaped plate marked *a* in fig. 1, a washer, *b*, shaped so as to form a seat for the convex shoulder of the nut *c*, which is threaded on the screw *d*. This screw, $1^{cm}\cdot 3$ in diameter and of a pitch of 8 threads per centimeter, enlarges at its upper end to a cup-shaped nut, which can be screwed upon the lower end of the center socket of the instrument. The washer *b* is not confined in its recess so closely but what it can move laterally and adapt itself to any position the vertical axis may assume in relation to the head of the stand. When the instrument is set upon the stand the lower end of the center socket will come to rest upon the cup-shaped nut before the foot screws can touch their supports, thus leaving it in an unstable position and making it practically impossible for the observer to forget to secure the instrument to the stand before it is carried to the place of work. The nut *c* is loosened before observing, and tightened only when the instrument and stand are to be carried from station to station.

D. THE INSTRUMENT BASE AND CENTER.

The instrument base, designated by *e* on the diagram, is a single piece of hard and fine-grained cast iron, furnished by the Brown & Sharpe Manufacturing Company, of Providence, R. I. In its three legs, at a radial distance of 9^{cm}, are threaded the foot screws *f*, of $9\frac{1}{2}^{mm}$ diameter and 15 threads per centimeter, and having a bearing of $2^{cm}\cdot 3$. The screws are of such length as to permit a motion of 6^{mm} above and below the normal position, thus allowing the instrument to be leveled even under unusual inclination of the head of the tripod. No position of the foot screws can prevent the fine-motion or micrometer screw from freely passing over them. The ends of the legs are split in the usual manner and provided with milled-head screws for clamping the foot screws. The clamp arm *g*, with its clamp screw *h*, is fitted into a groove near the top of the center socket, and carries at the outer end the fine-motion screw *i* for moving the telescope horizontally in azimuth. The central portion of the instrument base is bored out conically and affords a bearing throughout its length for the unusually long center (10^{cm}), which is made of the hardest grade of tool steel, Sanderson's No. 6. It is secured against being withdrawn by a small nut screwed to its lower end. Upon its upper end is fastened permanently, by screwing and riveting, a disk or flange *j*, of $5^{cm}\cdot 8$ diameter, made of hard cast iron, which forms the base of the supporting cylinder.

E. THE SUPPORTING CYLINDER.

This, indicated in Figs. 1, 2, and 3 by *k*, is a nickel-iron casting, as stated above. Its length is $21^{cm}\cdot 6$, its outer diameter $5^{cm}\cdot 9$, its inner diameter $5^{cm}\cdot 4$, leaving a thickness of wall of $2^{mm}\cdot 5$. At its middle point is a cylindrical boss or hub (*l* in Figs. 1, 2, and 3), of the same diameter as the flange of the center, to which it is firmly fastened by four steel screws. Two lugs, *m* in fig 2, are threaded to receive the pivoting screws *n*, which are made of nickel steel, and, with their points $2^{mm}\cdot 6$ below the center of the supporting cylinder, form a horizontal axis for the telescope. At a distance of $1^{cm}\cdot 2$ from the rear end and below is fastened, by two screws, the nut *o* (Fig. 1), made of nickel iron, which carries the fine-motion or micrometer screw *p*. This latter, of 39 threads per centimeter nearly (100 per inch) and 7^{mm} diameter, is provided at its upper



THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

end with a small tip of glass hard steel, and carries, below, an adjustable micrometer head of white zylonite q, which is $4^{cm}\cdot 1$ in diameter and is divided into 100 parts. A hard rubber disk with milled edge, projecting beyond the micrometer head, not only protects the graduation from the fingers, but, by reason of its large diameter, facilitates the setting of the sensitive level. An index for reading the micrometer head is provided.

The supporting cylinder carries a removable eccentric ring r inserted into its forward end (Figs. 1 and 2), of which the inner diameter is such as to permit the telescope pivoted between the screws n to rotate slightly without touching. A similar ring s (Figs. 1 and 3) at the rear end, however, is cut out so as to permit the telescope to move up and down, above and below the normal or horizontal position, by about 2^{mm}, while the sides of the ring permit of no lateral play, but form a guide for that amount of vertical motion.

Directly in front of the micrometer screw is fastened to the supporting cylinder a small case holding an eccentric which can be rotated by a lever handle at the right side of the instrument. When the lever handle is turned up the eccentric pushes against the telescope, lifts its weight off the micrometer screw, and presses it gently against a spring sunk into the upper part of the ring s. In this position the instrument can be carried without the risk of jarring the telescope and thereby disturbing the level adjustment. This device is not shown in the diagrams but can be seen in the photographic view (Fig. 4).

Against the hub l, on the right side of the instrument, is fastened a bracket carrying a small universal level, which is easily observed from the eye end of the telescope by means of a mirror mounted above it at an angle of 45° (see Fig. 4).

At the forward end of the supporting cylinder and below is mounted a post t (Fig. 1), reaching downward between the horizontal pointing screw i and the spring case of the clamp arm g.

The upper part of the supporting cylinder has cast into it a rectangular opening with a framing u surrounding it. A piece of plate glass, fitted into this framing by dovetail grooves, closes the opening against dust or air currents, but can quickly be moved forward for the purpose of adjusting the level by loosening a small milled head screw (see Fig. 4), and turning up a hinged locking piece. Over this opening and against the sides of the framing is mounted by brass arms v the glass mirror w, arranged so as to permit of a small rotary adjustment for the purpose of adapting the level reading device to individual observers. It may be stated here that the opening in the supporting cylinder was placed as near as possible to its rear end and away from the middle of the instrument, because the level could at that place be put closer to the line of collimation without entering the cone formed by the apertures of the objective and the reticle ring.

Small grooves around the ends of the supporting cylinder afford the means of fastening, by wire rings or narrow metal bands, the leather cones x (Fig. 1). They are fastened to the telescope in a similar manner, and effectively shut out dust and air currents without in the slightest degree preventing the telescope from assuming the position determined by the pivoting screws at one end and the micrometer screw at the other end of the supporting cylinder.

F. THE TELESCOPE.

The tube with the objective head and drawtube bearings, forming the telescope, is cast of nickel iron in one piece and bored and turned in the lathe. Its outer diameter being $4^{cm}.37$ and the inner $4^{cm}.05$, gives a thickness of wall of $1^{mm}.6$. Immediately at the eye end and at a distance of 9^{cm} from it are two constrictions forming the bearings *y* for the drawtube. A ring *z* is fitted and soldered into the telescope at the place where the 60° points of the pivoting screws *n* are bored into it ($28^{cm}.9$ from the eye end) for the purpose of strengthening it to resist strains caused by undue tightening of these screws.

The drawtube, cast solid of nickel iron and bored out, is fitted closely into its bearings, and carries within an enlargement at its outer end, by means of four nickel-steel screws, the nickel-iron reticle ring. Great care was taken to fit the threads of these screws very tightly to insure, as much as possible, invariability of the position of the reticle. One vertical and three horizontal spider threads of the finest grade obtainable are mounted upon the reticle ring. The horizontal threads are equidistant and the upper and lower embrace a space of 30^{cm} at a distance of 100^{m}. Two Steinheil eyepieces, of $12^{mm}.5$ and $9^{mm}.5$ (one-half inch and three-eighths inch), equivalent focus, to suit different weather conditions, are supplied. The objective lens is mounted in a cell cast of nickel iron. It is held in place by a spring ring, fastened with three small screws, in such manner as to hold it firmly in position, without restraining it from expanding and contracting with changes of temperature. It has a clear aperture of $4^{cm}.2$ and a focal length of 41^{cm}, giving a magnifying power of 32 diameters with the $12^{mm}.5$ and of 43 diameters with the $9^{mm}.5$ eyepiece. The drawtube is moved into focal distance in the usual way, by means of a rack and pinion, and has sufficient range to enable the observer to point on an object as near as 3.5 meters.

Just within or under the leather cones *x* the telescope carries two enlargements or collars, which are turned to equal diameters, and serve the purpose of placing the pointing line into the geometric axis of the telescope. This adjustment is made in the shop permanently. It is done by laying the telescope, with these collars, upon two metal wye supports provided with leveling foot screws. Pointing on an object and rotating the telescope in the wyes reveals any want of parallelism between the axis of the two collars and the line connecting the intersection of the vertical and middle horizontal threads and the optical center of the objective. This is corrected by means of the four screws holding the reticle ring. Since the spider threads move with the drawtube, it also must move in a line parallel to the axis of the collars, in order to preserve true collimation in any position required by focusing upon the rod at different distances. To insure this parallelism, great care was taken in making the telescopes. The objectives were centered with special care, and the collars were turned true at the same chucking under which the drawtube bearings were bored. Inasmuch as any error of collimation enters into the result of leveling only to the small amount due to differences between back and fore sights, it may be said that these instruments, as far as collimation error is concerned, are practically faultless.

In the same wye supports above mentioned, the level attached to the telescope is adjusted so that its axis is parallel to the vertical plane containing the line of collimation.

This adjustment eliminates what is commonly called the "wind" of the level, and can not readily be made in the field.

The position of the forward drawtube bearing and that of the micrometer screw were selected with the view to sufficient rigidity of that part of the telescope which rests upon the micrometer screw. The point of contact with the hardened tip of the screw is a small hardened steel plate a_1, fastened into the telescope at the forward drawtube bearing. The distance between the axis of the micrometer screw and the axis of rotation formed by the pivoting screws n is $19^{cm}.15$ nearly, which, with the screw pitch of 39 threads per centimeter, gives a value of about $2''.6$ per division of micrometer head The distance between the axis of rotation of the telescope and the vertical center is $9^{cm}.8$.

G. THE LEVELS.

The levels were made by A. Pessler, and are of the chambered type. They are $11^{cm}.5$ long, $1^{cm}.5$ in diameter, and carry a graduation 8^{cm} long in 2^{mm} spaces. The length of the bubble used is about 25 div., or $5^{cm}.0$. The values of the levels are $1''.94$ for level No. 7 and $1''.86$ for No. 8. The mounting of the vials has been attended to with special care, with the aim of securing the greatest possible constancy of adjustment. The glass vial rests within a tube of nickel iron upon the ends of four small screws b_1, piercing the tube, two at each end of the vial, 120° apart. A small tip c_1, at the end of a flat spring fastened to the tube and also piercing it, presses with sufficient force upon the vial at each end, exactly over the supporting screws, to hold it firmly in place and yet permit it to expand and contract independently of the tube. Longitudinally the vial is confined by a cork ring d_1 at each end, which, however, leave a small clearance, so that the vial is free also in that direction. This is the manner in which all level vials, excepting only the smaller ones, have been mounted in the shops of the Survey for the past thirteen years. The level tube, with the vial thus supported, is secured to the telescope, sunk through an oblong opening close to the cone formed by the apertures of the objective and reticle ring. At the forward end it is held by a screw holding it down to a rounded support e_1, screwed to the telescope, upon which it can be moved laterally by two opposing screws for adjusting the "wind." The other end is made adjustable in the vertical for the purpose of keeping the level parallel to the line of collimation. This is the only adjustment required on the part of the observer in the field. A square-headed vertical screw f_1, of about 27 threads per centimeter and fitting closely in the level tube end, is threaded tightly into that part of the telescope forming the forward drawtube bearing. Two strong helical steel springs, one on each side, press the level tube tightly upward against the shoulder of the screw f_1. A socket wrench, with a lever arm $7^{cm}.5$ long, permits of applying rotary force to the screw without exerting any other pressure against the instrument and thereby displacing the pointing of the telescope, as is the case when using a screw-driver or capstan bar, so that this delicate adjustment is made quickly and with ease, and seldom requires to be repeated.

As already stated, the adjustment of the reticle is made permanently in the shop, the observer having no means of testing it in the field. It is of great importance, therefore, that the reticle ring should not be disturbed, but that, when necessary, the level be moved into parallelism with the pointing line. In a new instrument the writer would conceal the four screws holding the reticle ring and so prevent displacement of the line of collimation.

It may be of interest to state here the manner in which the error of collimation is determined in the field, which can not be done better than by quoting from a set of instructions issued to the observers:

Once during each day of observation the error of the level should be determined in the regular course of the leveling and recorded in a separate opening of the record book, as follows: The ordinary observations at an instrument station being completed, transcribe the last fore sight reading as part of the error determination, call up the back rod and have it placed about 10^m back of the instrument, read the rod, move the instrument to a position about 10^m behind the front rod, read the front rod, and then the back rod. The rod readings must be taken with the bubble in the middle of its tube. The required constant *C* to be determined, namely, the ratio of the required correction to any rod reading to the corresponding subtended interval is—

$$E = \frac{(\text{sum of near rod readings}) - (\text{sum of distant rod readings}).}{(\text{sum of distant rod intervals}) - (\text{sum of near rod intervals}).}$$

The level should not be adjusted if *C* is less than 0·005. If a new adjustment of the level is made, *C* should at once be redetermined. It is desirable to have the determinations of level error made under the ordinary conditions as to length of sight, character of ground, elevation of line of sight above the ground, etc.

The value 0·005 for *C* means that the line tangent to the level vial at its middle point makes an angle of approximately three seconds with the pointing line of the telescope. The following statement of the behavior of the instruments in the field,* showing the constancy with which they maintain their adjustment, will testify to the fine workmanship put upon them, for which credit is due to Mr. C. Jacomini and O. Storm, instrument makers of the Survey:

The instrument was carefully put in adjustment at Washington and sent by express to a point in Kentucky. The observer there, on beginning work with it, found it to be still in adjustment and continued to use it for one and one-half months, during which time the value *C* never exceeded 0·005. At the end of that time it suddenly showed a magnitude of 0·015, which was corrected. After constant use for nearly one and one-half months more, the record showed the greatest error to be 0·006. The mean algebraic value of *C* during this period was +0·002, or but little more than one second of arc.

The attendant carrying the instrument from station to station readily learns to hold it in such position as to prevent any change of the length of the bubble by establishing communication between the chamber and interior of the vial. In the vials used for these instruments the openings in the chambers are not at the bottom, but slightly to the side, away from the reading device.

H. THE LEVEL READING DEVICE.

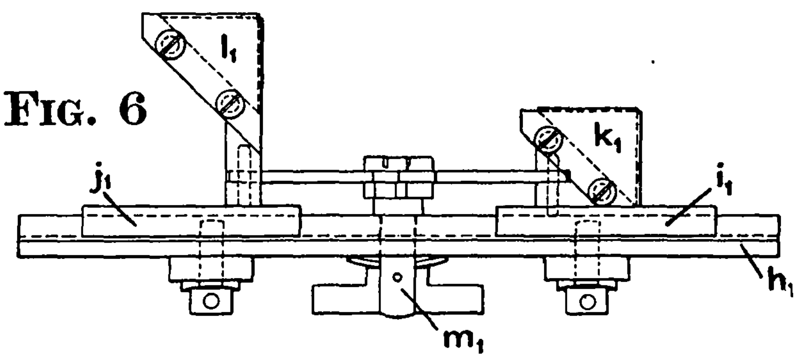
The operation of reading the position of three fine lines, the spider threads, projected upon the graduation of the level rod is a trying one under the best conditions, and subjects the observer, when the air is hazy or unsteady, to severe strains. As it is of the highest importance that these readings be taken only at the instant when the level indicates horizontality of the line of sight, the instrument should be designed particularly with a view to the observer's comfort, so as to enable him to observe the rod and the level as nearly as possible simultaneously. It is thought that the level

* See page 1142, Proceedings American Society of Civil Engineers, Vol. XXVI, No. 9.

reading device provided for these instruments fulfills all requirements, since only the time required for transferring mental attention from one object to another need elapse between the two observations. It is a modification of that used by Berthélemy, of Paris, in his precise level,* which consists of two adjustable prisms mounted upon the stride level and three prisms mounted in a casing fastened to the wye support of the telescope, with a short tube immediately on the side of the latter reaching as far as the eyepiece. Besides the objectionable feature of the overloaded stride level, the design has the fault of requiring the observer to shift his head between observations upon the rod and the level.

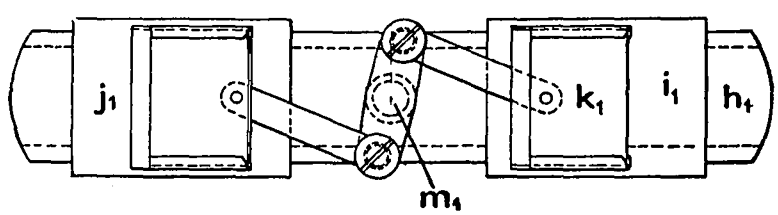
The modified form here described was already applied in the spring of 1899, when precise levels Nos. 1, 5, and 6 were remodeled, and it was amply tested in the field

FIG. 6



Prisms of Level Reading Device

FIG. 7



during the season of that year; but in designing an entirely new instrument it was possible to improve greatly upon the manner of its application. Two clamp rings, g_1, Fig. 3, support an aluminum tube with an eye end reaching back to a point even with the eyepiece of the telescope when focused for an average distance. Against this tube is screwed a dovetail bar, h_1, Figs. 6 and 7, upon which move, within the tube, two slides, i_1 and j_1, carrying the prisms k_1 and l_1. These slides are connected by arms with a lever mounted upon a stem with a milled head, m_1, the rotation of which moves the prisms equally toward or away from a central point between them. This motion is provided to adjust the distance of the prisms accurately to the length of the bubble, which, during the day's work, may vary by reason of temperature changes. Those

*See page 423 and illustration opposite, in Appendix No. 8, 1898-99.

faces of the prisms which are directed toward the eye are ground to such curvatures as, with the aid of a lens mounted between them and the eye end, to reduce to that of distinct vision of the normal eye the distance from the end of the bubble to the eye, by way of the mirror w, the reflecting faces of the prisms k_1 l_1 and the lens. For the benefit of the observer required to use glasses the eye cap of the level reading tube is arranged to hold such a lens as he may require to enable him to observe without spectacles.

The distance between the level reading tube and the telescope can be changed to suit each individual observer, and provision is made for the rotary adjustment of the prisms and the mirror necessary in consequence of any such change, as can be seen in Fig. 3. The appearance of the field of view of the level reading device is also shown in Fig. 3. The prisms are put in such position by means of the milled head, m_1, that the ends of the bubble and the graduation marks above them are brought into view, appearing as if the bubble were very short. The lines forming the graduation upon the level vial are marked by small dots in such manner that symmetrical lines, or lines equidistant from the center of the graduation, are readily distinguishable, thus relieving the observer of any strain in guarding against mistakes.

I. THE FINISH.

The telescope throughout its length—with the exception of the eye end of the draw tube and the two collars turned to equal diameters—the supporting cylinder, and the level tube were covered with a heavy coating of cloth dust of a bluish-gray color. This coating is put on by painting the parts with a mixture of Japan varnish, turpentine, and linseed oil, which is colored with white lead, lampblack, and ultramarine blue, to the same shade as that of the cloth dust; the latter is sifted over the freshly varnished pieces through a hair screen and pressed in with the hand. After allowing it to dry for two days and brushing off all loose cloth dust, a coating of a dilute solution of bleached shellac in alcohol is applied. This finish has the appearance of a fine quality of cloth, and affords considerable protection against sudden and temporary changes of temperature.

Other parts of the instrument, as the instrument base, mirror frame, level reading tube, etc., are finished in black enamel of the kind introduced so extensively through the bicycle industry. It is heavy, hard though elastic, and surpasses in appearance and durability any of the black lacquers heretofore used in the art of instrument making.

J. THE WEIGHT.

The weight of the instrument is $5^{kg}.2$. No doubt this can be considerably reduced when tubing made of nickel steel is obtainable in the market. The thickness of the cast tubing—about twice as great as would be necessary if wrought metal could be substituted—is considered as small as is safe to use in view of the loose texture of the alloy.

The weight of the tripod, $7^{kg}.2$, is somewhat greater than that of stands formerly used for the same class of instruments. This is due to the much greater length required in order to enable the observer to stand erect, which is considered of sufficient advantage to warrant a small sacrifice in the matter of weight.

APPENDIX No. 7.

REPORT 1900.

MANUAL OF TIDES.

PART IV A.

OUTLINES OF TIDAL THEORY.

BY ROLLIN A. HARRIS.

PREFACE TO PART IV A.

A little more than two centuries ago appeared the Principia of Newton, explaining the motions of the solar system and referring the tides to their primal cause. But the question as to how, or the mechanism whereby, the tides along various shores result from the disturbing forces of the sun and moon is still open. In fact few writers of note have in recent years cared to hazard their reputations on a problem so hopeless, where observations, if not vague and uncertain, generally seemed hard to reconcile with any hypothesis. But these two centuries have cleared away much of the mystery of ocean depths. As a consequence, whoever now attempts to explain the tides has a decided advantage over his predecessors; but it must not be inferred that such information is yet adequate for his purpose.

He has another great advantage in more extensive and more accurate observations. In this matter, however, there has been much inexcusable negligence. For instance, recent scientific expeditions have seldom made careful records concerning the tides when visiting distant or unknown shores. Again, although the ancient Egyptians gauged the height of their river and were the inventors of the nilometer—a simple but accurate form of tide gauge—at the present time there seems to exist no systematic record of the tide for any port, except Cape Town, on the Atlantic or Mediterranean coast of Africa. It is to be hoped that observations will soon be undertaken in all hitherto neglected parts of the world, and the results worked out and published, in order that the questions which have puzzled philosophers for the last two hundred years may be answered with tolerable certainty in the near future.

In preparing these chapters entitled "Outlines of Tidal Theory" no attempt has been made at anything beyond rude approximations to the cases found in nature; and even the results of these efforts may upon subsequent investigation, or upon comparison with values obtained from future observations, prove to be erroneous in many respects. However this may be, it will, I think, be admitted that the ways of attack here outlined, though containing in themselves little that is really new, are more promising than those generally followed in attempts to explain the tides and tidal phenomena. In fact little or nothing is included in these chapters which does not in some manner or degree apply to tidal motions somewhere existing; and so the hypothetical problems worked out by Laplace and elaborated and extended by several able mathematicians of later date, though commonly known as "Tidal Theory," are not considered at this time, important as they are from certain points of view.

It is assumed here that the tides are in most cases due to one of two modes of generation: the first, that implied in the corrected equilibrium theory, and which applies to small deep bodies of water; the second, and far more important, that of stationary waves or oscillating systems whose free periods are approximately the periods of the tidal forces. For some small bodies of water, however, an explanation involving their forced oscillations should be resorted to in preference to the equilbrium theory. Whether or not the systems outlined upon the charts of the world (Figs. 23, 24) really exist and serve to explain the tides, it is certain that they, or similar systems, will assist a person in seeing and bearing in mind the cotidal hours of various parts of the world, as well as in forming some estimate of the relative amounts of the rise and fall.

I am indebted to members of the Tidal Division for assistance in copying manuscript and preparing the tables included in and following the text, and especially to Mr. J. C. Hoyt for tracing the accompanying maps from various sources.

The depths and contour lines of the Pacific Ocean, shown upon the charts of depths (Figs. 19, 20), are taken from an unpublished compilation made by Mr. A. Lindenkohl, of this Survey.

CONTENTS OF PART IV A.

CHAPTER I.—TIDAL FORCES AND EQUILIBRIUM TIDES.

CHAPTER II.—HYDRODYNAMICS.

CHAPTER III.—OSCILLATING AREAS.

CHAPTER IV.—CONCERNING WAVES IN DEEP WATER AND LONG WAVES WHERE THE DEPTH MAY VARY.

CHAPTER VIII.—ON THE CLASSIFICATION OF RIVERS, STRAITS, BAYS, ETC., WITH REFERENCE TO THEIR TIDAL MOVEMENTS.

TABLES.


NEVADA
CALIFORNIA
ARIZONA
COLORADO RIVER
NEW YORK RANGE
CASTLE MOUNTAINS
LEWIS MOUNTAINS
Magnetic Station
Sage brush
Sandy slope
Stony slope
Great Piute Wash
Great wash
Gap or divide
Dry Lake well
Setter 3459
Searchlight
Lewis Holes
Indians
Yucca forest and Spanish bayonet undergrowth
High valley covered with yucca forest and Spanish bayonet
Sage brush and greasewood
Sand and gravel
Sage brush, greasewood, Spanish bayonet, yucca, cacti.
Cacti
Piute 2324
Coltie 2387
Fort Mohave
Needles
Note
The topography was sketched from flag stations on the west side of the river. No great degree of accuracy could be obtained. The river was sketched on the Needles data, the boundary line on data brought down from Lake Tahoe; these differ 8.6 in longitude. This sheet shows all of the work on Lake Tahoe data for uniformity. In January 1899 when the line was traced to the Colorado River it was during low water and the terminus fell on a sand flat; a rise of one foot would cover the flat and bring the terminus almost in the center of the running stream, which in 1893 and 1899 was nearly midway between the permanent bluff banks of sand and gravel. The curves are intended to show the general shape of hills and mountains rather than the relative elevations.


NEVADA
ARIZONA
CALIFORNIA
COLORADO RIVER
NEW YORK RANGE
CASTLE MOUNTAINS
LEWIS MOUNTAINS
Magnetic Station
Fort Mohave
Fort Piute Springs
Great Piute Wash
Sage brush
Stony slope
Sandy slope
High valley covered with yucca forest and Spanish bayonet
Yucca forest and Spanish bayonet undergrowth
Note
The topography was sketched from flag stations on the west side of the river. No great degree of accuracy could be obtained. The river was sketched on the Needles data, the boundary line on data brought down from Lake Tahoe; these differ 8.6 in longitude. This sheet shows all of the work on Lake Tahoe data for uniformity. In January 1899 when the line was traced to the Colorado River it was during low water and the terminus fell on a sand flat; a rise of one foot would cover the flat and bring the terminus almost in the center of the running stream, which, in 1893 and 1899 was nearly midway between the permanent bluff banks of sand and gravel. The curves are intended to show the general shape of hills and mountains rather than the relative elevations.

LIST OF ILLUSTRATIONS.

APPENDIX NO. 7. 1900.

MANUAL OF TIDES—PART IV A. OUTLINES OF TIDAL THEORY.

By Rollin A. Harris.

CHAPTER I.

TIDAL FORCES AND EQUILIBRIUM TIDES.

1. *Harmonic development of the horizontal forces.*

In § 39, Part I,* it has been shown that although the vertical disturbing forces are of about the same magnitude as the horizontal, the latter alone are responsible for the production of the tides. In any attempt at presenting a tidal theory which may in a measure account for the phenomenon in a rational manner, it is therefore natural to give at the outset a ready means of ascertaining these forces in any given locality.

The uncorrected equilibrium tide (the density of water being small as compared with that of the solid earth) constitutes a convenient representation of the tide-producing potential. But when the height of this hypothetical tide is used for the potential, it must be borne in mind that the unit of the forces which are obtained by differentiation is g, or the force of gravity acting upon a unit mass, say upon a pound of matter.

The ratio of a horizontal disturbing force to the force of gravity, denotes the angle (radian measure) by which the plumb line is deviated from the vertical.

Let the height of the hypothetical tide $\left(\frac{V}{g} \text{ or } h\right)$ be represented by three series of terms, and for convenience, let only one term of each be at first considered. The part of the height due to these terms may be written

$$\begin{aligned} UG_2C_2 \cos\,(c_2t + \arg_0 C_2) + UG_1C_1 \cos\,(c_1t + \arg_0 C_1) \\ + UG_0C_0 \cos\,(c_0t + \arg_0 C_0), \end{aligned} \tag{1}$$

where U denotes the universal coefficient, or $\frac{3}{2}\frac{M}{E}\left(\frac{a}{e}\right)^3 a$ $(= 1{\cdot}760 \text{ feet})$, and G_2, G_1, G_0 denote general coefficients equal to $\cos^2\lambda$, $\sin 2\lambda$, $\frac{1}{2} - \frac{3}{2}\sin^2\lambda$ respectively; C_2, C_1, C_0 denote coefficients† or abstract numbers proportional the theoretical amplitudes of the

* Published as Appendix No. 8, Report for 1897.

† Called "coefficients" in Table 1.

constituents designated by the same symbols; $\arg_0 C_2$, $\arg_0 C_1$, $\arg_0 C_0$ are the equilibrium arguments when $t = 0$. For changing to Greenwich time, t_g, we have

$$t = t_g - L = t_g - \frac{l}{15}, \tag{2}$$

$$\arg_0 C = \arg_{0g} C + L(c - 15p), \tag{3}$$

where p is an integer $= 2, 1, 0$ for semidiurnals, diurnals, and long-period tides, respectively; L, l denote west longitude in hours or degrees.

$$\therefore ct + \arg_0 C = ct_g + \arg_{0g} C - pl. \tag{4}$$

The above height becomes

$$\begin{aligned} UG_2C_2 \cos (c_2t_g + \arg_{0g} C_2 - 2l) + UG_1C_1 \cos (c_1t_g + \arg_{0g} C_1 - l) \\ + UG_0C_0 \cos (c_0t_g + \arg_{0g} C_0). \end{aligned} \tag{5}$$

We are to obtain harmonic developments for

$$-\frac{\partial h}{a \cos \lambda \partial l} = \text{eastward component force or angle of deviation of the plumb line,} \tag{6}$$

and for

$$-\frac{\partial h}{a \partial \lambda} = \text{southward component force or angle of deviation of the plumb line.} \tag{7}$$

Differentiating the above expression with respect to l, we obtain for the eastward component force

$$-\frac{U}{a \cos \lambda}\Big[2\, G_2C_2 \sin (c_2t_g + \arg_{0g} C_2 - 2\,l) + G_1C_1 \sin (c_1t_g + \arg_{0g} C_1 - l)\Big], \tag{8}$$

and differentiating with respect to λ we obtain for the southward component force

$$\begin{aligned} \frac{U}{a}\Big[2 \cos \lambda \sin \lambda\, C_2 \cos (c_2t_g + \arg_{0g} C_2 - 2\,l) - 2 \cos 2\lambda\, C_1 \cos (c_1t_g + \arg_{0g} C_1 - l) + \\ 3 \sin \lambda \cos \lambda\, C_0 \cos (c_0t_g + \arg_{0g} C_0)\Big]. \end{aligned} \tag{9}$$

Replacing C by the symbols designating the harmonic components, we have

Eastward component force

$$\begin{aligned} = -2\frac{U}{a} \cos \lambda \Big[& M_2 \sin (m_2t_g + \arg_{0g} M_2 - 2l) + S_2 \sin (s_2t_g + \arg_{0g} S_2 - 2l) \\ & + N_2 \sin (n_2t_g + \arg_{0g} N_2 - 2l) + \ldots \Big] \\ -2\frac{U}{a} \sin \lambda \Big[& K_1 \sin (k_1t_g + \arg_{0g} K_1 - l) + O_1 \sin (o_1t_g + \arg_{0g} O_1 - l) \\ & + P_1 \sin (p_1t_g + \arg_{0g} P_1 - l) + \ldots \Big]. \end{aligned} \tag{10}$$

Southward component force

$$= 2\frac{U}{a}\cos\lambda\sin\lambda\Big[\mathrm{M}_2\cos(\mathrm{m}_2t_g + \arg_{og}\mathrm{M}_2 - 2l) + \mathrm{S}_2\cos(\mathrm{s}_2t + \arg_{og}\mathrm{S}_2 - 2l)$$
$$+\mathrm{N}_2\cos(\mathrm{n}_2t_g + \arg_{og}\mathrm{N}_2 - 2l) + \quad . \quad . \quad . \Big]$$
$$-2\frac{U}{a}\cos 2\lambda\Big[\mathrm{K}_1\cos(\mathrm{k}_1t_g + \arg_{og}\mathrm{K}_1 - l) + \mathrm{O}_1\cos(\mathrm{o}_1t + \arg_{og}\mathrm{O}_1 - l)$$
$$+\mathrm{P}_1\cos(\mathrm{p}_1t_g + \arg_{og}\mathrm{P}_1 - l) + \quad . \quad . \quad . \Big]$$
$$+\frac{3}{}\frac{U}{a}\sin\lambda\cos\lambda\cdot\Big[\mathrm{Mf}\cos(\mathrm{mf}\ t_g + \arg_{og}\mathrm{Mf}) + \quad . \quad . \quad . \Big]. \tag{11}$$

2. *Graphical representation.*

Denoting the southward component force by X and the eastward by Y, we have for the semidiurnal forces expressed in gravitation units,

$$Y_2 = -\frac{2U}{a}C_2\cos\lambda\sin c_2t, \tag{12}$$
$$X_2 = \frac{2U}{a}C_2\cos\lambda\sin\lambda\cos c_2t,$$

the time being local and reckoned from the time of transit of the fictitious C_2 moon.

$$\therefore \quad \frac{X_2^2}{\left(\frac{2UC_2}{a}\cos\lambda\sin\lambda\right)^2} + \frac{Y_2^2}{\left(\frac{2UC_2}{a}\cos\lambda\right)^2} = 1, \tag{13}$$

$$\frac{Y_2}{X_2} = \tan\text{azimuth} = -\frac{1}{\sin\lambda}\tan c_2t, \tag{14}$$

$$\frac{y\text{-axis of force ellipse}}{x\text{-axis of force ellipse}} = \frac{1}{\sin\lambda}. \tag{15}$$

Thus the ellipse and the radiating lines denoting the forces at equal intervals of time constitute a distant view of a spoked wheel, the axis of the wheel is supposed to make an angle of $90° - \lambda$ with the line of sight.

In north latitudes the semidiurnal force lines are numbered clockwise from the south; in south latitudes they are numbered counterclockwise from the north. See accompanying figure, which shows the magnitude and direction of the tidal forces at each ten degrees of latitude; the lettering and numbering are for points north of the equator.

For the diurnals, the forces are

$$Y_1 = -\frac{2\,UC_1}{a}\sin\lambda\sin c_1t,$$
$$X_1 = -\frac{2\,UC_1}{a}\cos 2\lambda\cos c_1t; \tag{16}$$

$$\frac{X_1^2}{\left(\frac{2\,UC_1}{a}\cos 2\lambda\right)^2}+\frac{Y_1^2}{\left(\frac{2\,UC_1}{a}\sin\lambda\right)^2}=1, \qquad (17)$$

$$\frac{Y_1}{X_1}=\tan\text{azimuth}=\frac{\sin\lambda}{\cos 2\lambda}\tan c_1 t, \qquad (18)$$

$$\frac{y\text{-axis of force ellipse}}{x\text{-axis of force ellipse}}=\frac{\sin\lambda}{\cos 2\lambda}. \qquad (19)$$

Here also the ellipse and radiating lines constitute a distant view of a spoked wheel.

In north latitude below 45°, the diurnal force arrows are numbered counterclockwise from the north. Farther north they are numbered clockwise from the south. In south latitude less than 45°, they are numbered clockwise from the north. Farther south they are numbered counterclockwise from the south.

The value of the ratio U/a is 0·000 000 0842; and so the magnitude of the forces represented by the axis of the ellipses are 0·000 000 1684 $C_2 \cos\lambda \sin\lambda$, 0·000 000 1684 $C_2 \cos\lambda$ for semidiurnals, and 0·000 000 1684 $C_1 \cos 2\lambda$, 0·000 000 1684 $C_1 \sin\lambda$ for diurnals; gravity acting on unit mass being the unit force.

For M_2, C_2 is 0·45426 (Table 1), and for $K_1 + O_1$, C_1 is 0·45378. In case of these components, then, 0·000 000 1684 C_2 and 0·000 000 1684 C_1 became 0·000 000 0765 and 0·000 000 0764 respectively. Similarly for other components.

In the figure a length (about ⅜ of an inch) representing 5 degrees of latitude denotes a force equal to 0·000 000 1684 $C_2 g$ for semidiurnals, and to 0·000 000 1684 $C_1 g$ for dinrnals; in particular it denotes 0·000 000 0765 g for M_2 and 0·000 000 0764 g for $K_1 + O_1$.

3. *The corrected equilibrium theory for a small body of water having any shape.*

Let e denote the distance (expressed in feet) of a given point east from the no-tide point, and s its distance south; then at any instant the height of the tide (H or $H_e + H_s$) is $e \times$ eastward slope (numerically equal to the eastward component force) $+ s \times$ southward slope (or southward component force). As the constituent tides will generally best be considered separately, H will, for the present, generally denote a height due to but one of these terms; consequently H_e, H_s each have a time factor and so may be written in the form

$$C_e \sin(ct + \arg_{og} C - pl),\ C_s \cos(ct + \arg_{og} C - pl) \qquad (20)$$

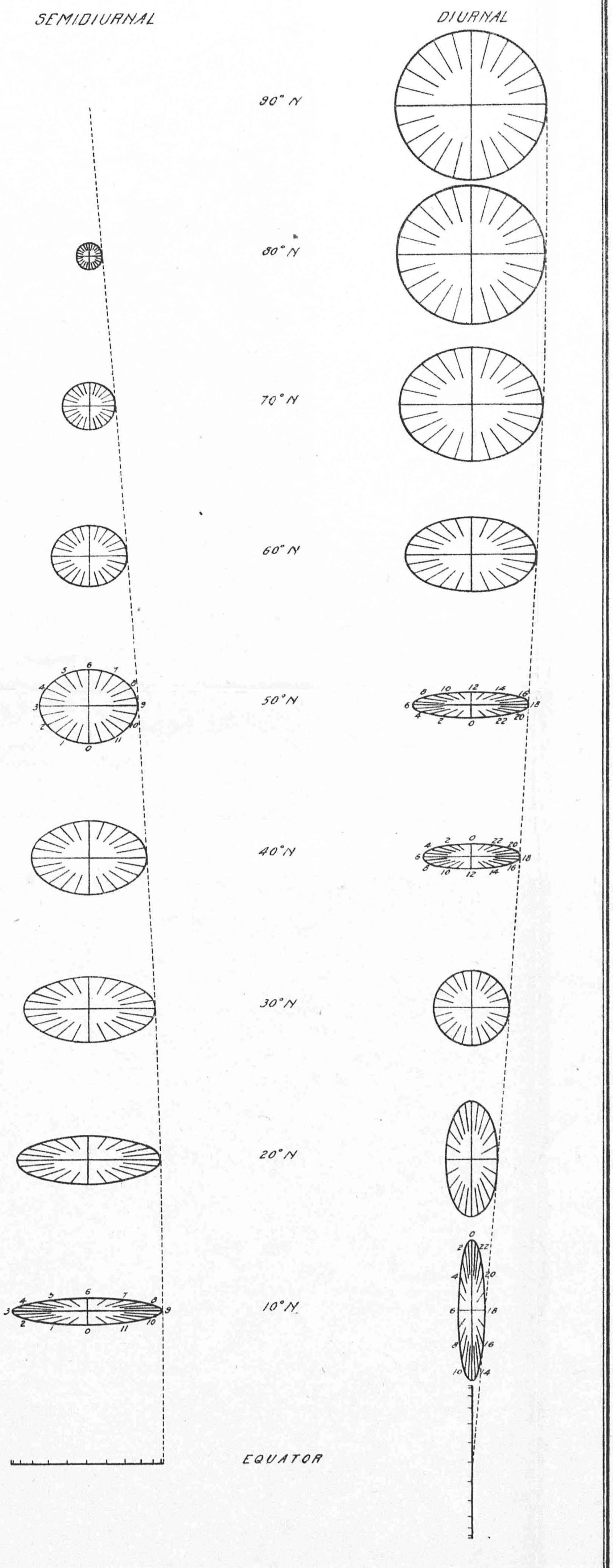
where C_e, C_s may be either positive or negative.

To find the cotidal lines for any particular tidal constituent.—For simplicity, suppose time reckoned from the time of transit of the fictitious tidal body across the local no-point meridian; then

$$H = H_e + H_s = C_e \sin ct + C_s \cos ct. \qquad (21)$$

For maxima and minima we have

$$\frac{dH}{dt} = C_e c \cos ct - C_s c \sin ct = 0, \qquad (22)$$



TIDAL FORCES

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

$$\tan ct = \frac{C_e}{C_s}, \quad ct = \tan^{-1}\frac{C_e}{C_s}; \tag{23}$$

$$\frac{C_{2e}}{C_{2s}} = -\frac{1}{\sin\lambda}\frac{e}{s}, \quad \frac{C_{1e}}{C_{1s}} = \frac{\sin\lambda}{\cos 2\lambda}\frac{e}{s}, \quad \frac{C_{0e}}{C_{0s}} = 0; \tag{24}$$

$$\tan c_2t = -\frac{1}{\sin\lambda}\tan\text{azimuth}, \quad \tan c_1t = \frac{\sin\lambda}{\cos 2\lambda}\tan\text{azimuth}, \quad \tan c_0t = 0. \tag{25}$$

Suppose that we wish to find the direction of the line of high water (cotidal line) at any given time after the transit of the fictitious body. This is converted into angle by multiplying by speed c; the tangent of this angle is then found and used in (25). It is generally best to suppose time to be reckoned in C-hours, and so the hourly speed c to be 30° for semidiurnals and 15° for diurnals. The great advantage of using C-time rather than mean solar time is that the same force diagram or cotidal diagram may be directly applied to all semidiurnal or diurnal tidal constituents, as the case may be.

From equations (21), (25) we have

$$H_2 = C_{2e}\sin ct + C_{2s}\cos ct, \tag{26}$$

$$C_{2e} = -y\frac{2U}{a}C_2\cos\lambda, \tag{27}$$

$$C_{2s} = x\frac{2U}{a}C_2\cos\lambda\sin\lambda, \tag{28}$$

$$\tan c_2t = -\frac{1}{\sin\lambda}\frac{y}{x} = -\frac{1}{\sin\lambda}\tan\text{azimuth}. \tag{29}$$

Eliminate C_{2s}, C_{2e}, c_2t. This is readily done by squaring H_2, replacing C_{2e}, C_{2s} by their equivalents, and $\sin c_2t$, $\cos c_2t$ by values derived from $\tan c_2t$. We obtain for each value of λ a system of similar ellipses whose equation is

$$y^2 + x^2\sin^2\lambda = \frac{H'^2_2}{\cos^2\lambda} \tag{30}$$

where

$$H_2' = H_2\Big/\frac{2U}{a}C_2;$$

$$\therefore y\text{-semiaxis} = \frac{H_2'}{\cos\lambda} = \frac{H_2}{\frac{2UC_2}{a}\cos\lambda}, \tag{31}$$

$$x\text{-semiaxes} = \frac{H_2'}{\cos\lambda\sin\lambda} = \frac{H_2}{\frac{2UC_2}{a}\cos\lambda\sin\lambda},$$

$$\frac{y\text{-axis of line of equal rise and fall}}{x\text{-axis of line of equal rise and fall}} = \frac{\sin\lambda}{1}.$$

The ellipses of equal range of tide are, therefore, of the same shape as the force ellipse at the place, but the axes are interchanged. Besides having the axes interchanged, the force ellipses must be multiplied by H_2 and divided by the product of the semiaxes. The value of the azimuth shows that the cotidal lines form with one of the ellipses of equal range the perspective of a spoked wheel. By regarding the east-and-west direction of the force ellipse as being south-and-north, and increasing the numbering of the hours by three, the force diagram will represent an ellipse of equal range and the cotidal lines radiating from the no-tide point.

For example, let $H_2 = 0{\cdot}01\, UC_2$; then

$$\begin{aligned} y\text{-semiaxis} &= \frac{0{\cdot}01a}{2\cos\lambda} &&= \frac{17{\cdot}2}{\cos\lambda}\text{ sea miles,} \\ x\text{-semiaxis} &= \frac{0{\cdot}01a}{2\sin\lambda\cos\lambda} &&= \frac{17{\cdot}2}{\sin\lambda\cos\lambda}\text{ sea miles.} \end{aligned} \qquad (32)$$

The value of UC_2 is 0·799 foot in the case of M_2, and 0·372 foot for S_2. ∴ On the equator one must go 17·2 sea miles from the no-tide line to obtain an amplitude of 0·008 foot for M_2.

At the equator the lines of equal rise and fall become parallel straight lines running north and south (see Fig. 2). The cotidal lines fall together in such a way that it is high water in the eastern half of a small body of water at component hour 9 and

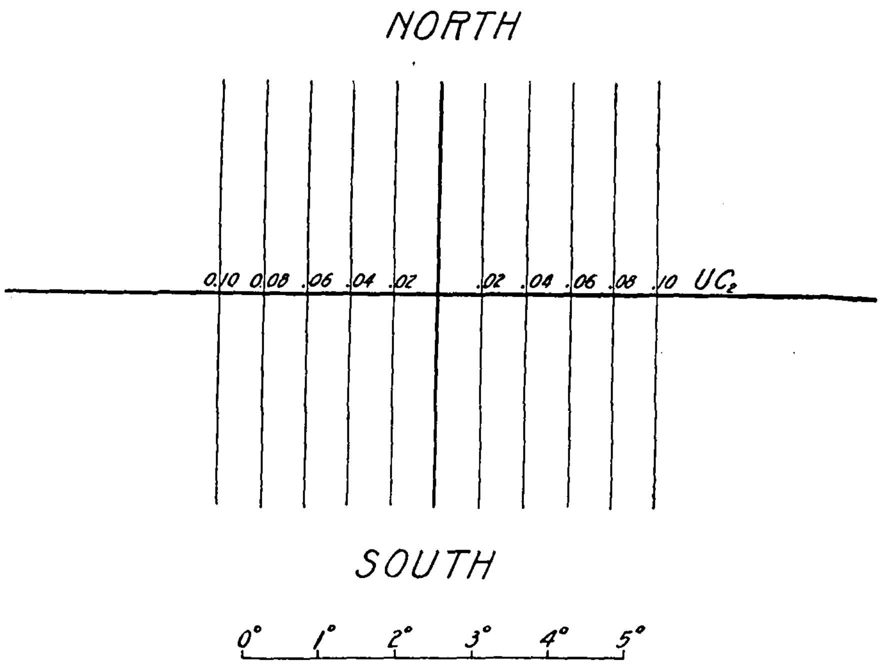


Fig. 2.

in the western half at component hour 3. The scale of distances below the diagram is expressed in degrees of the earth's circumference. Of course, the amplitudes shown on the diagram are somewhat in error when the distances are considerable. So for Fig. 3 below.

For the diurnals we have

$$H_1 = C_{1e} \sin c_1 t + C_{1s} \cos c_1 t, \tag{33}$$

$$C_{1e} = -y \frac{2\,UC_1}{a} \sin\lambda \tag{34}$$

$$C_{1s} = -x \frac{2\,UC_1}{a} \cos 2\lambda, \tag{35}$$

$$\tan c_1 t = \frac{\sin\lambda}{\cos 2\lambda} \frac{y}{x} = \frac{\sin\lambda}{\cos 2\lambda} \tan \text{azimuth}, \tag{36}$$

$$y^2 \sin^2\lambda + x^2 \cos^2 2\lambda = \frac{H_1}{\left(\frac{2\,UC_1}{a}\right)^2}, \tag{37}$$

$$\left.\begin{aligned} y\text{-semiaxis} &= \frac{H_1}{\frac{2\,UC_1}{a}\sin\lambda}, \\ x\text{-semiaxis} &= \frac{H_1}{\frac{2\,UC_1}{a}\cos 2\lambda}, \end{aligned}\right\} \tag{38}$$

$$\frac{y\text{-axis of line of equal rise and fall}}{x\text{-axis of line of equal rise and fall}} = \frac{\cos 2\lambda}{\sin\lambda}.$$

These ellipses may be obtained by regarding the east-and-west direction of the force ellipses as being south-and-north, provided we multiply the latter by H_1 and divide by the product of the semiaxes. The radiating lines with their numbering altered by six then represent cotidal lines.

Fig. 3 shows the cotidal lines and the lines of equal rise and fall for a diurnal component in latitude 30° north. The amplitudes are given in terms of UC_1. This quantity is 0·467 foot for K_1, 0·332 for O_1, 0·154 for P_1, 0·799 for $K_1 + O_1$.

It may be noted here that the time of tide at any point can be found from the force diagrams as they stand in the following manner: Connect the given point with the no-tide point by a straight line. Find where a line perpendicular to this line is tangent to the ellipse. The radiating hour line passing through this point of tangency shows the hour of high or low water. For, this hour line and the hour line passing through the same point when the diagram is turned in the manner mentioned above form a pair of conjugate axes of the ellipse. Being conjugates, they are orthographic representatives of diameters of a circle which cut each other perpendicularly, and so have numbers differing by 3 for semidiurnals and 6 for diurnals. (See § 40, Part I.)

4. *Cotidal lines for larger areas.*

When the body of water is more than a hundred or two hundred miles in diameter, the true cotidal lines begin to differ from those just described and to depend upon the shape of the bounding shore line. It is, however, not a very difficult matter to construct cotidal lines for any given enclosed sea. For doing this we can make use of an equatorial stereographic projection of the sphere showing the outlines of the body of water. Once for all can be made upon a like projection, a drawing of the uncorrected equilibrium semidiurnal tide, also one for the diurnal as in Fig. 4. By noting the heights of the contour lines along any given parallel of latitude, we see that if the

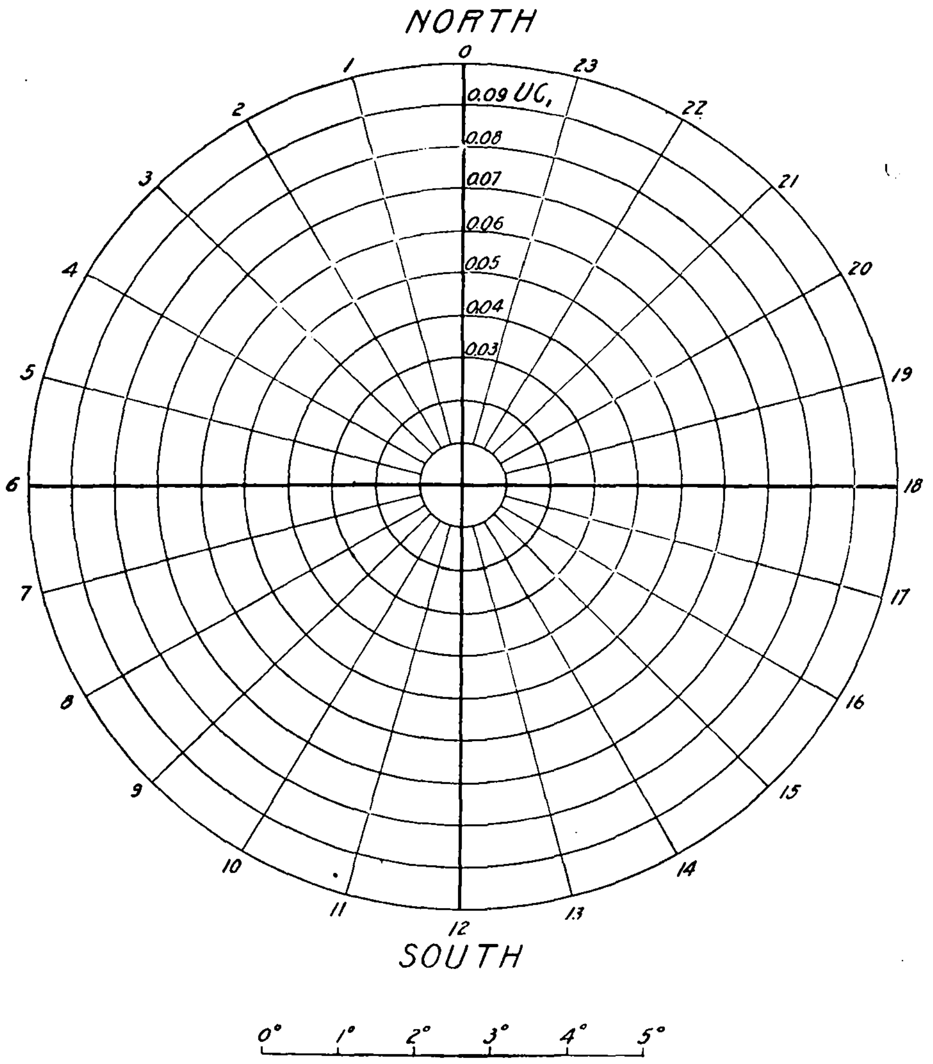


Fig. 3.

projection rotate uniformly about its pole the rise and fall of the uncorrected or hypothetical equilibrium tide along the parallel will be a simple harmonic motion. Consequently, if an aggregate of points or elementary areas constituting the surface of the given sea be considered, the average hypothetical tide for the whole body will follow to the same simple law. If the sea happens to be symmetrical with respect to the north-and-south line, then the zero hour of the tide diagram can be placed upon this central line, and the amplitude of the hypothetical rise and fall of the whole sea ascertained at once by multiplying each elementary area by its respective thickness, adding, and then dividing the resulting volume by the total area. If no such symmetry exists, then a similar process should be pursued for each twelfth or twenty-fourth part of the

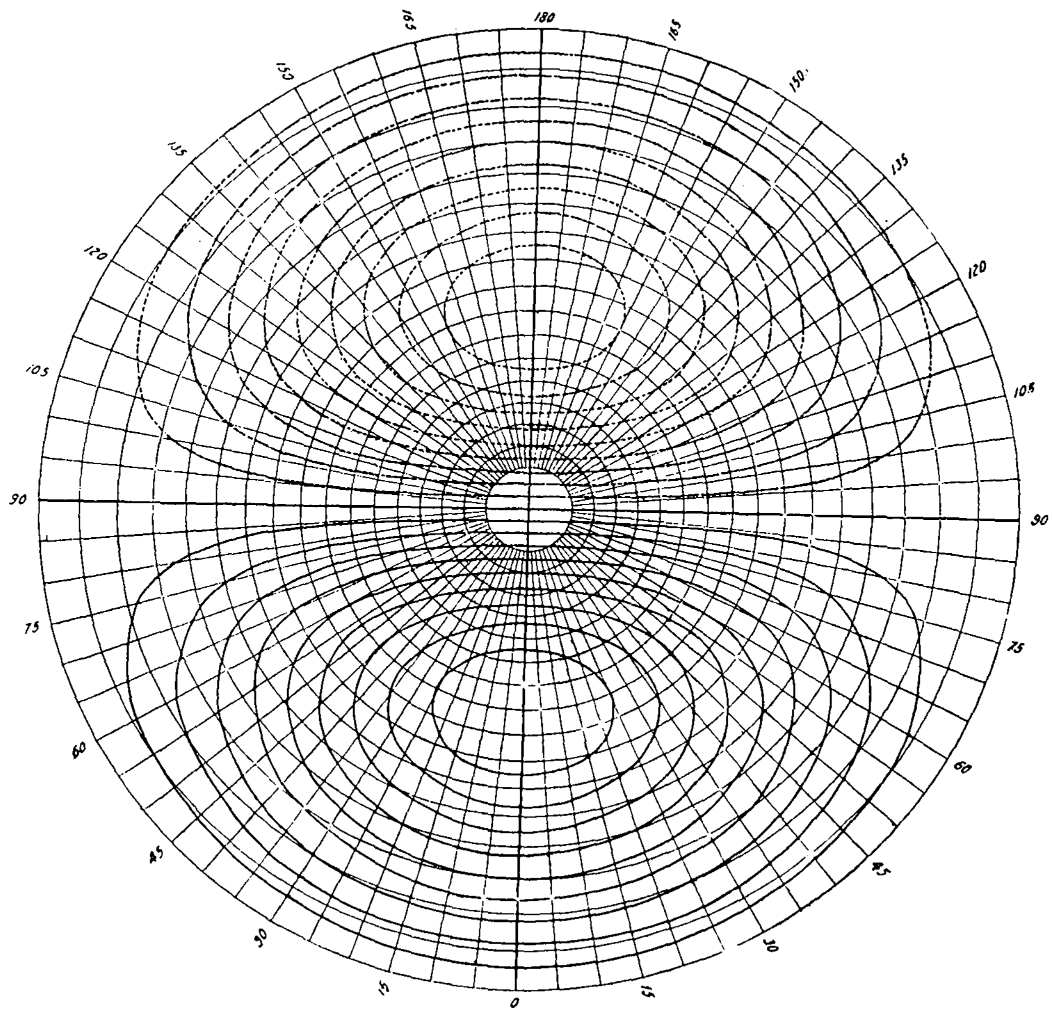


Fig. 4.

rotation. The resulting heights can then be plotted or analyzed and the amplitude determined. The corrected height of tide for any given point on the enclosed sea, and at any given time, is found by noting the uncorrected height upon the tide diagram and taking from it the simultaneous height of the enclosed sea as a whole. The time of high water is found by ascertaining the resultant maximum of the two simple harmonic or sine curves of like period just referred to, one representing the uncorrected or hypothetical equilibrium tide for the point in question, the other the same for the given sea as a whole, but with its vertical ordinates reversed. This latter curve represents what might be regarded as a correction to the uncorrected equilibrium tide.

Figs. 5 and 6 show the cotidal lines and lines of equal amplitude for a diurnal tide in a circular sea of 20° radius, the latitude of the center being 30° north. Taking *UC*

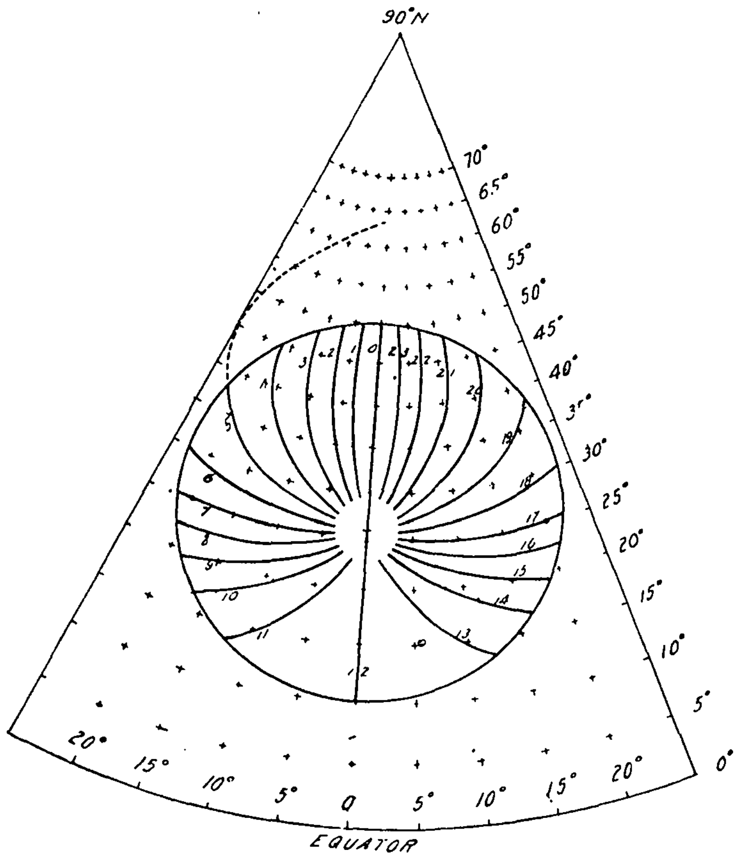


Fig. 5.

as the unit of height, we have, by aid of Fig. 4, 0·794 as the amplitude of the hypothetical rise and fall of this body of water. (See also Fig. 24.)

$$\therefore \text{ Height of corrected equilibrium tide} = G_1 \cos (15t - l) - 0{\cdot}794 \cos 15t. \qquad (39)$$

Here t is zero whenever the tidal body passes the meridian of the center of the sea, and l denotes longitude west from the central meridian. The cotidal lines have reference to this meridian. The times of maximum and minimum height at any assumed point of the circular sea are evidently given by the equation

$$G_1 \sin (15t - l) = 0{\cdot}794 \sin 15t; \qquad (40)$$

that is, given any two of the three quantities λ, l, and t, the remaining one becomes known by this equation.

Because of symmetry, the no-tide point falls upon the central meridian, and so its $l = 0$. Since the height of the tide must there vanish for all values of t, we have $G_1 = 0{\cdot}794$ or $\lambda = 26° \ 16'$.

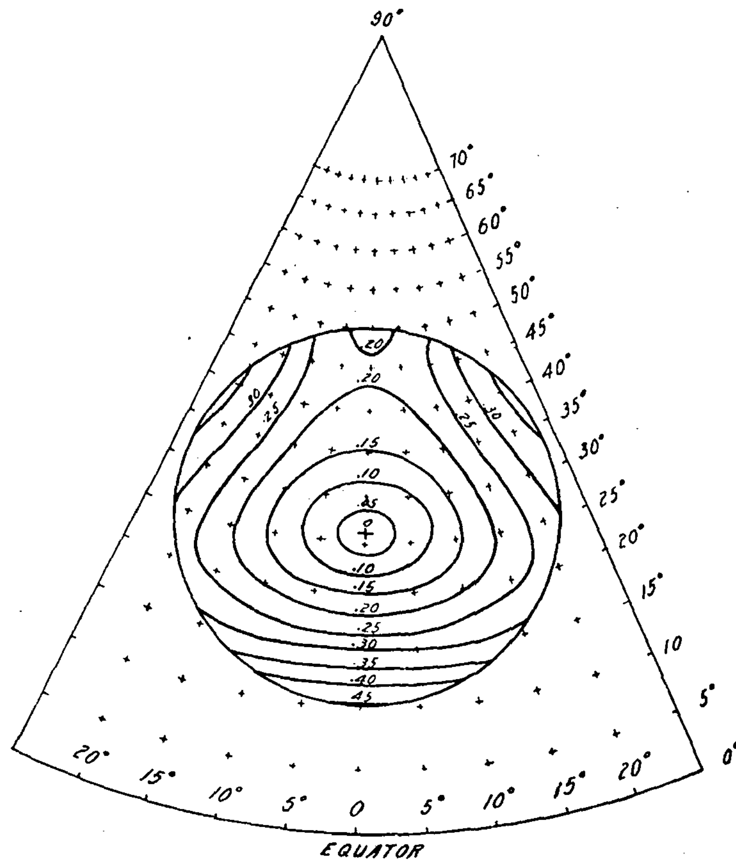


Fig. 6.

For a diurnal tide in circular seas of various radii having their centers on the 30th parallel of latitude, we have—

Radius.	Amplitude for sea as a whole.	Latitude of no-tide point.
°		° ′
0	0·866 UC_1	30 00
15	0·821 UC_1	27 35
20	0·794 UC_1	26 16
25	0·747 UC_1	24 10

UC_1 is equal to the amplitude of the diurnal tide considered, in latitude 45°, according to the uncorrected equilibrium theory.

CHAPTER II.

HYDRODYNAMICS.

5. This chapter treats of a liquid as being sensibly perfect and incompressible. By *perfect* is meant that the elementary particles glide upon one another without resistance, and so whatever stress exists between them is normal and one of compression.

The *density* (ρ) of a liquid is the mass of a unit volume or per unit volume. The density of distilled water at 4° C. is one gram (mass) per cubic centimeter.

The *heaviness* (γ) of a liquid is the weight of a unit volume or per unit volume.

$$\text{Heaviness} = g \times \text{density},$$

g being the acceleration of gravity.

Whenever it is stated or implied that

$$\text{weight} = g \times \text{mass, or mass} = \text{weight} \div g,$$

the meaning is that although a given lump of matter has a fixed mass usually expressed in pounds or grams, its actual weight must be divided by g in dynamical equations if gravitation force units are there used. When a pound of matter is taken as the unit of mass, the uniform force acting for one second required to impart to it a velocity of 32 feet per second may be denoted by g, or 32 if the units are properly chosen. The force required to impart to a pound of matter a velocity of 1 foot per second is one pound (force) $\div$ the numerical value of g. This absolute unit force is called a *poundal*. Pound (force) and poundal would become identical upon a sphere where the intensity of gravity is $\frac{1}{32}$ of its terrestrial value. The centimeter-gram-second unit of force is called a *dyne*. It is a force equivalent to the weight of a gram divided by g or 981. The gram (force) and dyne would become identical upon a sphere where the intensity of gravity is $\frac{1}{981}$ of its terrestrial value.

A pound force (i. e., 32 poundals, or a force equivalent to the force required to be applied to a pound of matter to overcome gravity) acting through a distance of one foot against an equal resisting force, performs a *foot-pound* of work. A dyne force, acting through a distance of one centimeter against an equal resisting force, performs an *erg* of work. The resisting force is often the force of inertia of the body to which forces are applied. Work is thus done upon the body; it is positive when it increases the velocity of the body.

When a body is capable of performing work it is said to possess *energy*. Energy, like the work which it represents or may create, is measured in foot-pounds, foot-poundals, or in ergs. *Kinetic energy* exists by virtue of the motions of the body. All other energy which the body may have is called *potential*. Suppose a body to start from rest at a given height and fall in vacuo. Its potential energy before the fall is

$$g \times \text{mass} \times \text{height}.$$

But the velocity acquired at or very near the end of the fall, when its potential energy becomes zero, is given by the equation

$$v^2 = 2g \times \text{height}; \tag{41}$$

and so

$$\text{height} = \frac{v^2}{2g}. \tag{42}$$

This substituted in the original expression for energy gives for its value

$$\tfrac{1}{2}v^2 \times \text{mass}. \tag{43}$$

The form of energy is now wholly kinetic. In case of liquids the height due to velocity (42) is sometimes called the *velocity head.*

The potential of a body or bodies at a given point is such a function of the coördinates of the point that its partial derivative in any given direction is equivalent to $\substack{\text{minus the}\\ \text{the}}$ force exerted by the body or bodies upon a material point of unit mass situated at this point, the force at the point being taken in the same direction as the differentiation. Hence, generally, the values assigned to surfaces of equal potential $\substack{\text{increase}\\ \text{decrease}}$ as we go outward from an attracting body, but $\substack{\text{decrease}\\ \text{increase}}$ as we go outward from a body which repels. We shall always assume that the bodies attract. But as to which definition of potential may seem preferable will depend upon circumstances. In Part II and in Chapter I, Part IV (A), the second definition was the one used; hereafter the first will generally be understood. The material point, if free to move, will pass toward a surface of $\substack{\text{lower}\\ \text{higher}}$ potential. For a point above a spherical, attracting body like the earth and distant r from its center, we have, denoting by R the (essentially negative) force along r increasing,

$$\frac{\partial V}{\partial r} = \mp R; \tag{44}$$

at the surface of the earth this $\frac{\partial V}{\partial r}$ is equal to a force directed $\substack{\text{upward}\\ \text{downward}}$ whose intensity is g.

Being defined through differentiation, the potential does not have, like energy or like work, an absolute value. But, having assigned to one equipotential surface a definite value, the values belonging to the others become fixed. Since at any equipotential surface we can, presumably, calculate the work required to remove a unit of mass to infinity, or the energy of a particle as it reaches this surface starting from rest at infinity, we can take this as the numerical value of the potential at the given surface. To this is to be prefixed the sign $\mp$. The gravitational potential, which is essentially $\substack{\text{negative,}\\ \text{positive,}}$ is of the form $\mp\frac{m}{r}\left(=\mp\int_{r=r}^{r=\infty}\frac{m}{r^2}dr\right)$, m being the mass of the attracting body. And so as r increases the potential $\begin{matrix}\text{increases.}\\ \text{decreases.}\end{matrix}$ The outward force is

$$\mp\frac{\partial}{\partial r}\left(\mp\frac{m}{r}\right)=-\frac{m}{r^2}. \tag{45}$$

For short distances the potential varies as $\pm$ the height upward. Let $r=r_0+h$; then

$$\mp\frac{m}{r}=\mp\frac{m}{r_0+h}=\mp m\left(\frac{1}{r_0}-\frac{h}{r^2_0}+\frac{h^2}{r^3_0}-\quad\cdot\quad\cdot\quad\cdot\quad\cdot\right). \tag{46}$$

If m denote the mass of the earth, and r_0 its radius, we have

$$V\left(=\mp\frac{m}{r}\right)=\pm gh \tag{47}$$

after rejecting the constant $\frac{m}{r_0}$.

Using the first definition of potential, we have

$$g\times\text{unit mass}\times\text{height}=\text{potential}+\text{constant}, \tag{48}$$

$$g\times\text{mass of attracted body}\times\text{height}=\text{work or potential energy}. \tag{49}$$

If gravitation force units are used, expression (48) shews that the difference in potential is numerically equal to the difference in level. In the case of liquids, the height is sometimes called the *potential head*. If absolute force units are used, then, numerically,

$$\text{Potential head}=\text{potential}\div g, \tag{50}$$

omitting the constant in (48).

6. When used in connection with solid bodies, or with solid bodies and a fluid, the word *pressure* means a force, and this, like any other force, has a fixed direction. To ascertain the nature of internal fluid pressure, imagine a very small sphere to be immersed in and float with the fluid. In other words, let a minute portion of the fluid be replaced by a solid sphere of like density. The fluid can exert only normal pressure, because otherwise a tangential stress would be called into play, and this perfect fluids do not possess. The intensity of the pressure (or pressure per unit area) upon this very small sphere will be the same in any chosen direction; otherwise this sphere would move relatively to the neighboring particles of the fluid, which it does not do. It is to be remarked that the hypothetical sphere or other body which we may imagine for aiding the conception of pressure, is extremely minute in comparison with one of the elements into which the fluid will be supposed to be divided in obtaining the so-called equations of motion. Hence we can speak of the pressure (or the intensity of pressure) at any particular point, meaning thereby the force exerted upon a minute unit area situated at that point. Since this unit of area may face any direction, the direction of fluid pressure at a given point is indeterminate, but its magnitude or intensity is a perfectly definite quantity, depending, at a given instant, upon the coördinates of the point. In other words, we can, for a given instant, construct surfaces of equal pressure, just as we can construct equipotential surfaces with reference to the earth or other attracting body.

In a stagnant body of water the pressure increases directly with the depth below the surface, and so the surfaces of equal pressure are horizontal planes.

Fluid pressure resembles potential as given by the first definition in that a particle under its influence tends from a surface of given pressure toward one of lower pressure. The force per unit area urging the fluid element to move in any direction, r, is R or $-\frac{\partial p}{\partial r}$. The value of the pressure at a given point in a liquid is often known, or measured, by the depth of liquid above the point, together with the weight of the atmosphere. On the other hand, like gravitational potential according to the second definition, fluid pressure is regarded as essentially positive.

The energy or work expended in replacing a given volume of liquid where the pressure is p-per square unit is equal to p multiplied by the volume. For, suppose that we imagine the cavity containing this volume of liquid to be so partitioned with walls of no thickness that it consists of a coil or heap of slender canals or pipe whose cross section is everywhere of the same small unit area. Suppose one mouth of this canal to terminate in the liquid, while in the other mouth a piston head is inserted. The work done by the piston head in driving out the liquid is clearly equal to $p \times$ cross section $\times$ the length of canal, or p times the volume of liquid displaced.

7. *Bernoulli's theorem.*

These definitions may be illustrated by an example. Suppose we have two elastic bags connected by a small pipe, all being filled with a liquid. Suppose that pressures are applied to the outer surface of each bag such that the constant pressure at cross section F_1 of the pipe should be p_1 (as indicated by a piezometer) and at F_2, p_2; determine the motion in the pipe, taking for granted the principle that no energy is gained or lost in this region where the motion is steady.

In the flow of a liquid, energy is being continually changed from potential to kinetic, or vice versa. Through a given cross section the quantity of water passing in unit time is measured by the product of velocity and cross section. Consider two cross sections of the tube F_1, F_2; the mass passing F_1 per unit time is $\rho\, v_1\, F_1$, while the equal mass passing F_2 is $\rho\, v_2\, F_2$.

$$\therefore v_1 F_1 = v_2 F_2. \tag{51}$$

The work done on this region by the mass entering F_1 per unit of time is $p_1\, v_1\, F_1$, while the amount done on the region beyond F_2 by the mass as it leaves at F_2 is $p_2\, v_2 F_2$; for, work = pressure $\times$ volume displaced, § 6. The former mass brings into the region considered extending from F_1 to F_2 the energy

$$\rho\, v_1 F_1 \left(\tfrac{1}{2} v_1^2 + \Omega_1\right),$$

where Ω_1 is the potential of the gravitational force of the earth, and is such that $\frac{\partial \Omega_1}{\partial z} = g$; the latter carries from this region the energy

$$\rho\, v_2 F_2 \left(\tfrac{1}{2} v_2^2 + \Omega_2\right).$$

Since the motion is steady and there is assumed to be no friction, the region considered neither gains nor loses energy;

$$\therefore p_1 v_1 F_1 + \rho v_1 F_1 \left(\tfrac{1}{2} v_1^2 + \Omega_1\right) = p_2 v_2 F_2 + \rho v_2 F_2 \left(\tfrac{1}{2} v_2^2 + \Omega_2\right). \tag{52}$$

$$\frac{p_1}{\rho}+\frac{v_1^2}{2}+\Omega_1=\frac{p_2}{\rho}+\frac{v_2^2}{2}+\Omega_2 \tag{53}$$

since $\rho\, v_1\, F_1=\rho\, v_2\, F_2$. But $\gamma=g\rho$, $\Omega_1=gz_1$, $\Omega_2=gz_2$, and so the above becomes

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+z_2 \tag{54}$$

8. This relation between the various heads can be found in the following manner also:

A particle or liquid element in the pipe is acted upon by a force (pressure) at each end of the particle and by its own weight. The change of pressure or the difference at its two ends is dp or $\frac{dp}{ds}\,ds$. This retarding force multiplied by the area of the section of the pipe is

$$Fdp \text{ or } F\frac{dp}{ds}\,ds. \tag{55}$$

The force due to its own weight tending to drive it forward is

$$\text{mass of element} \times g\cos\varphi,$$

or

$$\frac{F\gamma ds}{g}\times g\cos\varphi=-F\gamma dz, \tag{56}$$

where φ is the angle made between the axis of the pipe and the nadir and z increases upward.

Calling, for the present, the acceleration k, we have from the elementary equations

$$v=\frac{ds}{dt},\quad k=\frac{dv}{dt},\ \text{the equation } vdv=kds.$$

The effective force, or force imparted to the element, is

$$\text{mass of element} \times k;$$

$$\therefore\ k\times\text{mass}=-Fdp-F\gamma dz,$$

$$k=-\frac{F}{\text{mass}}\left(dp+\gamma dz\right),\quad [\text{Cf. } (86),\ (87).] \tag{57}$$

$$vdv=-\frac{F}{\text{mass}}\left(dp+\gamma dz\right)ds, \tag{58}$$

$$\text{mass}=\frac{F\gamma ds}{g},$$

$$\therefore\ \frac{v_1^2-v_2^2}{2}=-\frac{g}{\gamma}\Big[p_1-p_2+\gamma\,(z_1-z_2)\Big], \tag{59}$$

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+z_2. \tag{60}$$

This is Bernoulli's theorem, which asserts that *in a steady flow without friction the sum of the velocity head, pressure head, and potential head is a constant quantity wherever the cross section may be taken.*

The above expressions for the mass and velocity show that $F_1 v_1 = F_2 v_2$, t being the independent variable and the motion being steady.

Torricelli's theorem follows readily as a special case of Bernoulli's. Let

$$\begin{array}{ll} p_1 = \text{atmospheric pressure} = p_0, & p_2 = \text{atmospheric pressure} = p_0, \\ v_1 = 0, & v_2 = v, \\ z_1 = h, & z_2 = 0; \\ \therefore & v^2 = 2gh. \end{array}$$

9. *Applications of Torricelli's theorem.*

A vessel or reservoir is supposed to communicate with an infinitely large body of water through one or more small openings or short pipes. The ratio of the area of the cross section of the openings to the area of the reservoir is supposed to be a rather small quantity (ε). The reservoir is so deep that its surface is practically level at each instant. No allowance is here made for frictional resistance or for the *vena contracta.*

Problem I.—The outside water remaining at a constant height $h_{\prime}$, above a fixed arbitrary datum, and the water inside reading z_0 above the same datum at a given time t_0, required the marigram for the inner body.

By Torricelli's theorem the velocity in the orifice is

$$v = \sqrt{[2\,g\,(h_{\prime} - z)]}. \tag{61}$$

But the vertical velocity of the surface of the reservoir or $\dfrac{dz}{dt}$ is εv;

$$\therefore \left(\frac{dz}{dt}\right)^2 = 2\,g\varepsilon^2\,(h_{\prime} - z), \tag{62}$$

$$dt = \frac{dz}{\varepsilon\sqrt{(2\,g)}\sqrt{(h_{\prime} - z)}},$$

$$t = \frac{1}{\varepsilon\sqrt{(2\,g)}}\int\frac{dz}{\sqrt{(h_{\prime} - z)}} + \text{constant} = -\frac{\sqrt{[2\,(h_{\prime} - z)]}}{\varepsilon\sqrt{g}} + \text{constant}; \tag{63}$$

$$\therefore \text{constant} = t_0 + \frac{\sqrt{[2\,(h_{\prime} - z_0)]}}{\varepsilon\sqrt{g}}.$$

For simplicity, suppose $t_0 = 0$, then

$$t - \sqrt{\frac{2}{g}}\frac{\sqrt{(h_{\prime} - z_0)}}{\varepsilon} = -\sqrt{\frac{2}{g}}\frac{\sqrt{(h_{\prime} - z)}}{\varepsilon}. \tag{64}$$

The marigram is therefore for a time the arc of a parabola opening downward, the vertex being situated at the point $t = \frac{1}{\varepsilon}\sqrt{\frac{2}{g}}(h_{\prime} - z_0), = 0\cdot2493\frac{\sqrt{(h_{\prime} - z_0)}}{\varepsilon}$, $z = h_{\prime}$. The latus rectum is $\frac{1}{\varepsilon}\sqrt{\frac{2}{g}}$, which is independent of $(h_{\prime} - z_0)$. The time required for filling the reservoir to the level with the water without is $0{\cdot}2493 \frac{\sqrt{(h_{\prime} - z_0)}}{\varepsilon}$. After the lapse of this time the marigram is the straight horizontal line $z = h_{\prime}$.

Problem II.—The height of the outside water or sea being $A_{\prime} \cos (at + \alpha_{\prime})$ above mean sea level, required the marigram for the inner body.

In this case the velocity in the strait is

$$v = \sqrt{2\,g\,[A_{\prime} \cos (at + \alpha_{\prime}) \sim z]}. \tag{65}$$

$$\therefore \left(\frac{dz}{dt}\right)^2 = 2\,g\varepsilon^2\,[A_{\prime} \cos (at + \alpha_{\prime}) - z] \tag{66}$$

when the flow is inward, and

$$\left(\frac{dz}{dt}\right)^2 = 2g\varepsilon^2\,[z - A_{\prime} \cos (at + \alpha_{\prime})] \tag{67}$$

when the flow is outward.

When at is a small angle compared with 90° we have

$$\left(\frac{dz}{dt}\right)^2 = 2g\varepsilon^2\,[A_{\prime} \cos \alpha_{\prime} - z],$$

and so

$$t - \sqrt{\frac{2}{g}}\frac{\sqrt{(A_{\prime} \cos \alpha_{\prime} - z_0)}}{\varepsilon} = -\sqrt{\frac{2}{g}}\frac{\sqrt{(A_{\prime} \cos \alpha_{\prime} - z)}}{\varepsilon} \tag{68}$$

where z_0 denotes the value of z when $t = 0$.

Starting with any initial value of z, the curve can be traced step by step from the successive values of $\frac{dz}{dt}$ which fix the direction of the tangent.

If $\alpha_{\prime}$ be taken as zero, it indicates that the time is reckoned from the time of high water outside.

For simplicity let $at = x$; then

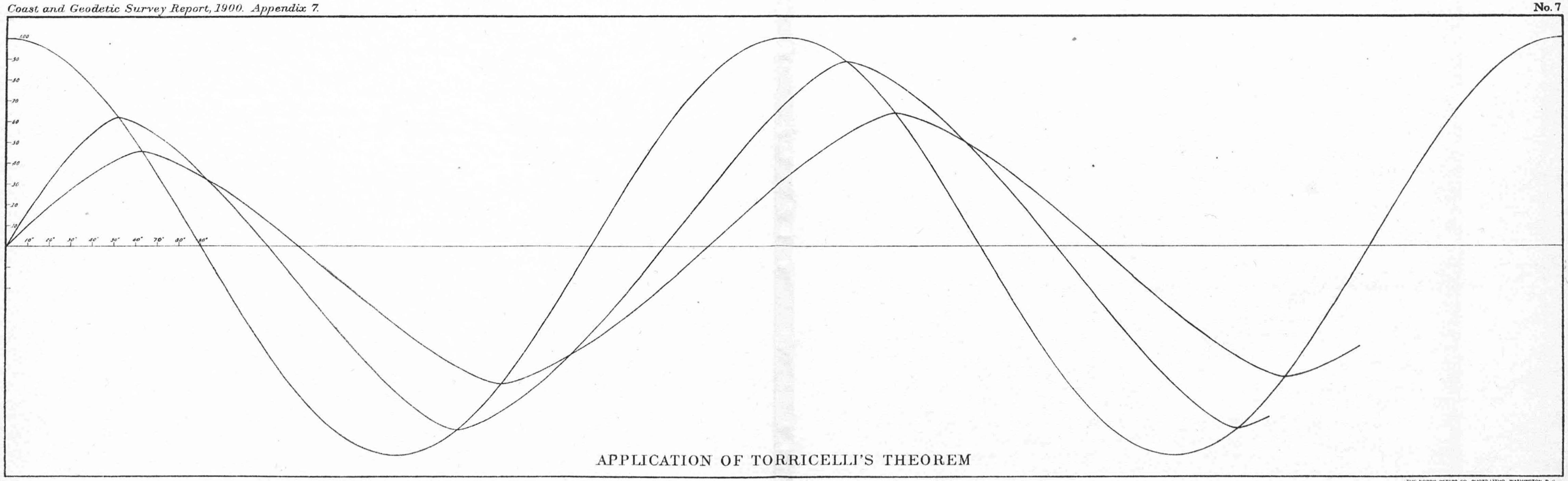
$$\left(\frac{dz}{dx}\right)^2 = \frac{2g\varepsilon^2}{a^2}\,[A_{\prime} \cos x - z] = \kappa^2\,[A_{\prime} \cos x - z]. \tag{69}$$

$\frac{dz}{dx}$ is $\frac{1}{a}$ times the vertical velocity of the water; a is to be expressed in radians per second, and is 0·00014052 for the semidiurnal lunar tide and 0·00007026 for the diurnal. $\sqrt{(2g)} = 8{\cdot}0215$.

$$\begin{aligned} \therefore\ \kappa &= 57\ 085\,\varepsilon \text{ for } M_2, & \kappa &= 114\ 170\,\varepsilon \text{ for } M_1; \\ \varepsilon &= 0{\cdot}000017518\,\kappa \text{ for } M_2, & \varepsilon &= 0{\cdot}000008759\,\kappa \text{ for } M_1. \end{aligned} \tag{70}$$

It is sometimes convenient to take $A_{\prime}$ as unity; in which case g, z, and the velocity are be expressed in terms of the same unit.

In Fig. 7 the cosine curve represents the rise and fall of the surface of the water outside the bay or float box, as the case may be. The amplitude $A_{\prime}$ is assumed to be 1 foot. The time is reckoned from the instant of high water outside, and the initial



APPLICATION OF TORRICELLI'S THEOREM

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

height of the inner body is assumed to be mean outside water level. For the curves (marigrams) representing the tide of the inner body, $\kappa^2 = \frac{\pi}{1 \cdot 8} = 1 \cdot 745$, $\kappa^2 = \frac{1 \cdot 8}{\pi} = 0 \cdot 573$; $\kappa = 1 \cdot 321$, $0 \cdot 757$, respectively. It will be noted that as the curves approach a permanent relation (i. e., a relation independent of the initial conditions) they follow the outside tide by intervals of about 29° and 51°, respectively, while the amplitudes are about 0·87 and 0·63. These agree fairly well with approximate results given below. Assuming the tide semidiurnal, (70) gives $\varepsilon = 0 \cdot 00002314$, $0 \cdot 00001326$. In other words, if a float box were 1 foot square and the orifice admitting the water were a square 0·00481, or 0·00364 foot on a side, we should obtain the delay and diminution of amplitude here shown. This, of course, makes no allowance for the resistance and the *vena contracta*.

The construction of any such curve from a cosine curve whose equation is $z = \cos x$ is facilitated by the use of a parabola whose equation is

$$z' = \kappa \sqrt{\,[\cos x - z]} = \kappa \sqrt{d}.$$

This parabola should be drawn upon cross-section paper numbered up to unity on the d-axis, also to unity on the z'-axis. From the cosine curve and the curve under construction we find d, and from the parabola $\kappa \sqrt{d}$, or by (69), $\frac{dz}{dx}$. The paper should be cut along the z'-axis, also along a line parallel to it and distant unity from the same. If a radian on the x-scale is not equal to a unit on the z-scale we transfer the value of the tangent ($\kappa \sqrt{d}$) to the principal sheet, not from the extreme edge of the sheet containing the parabola, but from a line a radian distant from the z'-axis, the vertex of the parabola being placed at the point last determined on the curve being constructed.

It would be an easy matter to construct a hydraulic apparatus for drawing such curves; in other words, for integrating the differential equation (69).

The curves drawn show that as the amplitude diminishes, high and low water stands are very short for the inner body; also, that the marigram is almost a straight line from a high to a low water. Hence there must be a large M_6 and we must have $3M_2° - M_6° = 0$, very nearly. Thus we see the origin of an overtide where the shallowness of the water is not responsible.

The ordinates of the current curves in the strait are proportional to the slopes of these curves. Hence the ordinates (velocities) change rapidly at the times of high and low water within, and so slack water is of very short duration. For intermediate times the slope of the inner marigram is nearly constant, and so the velocities of considerable value continue for a long time. (Cf. § 36, Part I.) The velocity curve being the derivative of the height curve, it follows that the ratio of the amplitude of the sixth-diurnal current component to that of the semidiurnal is three times as great as the corresponding tidal ratio. Hence current curves will show when wave motion begins to give way to motion due simply to difference of head much clearer than will tidal marigrams.

Let us assume that the height within may ultimately (i. e., when the initial conditions have disappeared) be represented by the periodic function

$$z = A \cos (x + \alpha) + B \cos 3 (x + \alpha) + \quad . \quad . \quad . \quad . \qquad (71)$$

where A, B, ... and α are to be determined by the conditions of the problem. This assumption is reasonable because of the known periodicity of the value of z and because the curve is symmetrical about an ordinate drawn through a point of maximum or minimum.*

$$\frac{dz}{dt} = -A \sin (x+\alpha) - 3B \sin 3(x+\alpha) - \quad . \quad . \quad . \quad . \tag{72}$$

The height without being $A_{,} \cos x$, we have

$$\begin{aligned} &[A \sin (x+\alpha) + 3B \sin 3(x+\alpha) + \ . \ . \ .]^2 \\ &= \kappa^2 [A_{,} \cos x - A \cos (x+\alpha) - B \cos 3 (x+\alpha) - \quad . \quad . \quad .]. \end{aligned} \tag{73}$$

If $x = -\alpha$, z has its maximum value and the height within is then the same as the simultaneous height without. The above equation gives

$$A_{,} \cos \alpha = A + B + C + \quad . \quad . \quad . \quad .$$

The same relation is found by putting $x = -\alpha + 180°$, z then having its minimum value. If $x = -\alpha + 90°$,

$$(A - 3B + 5C - \quad . \quad . \quad . \quad)^2 = \kappa^2 A_{,} \sin \alpha. \tag{74}$$

By taking a sufficient number of values of x any number of coefficients can be determined. As a first approximation assume that $B = C = \quad . \quad . \quad . \quad = 0$; then

$$A = A_{,} \cos \alpha, \tag{75}$$

$$\sin \alpha = -\tfrac{1}{2}\frac{\kappa^2}{A_{,}} + \frac{1}{2A_{,}}\sqrt{(4A_{,}^2 + \kappa^4)} = \tfrac{1}{2}\frac{\kappa^2}{A_{,}}\left[-1 + \sqrt{\left(1 + \frac{4A_{,}^2}{\kappa^4}\right)}\right]. \tag{76}$$

For $\kappa^2/A_{,} =$	0,	$\frac{1}{10}$,	$\frac{1}{4}$,	$\frac{1}{2}$,	1,	2,	10,	100,	∞,	
$\alpha =$	90°,	72° 02′,	61° 59′,	51° 20′,	38° 10′,	24° 28′,	5° 41′,	0° 34′,	0° 00′,	(77)
$\cos \alpha = A/A_{,} =$	0,	0·308,	0·470,	0·625,	0·786,	0·910,	0·995,	1·000,	1·000.	

For $\kappa^2/A_{,} = 1·745$, $\alpha = 27° \ 02'$, $\cos \alpha = 0·891$; for $\kappa^2/A_{,} = 0·573$, $\alpha = 48° \ 54'$, $\cos \alpha = 0.657$.

In § 37, Part I, it was noted that the velocity in a strait connecting two large bodies of water, one or both of which are tided, is of the form (71). In the present case both bodies have tides, but the rise and fall of the inner body is due to water transmitted to it from the outer. As already stated, its vertical velocity is proportional to the horizontal velocity of the water in the strait.

For an orifice or short strait so small that the rise and fall of the inner body is several or many times less than the rise and fall outside, the velocity will at each instant be very nearly proportional to the square root of the height outside reckoned from mean level (65). From this law of variation it follows that any rather small increase in the amplitude of the tide outside increases the amplitude of the velocity of the current in the strait by only one-half as large a percentage of its mean value. In other words, $S_2/\dot{M}_2$, $\dot{N}_2/\dot{M}_2$, etc., in the strait will be only one-half as great as the

* See Byerly, Fourier's Series, etc., p. 62.

corresponding tidal ratios outside; also, ignoring any differences in the duration of the range, the ratios S_2/M_2, N_2/M_2, etc., should be one-half as great for the inner body as for the outer. It is here assumed that M_2 is the controlling component tide. We also should have as approximate epoch relations

$$\dot{M}_2^\circ \text{ (flood)} = M_2^\circ \text{ (outside)},\ M_2^\circ \text{ (inside)} = M_2^\circ \text{ (outside)} + 90^\circ,$$
$$\dot{S}_2^\circ \text{ (flood)} = S_2^\circ \text{ (outside)},\ S_2^\circ \text{ (inside)} = S_2^\circ \text{ (outside)} + 90^\circ.$$

The current epochs refer to maximum velocity.

If the outer wave consists of a diurnal and semidiurnal part, the coefficients of these parts for the inner body can be determined for any given case. For a first approximation it may be assumed that if the outer wave be written

$$z_{\prime} = A_{\prime} \cos 2x + B_{\prime} \cos (x + \beta_{\prime}); \tag{78}$$

the inner may be written

$$z = A \cos (2x + \alpha) + B \cos (x + \beta). \tag{79}$$

These expressions are to be substituted in the equation

$$\left(\frac{\partial z}{\partial x}\right)^2 = \kappa^2 (z_{\prime} - z). \tag{80}$$

Then, by giving to x four arbitrary values such as $x = 0, -\frac{1}{2}\alpha, -\beta, -\beta_{\prime}$, the unknown quantities A, B, α, β can be determined.

Reasoning as before, we see that for an orifice or short strait so very small that the tide produced in the inner body has no considerable effect upon the current, the ratio $(\dot{K}_1 + \dot{O}_1)/\dot{M}_2$ should be one-half as great as the corresponding ratios for the tides outside. The ratio $(K_1 + O_1)/M_2$, if small, is about one-half as great for the inner as for the outer body. But when or where the durations of the four ranges of a day differ considerably, the diurnal inequality inside will be increased by this fact. For it is obvious that the longer the duration of a range the more will the inner body be raised or lowered by the water flowing in or out, and vice versâ for a short range.

The difference in phase between the diurnal and semidiurnal waves will be about the same for the current in the strait as for the tide outside; that is $\dot{M}_2^\circ \sim (\dot{K}_1^\circ + \dot{O}_1^\circ)$ should be about equal to $M_2^\circ \sim (K_1^\circ + O_1^\circ)$. The corresponding difference for the tide inside will be altered somewhat.

10. *Equation of continuity for a liquid.*

During a short time dt, the amount of liquid which enters a rectangular element through the face $x = x_0$ whose area is $dy\,dz$ is $u\,dy\,dz\,dt$ while the amount entering by the face $x = x_0 + dx$ is $-(u + \frac{\partial u}{\partial x} dx)\,dy\,dz\,dt$, and so $-\frac{\partial u}{\partial x} dx\,dy\,dz\,dt$ is the volume gained on account of these two faces. Similarly for the other pairs of faces. But the amount of liquid must remain constant;

$$\therefore\ \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0. \tag{81}$$

This and the three equations of motion given beyond, are involved in the determination of the four quantities u, v, w, p in terms of x, y, z, and t.

If a *velocity potential* φ exists such that

$$\frac{\partial \varphi}{\partial x}=-u, \quad \frac{\partial \varphi}{\partial y}=-v, \quad \frac{\partial \varphi}{\partial z}=-w, \tag{82}$$

the equation of continuity takes the form of Laplace's equation and is

$$\frac{\partial^2 \varphi}{\partial x^2}+\frac{\partial^2 \varphi}{\partial y^2}+\frac{\partial^2 \varphi}{\partial z^2}=0.$$

To find the equation of continuity in terms of polar coördinates, take a rectangular element whose sides are dr, $rd\,\theta$, $r \sin \theta\, d\, \varphi$ and let u, v, w denote the velocities in these directions. It is easily seen that the required equation is

$$\sin \theta\, \frac{\partial (r^2 u)}{\partial r}+r\, \frac{\partial\, (v \sin \theta)}{\partial \theta}+r\, \frac{\partial w}{\partial \varphi}=0. \tag{83}$$

Suppose we have a sheet of water of uniform depth h, and suppose the motion to be such that the vertical acceleration may be neglected. The flux or rate at which the liquid matter increases within an elementary prism whose base is $d\,x\,d\,y$, is $\frac{\partial \zeta}{\partial t}\, d\,x\,d\,y$. The rates of flow across the faces lying parallel to $y\,z$ are $u\,h\,d\,y$ and $\left(u+\frac{\partial u}{\partial x}\,d\,x\right)h\,d\,y$, respectively; the rate of outward flow is therefore $h\,\frac{\partial u}{\partial x}$ on account of these two faces. Similarly for the faces lying parallel to $x\,z$. Hence the equation of continuity becomes for the case here considered

$$\frac{\partial \zeta}{\partial t}=-h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right). \tag{84}$$

11. *The equations of motion.*

In ascertaining the acceleration of a moving particle it is necessary to see what the velocity is at two successive instants of time. In the flow of water in a pipe of uniform cross section the velocity is the same throughout—that is, it is independent of x, y, z, but may depend upon t. To see how this can be so, imagine two large reservoirs connected with a pipe of any length. Suppose water is so supplied or withdrawn that there is, say, a periodic rising and falling of the surface of one of them. The velocities at all points in the pipe are alike at any given instant, because it is assumed that pressure is transmitted instantaneously; but they vary with the time. For steady motion the velocity is constant for all time and at each cross section of this pipe. If we substitute for this pipe one of variable cross section, then even for steady motion the velocity will depend upon x, y, z.

General expressions for acceleration in any fluid body.—If we are concerned with successive positions of the same particle it is obvious that x, y, z depend upon the initial coördinates and t. The component velocities are $\frac{dx}{dt}$, $\frac{dy}{dt}$, $\frac{dz}{dt}$, and the component accelerations $\frac{d^2x}{dt^2}$, $\frac{d^2y}{dt^2}$, $\frac{d^2z}{dt^2}$.

If, on the other hand, we do not seek to preserve the identity of the particle, and consider what goes on at any assumed point x, y, z, the velocity must then be a function of x, y, z, and t as independent variables, and not of t and the initial coordinates. Considering one component velocity u we may write

$$u = f(x, y, z, t);$$
$$\therefore \frac{du}{dt} = \frac{\partial f}{\partial x}\frac{dx}{dt} + \frac{\partial f}{\partial y}\frac{dy}{dt} + \frac{\partial f}{\partial z}\frac{dz}{dt} + \frac{\partial f}{\partial t} = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} + \frac{\partial u}{\partial t}. \tag{85}$$

Similarly for $\frac{dv}{dt}$ and $\frac{dw}{dt}$. Thus it is seen that even here in getting the acceleration belonging to a given point and time, we revert to a consideration of the identity of a moving particle long enough to see how its velocity changes in a short interval of time. For steady motion $\frac{\partial u}{\partial t}, \frac{\partial v}{\partial t}, \frac{\partial w}{\partial t} = 0$.

An equation of motion for any particular direction is a formal expression for the dynamical proposition (which is an immediate result of D'Alembert's principle):

Elementary mass × acceleration = force applied to elementary mass — resistance due to increase of pressure on opposite faces of the elementary volume.

The term constituting the left-hand member of this equation denotes the effective force. The first term on the right represents an impressed force like gravity acting upon the fluid particle. The effect of pressure may be illustrated by the well-known tendency of the atmosphere to flow from a region of high pressure to one of low, thereby causing the winds.

For the x-direction we have

$$\rho\, dx\, dy\, dz \frac{du}{dt} = \rho\, dx\, dy\, dz\, X - \frac{\partial p}{\partial x} dx\, dy\, dz,$$

or

$$\frac{du}{dt} = X - \frac{1}{\rho}\frac{\partial p}{\partial x}. \tag{86}$$

Substituting from (85) we have

$$\begin{aligned}
\frac{du}{dt} &= \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = X - \frac{1}{\rho}\frac{\partial p}{\partial x}, \\
\frac{dv}{dt} &= \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = Y - \frac{1}{\rho}\frac{\partial p}{\partial y}, \\
\frac{dw}{dt} &= \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = Z - \frac{1}{\rho}\frac{\partial p}{\partial z}.
\end{aligned} \tag{87}$$

When x, y, z are to be regarded as functions of time and the initial coördinates, the equations of motion become

$$\frac{d^2x}{dt^2} = X - \frac{1}{\rho}\frac{\partial p}{\partial x}, \tag{88}$$

etc.

If the motion be small, as is usually the case in oscillations, x, y, z (here the initial coördinates) may be taken as constant for all time, and so the velocities and accelerations may be written

$$\frac{\partial \mathbf{x}}{\partial t}\left(=\frac{\partial\,(x+\mathbf{x})}{\partial t}\right),\ \frac{\partial \mathbf{y}}{\partial t},\ \frac{\partial \mathbf{z}}{\partial t}; \tag{89}$$

$$\frac{\partial^2 \mathbf{x}}{\partial t^2},\ \frac{\partial^2 \mathbf{y}}{\partial t^2},\ \frac{\partial^2 \mathbf{z}}{\partial t^2}.$$

In this case the true coördinates of the point are

$$x+\mathbf{x},\ y+\mathbf{y},\ z+\mathbf{z};$$

and so, in strictness, these expressions are velocities and accelerations at $x+\mathbf{x}$, etc.

If the motion of a liquid be horizontal in the main, so that the vertical acceleration can be neglected in comparison with the horizontal, the pressure at a given point will depend only upon its depth below the free surface. Assuming that there is no vertical disturbing force Z, we have

$$p-p_0=g\rho\,(z_0+\zeta-z) \tag{90}$$

where p_0 denotes the pressure at the free undisturbed surface (i. e., about one atmosphere), z_0 the ordinate of this undisturbed surface, ζ the elevation above it of the actual or disturbed free surface.

$$\therefore\ \frac{\partial p}{\partial x}=g\rho\,\frac{\partial \zeta}{\partial x}. \tag{91}$$

Substituting this value in (87) and the similar equation for the y-direction we obtain, for the case of no external forces other than gravity,

$$\frac{du}{dt}=-g\,\frac{\partial \zeta}{\partial x}, \tag{92}$$

$$\frac{dv}{dt}=-g\,\frac{\partial \zeta}{\partial y}, \tag{93}$$

which are the dynamical equations freed from p. They show that at a given locality the greatest acceleration (and so zero velocity in simple wave motion) occurs when the slope of the surface is there greatest. Differentiating the equation of continuity of the form (84) with respect to t and (92), (93) with respect to x and y, respectively, there results for small motions

$$\frac{\partial^2 \zeta}{\partial t^2}=gh\left(\frac{\partial^2 \zeta}{\partial x^2}+\frac{\partial^2 \zeta}{\partial y^2}\right). \tag{94}$$

This equation may be readily obtained from the three equations given below, upon differentiating the first with respect to x, the second with respect to y, and making use of the third, which is the equation of continuity:

$$\frac{\partial^2 \xi}{\partial t^2}=-g\,\frac{\partial \zeta}{\partial x}, \tag{95}$$

$$\frac{\partial^2\eta}{\partial t^2} = -g\frac{\partial\zeta}{\partial y}, \tag{96}$$

$$\frac{\partial\xi}{\partial x} + \frac{\partial\eta}{\partial y} + \frac{\zeta}{h} = 0. \tag{97}$$

(Cf. § 17, Part I.)

12. If the impressed forces have a potential Ω so that

$$\frac{\partial\Omega}{\partial x} = -X,\ \frac{\partial\Omega}{\partial y} = -Y,\ \frac{\partial\Omega}{\partial z} = -Z, \tag{98}$$

and if the velocities also have a velocity-potential φ so that

$$\frac{\partial\varphi}{\partial x} = -u,\ \frac{\partial\varphi}{\partial y} = -v,\ \frac{\partial\varphi}{\partial z} = -w, \tag{99}$$

then the three equations of motion can be integrated, i. e., written in the form

$$\int\frac{dp}{\rho} = \frac{\partial\varphi}{\partial t} - \Omega - \frac{1}{2}q^2 + F(t) \tag{100}$$

where $q = \sqrt{(u^2 + v^2 + w^2)}$ denotes the resultant velocity and $F(t)$ an arbitrary function of t alone. To show this, it is of course only necessary to differentiate with respect to x, y, and z. For steady motion in a liquid this becomes

$$\frac{p}{\rho} = -\Omega - \frac{1}{2}q^2 + \text{constant}, \tag{101}$$

or

$$\frac{p}{\gamma} + z + \frac{q^2}{2g} = \text{constant} \tag{102}$$

where gravity is the only external impressed force acting.

The equation of motion (58) used in establishing Bernoulli's theorem pertains not to an arbitrary direction, but to the direction of the path of the particle. It is integrated along the path of the particle or a stream line; i. e., s is really the independent variable in the integration. If (87) be integrated along a stream line, the form (101) is obtained without assuming a velocity-potential; but the constant is no longer absolute; its value is constant only along a particular stream line.

Consider a mass of liquid rotating, under the action of gravity only, with constant and uniform angular velocity, representing, perhaps, a portion of a river at a bend where the stream lines are assumed to be concentric circles, or perhaps an eddy.

Let the origin be the center of curvature of the stream lines; then

$$u = -\omega y,\ v = \omega x,\ w = 0;$$
$$X = 0, \qquad Y = 0, \quad Z = -g.$$

These values of u, v, and w satisfy the equation of continuity. The dynamical equations are

$$-\omega^2 x = -\frac{1}{\rho}\frac{\partial p}{\partial x},\ -\omega^2 y = -\frac{1}{\rho}\frac{\partial p}{\partial y},\ 0 = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g.$$

These equations are satisfied if

$$\frac{p}{\rho}=\frac{1}{2}\omega^2(x^2+y^2)-gz+\text{constant.} \tag{103}$$

The surfaces of equal pressure are therefore paraboloids of revolution about the axis of z having their concavities upwards, and a common latus rectum $2g/\omega^2$. If we call the elevation of the surface at the center h_0, and make p equal to the atmospheric pressure, the constant will be determined.

The fact that

$$\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}=2\omega,$$

shows that a velocity-potential does not exist. [See equation (99).]

The equation of the free surface may be obtained independently, as follows:

Centrifugal force on unit mass $=\frac{q^2}{\rho}=\omega^2\rho$, ρ here denoting the radius of curvature.

Force of gravity on unit mass $=g$.

$\therefore$ slope at point distant ρ from the center $=\omega^2\rho/g$.

Let $z=$ elevation of the surface above the surface at the inner edge, then

$$z=\int_{\rho=\rho_0}^{\rho=\rho}\frac{\omega^2\rho}{g}\,d\rho=\frac{\omega^2}{2g}(\rho^2-\rho_0^2).$$

Of course ω is to be expressed in radians per second.

13. *Equations of motion and continuity for the surface of a sphere.*

The component accelerations of any moving point referred to fixed rectangular axes are

$$\frac{d^2x}{dt^2},\quad\frac{d^2y}{dt^2},\quad\frac{d^2z}{dt^2}.$$

The accelerations in the directions in which the polar coördinates increase are,

$$\text{Acceleration}_r=\frac{d^2r}{dt^2}-r\left(\frac{d\theta}{dt}\right)^2-r\sin^2\theta\left(\frac{d\varphi}{dt}\right)^2, \tag{104}$$

$$\text{Acceleration}_\theta=r\frac{d^2\theta}{dt^2}+2\frac{dr}{dt}\frac{d\theta}{dt}-r\sin\theta\cos\theta\left(\frac{d\varphi}{dt}\right)^2, \tag{105}$$

$$\text{Acceleration}_\varphi=r\sin\theta\frac{d^2\varphi}{dt^2}+2\sin\theta\frac{dr}{dt}\frac{d\varphi}{dt}+2r\cos\theta\frac{d\theta}{dt}\frac{d\varphi}{dt} \tag{106}$$

These can, with some difficulty, be obtained from the rectangular accelerations by means of the relations between the two sets of coördinates,

$$\begin{aligned}x&=r\sin\theta\cos\varphi,\\ y&=r\sin\theta\sin\varphi,\\ z&=r\cos\theta.\end{aligned} \tag{107}$$

They can, however, be more readily obtained directly by considering two neighboring positions of the moving particle.*

If the motions be confined to the surface of a sphere, the determination of the accelerations along θ and φ increasing becomes a two-dimensional problem.

If we denote, for the moment, the polar coördinates of any plane path by ρ, ψ, then it is easily shown that the acceleration along ρ increasing is,

$$\text{Acceleration}_\rho = \frac{d^2\rho}{dt^2} - \rho\left(\frac{d\psi}{dt}\right)^2, \tag{108}$$

and that perpendicular to ρ is,

$$\text{Acceleration}_\psi = \rho\frac{d^2\psi}{dt^2} + 2\frac{d\rho}{dt}\frac{d\psi}{dt}. \tag{109}$$

Next, suppose that we have a point (r, θ, φ) moving in the surface of a sphere whose center is at the origin of coördinates. Let a plane tangent at this point be drawn at any given instant of time. For a short time the point will move as if in this tangent plane. Let the origin of plane coördinates (ρ, ψ) to which the moving point may be referred, be taken at the point where the axis of the sphere from which θ is reckoned pierces the tangent plane. We then have the obvious relations

$$\begin{aligned} &\rho = r\tan\theta, && d\psi = \frac{r\sin\theta}{r\tan\theta}d\varphi = \cos\theta\, d\varphi, \\ &d\rho = r\,d\theta, && d^2\psi = \cos\theta\, d^2\varphi. \\ &d^2\rho = r\,d^2\theta; && \end{aligned} \tag{110}$$

Substituting in (108) and (109), we have

$$\text{Acceleration}_\theta = r\frac{d^2\theta}{dt^2} - r\sin\theta\cos\theta\left(\frac{d\varphi}{dt}\right)^2, \tag{111}$$

$$\text{Acceleration}_\varphi = r\sin\theta\frac{d^2\varphi}{dt^2} + 2r\cos\theta\frac{d\theta}{dt}\frac{d\varphi}{dt}. \tag{112}$$

If φ denotes the east longitude of any point of a body which rotates uniformly upon its axis from west to east, the coördinates of the point become

$$\begin{aligned} x &= r\sin\theta\cos(\varphi + \mathrm{k}_1 t), \\ y &= r\sin\theta\sin(\varphi + \mathrm{k}_1 t), \\ z &= r\cos\theta, \end{aligned} \tag{113}$$

k_1 being here supposed to represent the angular velocity. Replacing in (104), (105), (106), $\frac{d\varphi}{dt}$ by $\frac{d(\varphi + \mathrm{k}_1 t)}{dt}$ or $\frac{d\varphi}{dt} + \mathrm{k}_1$, and $\frac{d^2\varphi}{dt^2}$ by $\frac{d^2(\varphi + \mathrm{k}_1 t)}{dt^2}$ or $\frac{d^2\varphi}{dt^2}$, we have the values of the acceleration for a point in a uniformly rotating body or upon a uniformly rotating sphere.

*Routh, Dynamics of a Particle, p. 305; Ziwet, Theoretical Mechanics, Part I, p. 162; see Williamson and Tarleton, Dynamics, 2d edition, p. 424, ex. 2.

Let ξ, $\eta \sin \theta$ denote small displacements from the zero position in the directions θ, φ increasing and suppose the radial displacement to be a much smaller quantity. The corresponding velocities are assumed to be small in comparison with the equatorial velocity of rotation $k_1 r$.

Either (111), (112) or (105), (106) give for the terms containing t

$$\text{Acceleration}_\theta = \frac{\partial^2 \xi}{\partial t^2} - 2\,k_1 \sin\theta\cos\theta\,\frac{\partial \eta}{\partial t}, \tag{114}$$

$$\text{Acceleration}_\varphi = \sin\theta\,\frac{\partial^2 \eta}{\partial t^2} + 2\,k_1 \cos\theta\,\frac{\partial \xi}{\partial t}. \tag{115}$$

These expressions denote the effective force per unit mass along and perpendicular to the meridian. Now, the external impressed horizontal forces are minus the partial derivatives of the tide-producing potential (i. e., of $-g\mathfrak{k}$) in the corresponding directions while the retarding forces due to pressure, like $\frac{1}{\rho}\frac{\partial p}{\partial x}, \frac{1}{\rho}\frac{\partial p}{\partial y}$, are the partial derivatives of g times the height of the true tide ($\mathfrak{h}$).

Hence the equations of motion are*

$$\frac{\partial^2 \xi}{\partial t^2} - 2k_1 \sin\theta\cos\theta\,\frac{\partial \eta}{\partial t} = -\frac{g}{a}\frac{\partial}{\partial \theta}(\mathfrak{h} - \mathfrak{k}), \tag{116}$$

$$\sin\theta\,\frac{\partial^2 \eta}{\partial t^2} + 2k_1 \cos\theta\,\frac{\partial \xi}{\partial t} = -\frac{g}{a\sin\theta}\frac{\partial}{\partial \varphi}(\mathfrak{h} - \mathfrak{k}). \tag{117}$$

The equation of continuity for a sea whose depth (γ) is small in comparison with the earth's radius can be determined by considering an elementary prism whose undisturbed height is γ and whose sides are $ad\theta$, $a \sin \theta d\varphi$ in length. At any given time the contents have been increased by $ad\theta.\, a \sin \theta d\varphi.\mathfrak{h}$. Now the amount which has entered through the face of the prism facing the pole from which θ is reckoned is $\xi\gamma\, a \sin \theta d\varphi$, while the amount which has left through the opposite face is

$$\xi\gamma a \sin\theta d\varphi + \frac{\partial}{\partial\theta}(\xi\gamma a \sin\theta)\, d\theta d\varphi.$$

The loss of volume is therefore, since a is constant,

$$a\frac{\partial}{\partial\theta}(\xi\gamma\sin\theta)\, d\theta d\varphi.$$

Similarly the loss occasioned by the excess of the outward flow across the east face over the influx across the opposite face is

$$a\frac{\partial}{\partial\varphi}(\eta\gamma)\sin\theta d\varphi d\theta.$$

But the loss must equal the increase. We thus have, upon dividing through by $ad\theta d\varphi$,

$$\mathfrak{h}a\sin\theta + \frac{\partial}{\partial\theta}(\gamma\xi\sin\theta) + \sin\theta\frac{\partial}{\partial\varphi}(\gamma\eta) = 0. \tag{118}$$

for the equation of continuity.

*Cf. § 102, Part I.

14. *Lagrange's indeterminate equation of motion.*

If no motion exists, the velocities are each zero, and so the right-hand portions of the equations of motion equated to zero pertain to the equilibrium of fluids. For some purposes, as in the mechanics of solids, there are advantages of introducing the principle of virtual work. In this case an elementary mass of the fluid is supposed to be slightly displaced from its position of equilibrium in any arbitrary manner compatible with the conditions of the system. The equation

$$\left(X-\frac{1}{\rho}\frac{\partial p}{\partial x}\right)\delta x+\left(Y-\frac{1}{\rho}\frac{\partial p}{\partial y}\right)\delta y+\left(Z-\frac{1}{\rho}\frac{\partial p}{\partial z}\right)\delta z=0 \tag{119}$$

is, because δx, δy, δz are arbitrary and so independent of one another, equivalent to the three equations for no motion, viz.,

$$X-\frac{1}{\rho}\frac{\partial p}{\partial x}=0, \quad Y-\frac{1}{\rho}\frac{\partial p}{\partial y}=0, \quad Z-\frac{1}{\rho}\frac{\partial p}{\partial z}=0.$$

A still more compact form for (119) is

$$\delta p=\rho\,(X\delta x+Y\delta y+Z\delta z). \tag{120}$$

The second member represents the work done by the three impressed forces acting through short distances in their respective directions. In making these displacements we pass from a surface of certain pressure to a surface whose pressure is altered by δp. The second member will be an exact differential—i. e., X, Y, Z will be such functions of x, y, z that the second member may be written δF, or

$$\frac{\partial F}{\partial x}\delta x+\frac{\partial F}{\partial y}\delta y+\frac{\partial F}{\partial z}\delta z,$$

if

$$\frac{\partial \rho X}{\partial y}=\frac{\partial \rho Y}{\partial x}, \frac{\partial \rho X}{\partial z}=\frac{\partial \rho Z}{\partial x}, \frac{\partial \rho Y}{\partial z}=\frac{\partial \rho Z}{\partial y}; \tag{121}$$

that is, if ρX, ρY, ρZ be proportional to the partial derivatives of F; they are not altogether independent of one another. If ρ be constant, as is here generally assumed, it divides out of (121) as a factor. Whether ρ is constant or not, (121) leads to the condition

$$X\left(\frac{\partial Y}{\partial z}-\frac{\partial Z}{\partial y}\right)+Y\left(\frac{\partial Z}{\partial x}-\frac{\partial X}{\partial z}\right)+Z\left(\frac{\partial X}{\partial y}-\frac{\partial Y}{\partial x}\right)=0, \tag{122}$$

which is independent of ρ. This equation expresses the relation which must exist between X, Y, Z when equilibrium of any fluid is possible. If this condition exists, then by aid of a factor, ρ, $X\delta x+Y\delta y+Z\delta z$ can be made an exact differential.

If the displacement be taken in the free surface or in any other surface of equal pressure δp will be zero, and so

$$X\delta x+Y\delta y+Z\delta z=0 \tag{123}$$

is the equation of such a surface.

Putting $-\delta V$ for $X\delta x+Y\delta y+Z\delta z$ the equilibrium equation (120) becomes

$$\delta V+\frac{\delta p}{\rho}=0. \tag{124}$$

If there be motion instead of rest, we have in place of the impressed forces X, Y, Z the forces (impressed and reversed effective) $X-\frac{d^2x}{dt^2}$, $Y-\frac{d^2y}{dt^2}$, $Z-\frac{d^2z}{dt^2}$; and so the three equations of motion may be written as one

$$\frac{d^2x}{dt^2}\,\delta x+\frac{d^2y}{dt^2}\,\delta y+\frac{d^2z}{dt^2}\,\delta z=X\delta x+Y\delta y+Z\delta z-\frac{\delta p}{\rho}, \tag{125}$$

or

$$\frac{d^2x}{dt^2}\,\delta x+\frac{d^2y}{dt^2}\,\delta y+\frac{d^2z}{dt^2}\delta g=-\,\delta V-\frac{\delta p}{\rho} \tag{126}$$

assuming that $X\delta x+Y\delta y+Z\delta z$ is an exact differential.

Lagrange embodied the whole theory of motion in one general equation, which is a formal expression for D'Alembert's principle combined with the principle of virtual work.

$$\Sigma\left\{\left(X-m\frac{d^2x}{dt^2}\right)\delta x+\left(Y-m\frac{d^2y}{dt^2}\right)\delta y+\left(Z-m\frac{d^2z}{dt^2}\right)\delta z\right\}=0, \tag{127}$$

where the Σ refers to each material point $m_1, m_2, \ldots$ whose coördinates are $x_1, y_1, z_1; x_2, y_2, z_2; \ldots$ and which points are acted upon by the forces $X_1, Y_1, Z_1; X_2, Y_2, Z_2; \ldots$ So long as all points are free, $\delta x_1, \delta y_1, \delta z_1; \delta x_2, \delta y_2, \delta z_2; \ldots$ are wholly arbitrary, and their coefficients are severally equal to zero. In order to state any problem for a system of points, it is necessary to assume that the coördinates of the several points are not altogether independent quantities, but that relations of the form

$$F(x_1, y_1, z_1;\ x_2, y_2, z_2;\ \ldots)=0 \tag{128}$$

subsist between them because the points are subject to mutual constraints. If these relations do not contain t, d can always be substituted for δ.

In a fluid each particle is free to move anywhere independently of all others. That is, individual constraints between the neighboring particles are wanting, though in a collective manner certain restraints are responsible for the pressures to which the different portions of the fluid are subjected. But the rigid surfaces which bound the fluid have their equations. These are the only equations which are analogous to the ordinary constraint relations in the dynamics of a material system whose particles are definitely connected. The equation of the free surface of a liquid involves the consideration of continuity in its determination; but if the equation of the free surface (generally involving t) were given, together with the equations of the other bounding surfaces, they would constitute all of the conditional equations. That is, they and the three equations of motion fix or define the movement of the liquid.

15. *Two-dimensional motion.*

It has been already noted that when a velocity-potential exists the equation of continuity may be written

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}+\frac{\partial^2\varphi}{\partial z^2}=0. \tag{129}$$

For plane or two-dimensional motion this becomes

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}=0. \tag{130}$$

Now, the condition that

$$\frac{d(X+iY)}{d(x+iy)} \tag{131}$$

have a definite value regardless of the direction in which $d(x+iy)$ is taken; i. e., that

$$\frac{\frac{\partial X}{\partial x}dx + \frac{\partial iY}{\partial x}dx + \frac{\partial X}{\partial y}dy + \frac{\partial iY}{\partial y}dy}{dx + idy}$$

be free from the variable quantities dx, dy, is

$$\frac{\partial X}{\partial x} = \frac{\partial Y}{\partial y}, \quad \frac{\partial X}{\partial y} = -\frac{\partial Y}{\partial x}. \tag{132}$$

When these relations are satisfied, $X+iY$ is a monogenic function of $x+iy$, and conversely. These equations differentiated with respect to x and y show that X or Y is a solution of (130), and so will be any linear expression containing them; e. g., $X+iY$ is a solution, so, of course, is a function of $X+iY$ a solution because it is still a function of $x+iy$. For the present we may suppose that the required solution φ is the X or Y of some monogenic function. X and Y are conjugate functions in x, y; x and y are conjugate functions in X, Y. If one plane be divided orthogonally and isothermally by a pair of curve systems, so is the other. All angles are preserved except at the critical points.

A line of motion or stream line coincides in direction with the direction of the velocity. Its equation may be written

$$\psi = \text{constant}.$$

At any point on such a line we evidently have

$$\frac{v}{u} = \frac{dy}{dx}, = -\frac{\partial \psi}{\partial x}\Big/\frac{\partial \psi}{\partial y}, \tag{133}$$

and so

$$u\frac{\partial \psi}{\partial x} + v\frac{\partial \psi}{\partial y} = 0. \tag{134}$$

The equation of continuity is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \tag{135}$$

By putting

$$u = -\frac{\partial \psi}{\partial y}, v = \frac{\partial \psi}{\partial x} \tag{136}$$

the above two equations are satisfied. From the values of u and v we have

$$d\psi = \frac{\partial \psi}{\partial y}dy + \frac{\partial \psi}{\partial x}dx = udy - vdx \tag{137}$$

which expresses the quantity of water which flows across a section of unit height or thickness and extending normally from the line $\psi =$ constant to $\psi =$ constant $+ d\psi$, per unit of time. dx, dy are here determined by the extent of this cross section and do not refer to an arc element as is usually the case.

But

$$u = -\frac{\partial \varphi}{\partial x}, \; v = -\frac{\partial \varphi}{\partial y}; \tag{138}$$

$$\therefore \frac{\partial \varphi}{\partial x} = \frac{\partial \psi}{\partial y}, \; \frac{\partial \varphi}{\partial y} = -\frac{\partial \psi}{\partial x}. \tag{139}$$

Comparing with (132) we see that if the X of a monogenic function denote the velocity-potential φ, then the Y will denote the stream-function ψ. In other words, $\varphi + i\psi$ will be a monogenic function of the variable $x + iy$. Since Y is a solution of (130), so is ψ; or

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = 0. \tag{140}$$

Along fixed boundaries the normal component of the velocity must be zero. This requires that $\psi =$ constant at all points of such boundaries. If a portion of the boundary be moving uniformly along the x-direction with a velocity U, then along this portion we must have $\psi = -Uy +$ constant. Similarly, if it move with a velocity V in the y-direction, we must have $\psi = +Vx +$ constant. If the velocity of the liquid exceed a certain limit, there will occur, especially beyond a sharp cape or edge, a region of nearly still water separated from the moving water by a surface of discontinuity. Along this surface the pressure must be constant, otherwise there could be no still water adjacent to it. The velocity of the moving water along this surface must, therefore, be constant; this is one of the boundary conditions to be satisfied when discontinuous motion is contemplated.

The problem of finding functions which satisfy prescribed boundary conditions has received the attention of Schwarz, Christoffel, Kirchoff, and others. The following references may be given here: A. B. Bassett, A Treatise on Hydrodynamics, Vol. I, Chs. V, VI; J. J. Thomson, Notes on Recent Researches in Electricity and Magnetism, Ch. III; Horace Lamb, Hydrodynamics, Ch. IV.

This theory, as will be pointed out below, finds only limited applications to tides and tidal currents. For this reason only a few examples will be given. In the theory of functions it is usual to denote by z, $= x + iy$, the independent variable; that is, the variable whose paths are assumed to be straight lines dividing the z-plane into equal elementary squares, or to be some other simple curves. In hydrodynamics it is convenient to assume that the paths of Z, $= X + iY$, divide the Z-plane into equal elementary squares. Regarding z as a function of Z, the curves in the z-plane which are images of $X =$ constant or $Y =$ constant must conform to the prescribed boundary conditions. In practice, the line $\psi =$ constant, which coincides with a given boundary, is usually a *reduced image*, because the bounding walls are usually straight lines or some other simple curves, while the other stream lines are curves of a higher order.

It is to be particularly noted that any functional transformation gives a solution for an indefinite number of possible hydrodynamical problems. For, along any stream line a boundary wall may be erected and the motion will go on as before.

The motion of a curved stratum of uniform thickness can be obtained by conformally representing the region considered upon a plane. There seems to be no occasion for taking curvature into account in considering tidal streams. Ocean currents may, however, require such treatment.

16. *Line source and Descartes' vortex theory.*

Let

$$X + iY = \log(x + iy), \tag{141}$$

or

$$x + iy = e^{X+iY};$$
$$x = e^X \cos Y,$$
$$y = e^X \sin Y;$$

$$x^2 + y^2 = e^{2X},\ 2X = \log(x^2 + y^2),\ = 2\log r; \tag{142}$$

$$\frac{y}{x} = \tan Y,\ Y = \tan^{-1}\frac{y}{x} = \theta. \tag{143}$$

If $X = \varphi =$ constant, $x + iy$ describes a circle of radius e^φ about the origin. Hence the lines of equal velocity-potential are concentric circles. For $Y = \psi =$ constant, the point $x + iy$ describes a straight line through the origin, making the angle ψ with the x-axis. Lines of equal stream-function are therefore radiating straight lines. If from a small circular perforated pipe, that is a line source or line sink, perpendicular to the plane xy, water flow equally in all directions, the motion will be that just described. For, $\frac{\partial X}{\partial x}, \frac{\partial X}{\partial y}$ evidently become zero at infinity where we know the component velocities must be zero.

This nearly represents the motion in a funnel-shaped river of uniform depth discharging into a sea where the velocity is practically zero. The banks are supposed to consist of diverging straight lines or walls.

Suppose that we now put $Y = \varphi$ and $X = \psi$. The lines of equal velocity-potential will now be the radiating straight lines, while the stream lines will be the concentric circles. In this case the linear velocities $\left(-\frac{\partial\varphi}{\partial s} = -\frac{\partial\theta}{\partial s} = -\frac{1}{r}\right)$ are inversely as the distance from the center, and so the periodic times are as the square of the distances. The vortex theory of Descartes supposed matter carried about the axes of the sun and earth in spherical shells or vortices; we can imagine as many plane circular orbits. This example shows that if the motion have a velocity-potential the periodic times of the planets must then be as the squares of their respective distances. Newton found the same rule in considering spherical layers of a viscous fluid between which the resistance varies directly with the relative velocities. But this rule contradicts Kepler's third law. Cf. § 80, Part I.

17. *Transformations implied in a rational algebraic function of the variable, and in the logarithm of such a function.*

Let the transforming equation be

$$X + iY = \frac{(z - c_1)(z - c_2)(z - c_3)\ \ldots}{(z - d_1)(z - d_2)(z - d_3)\ \ldots} \tag{144}$$

If m denote the order of the numerator and n the order of the denominator, the curves corresponding to $X =$ constant or $Y =$ constant are of the order $m + n$ or $2n$, according to which value is the greater.

If $n = 0$, the systems corresponding to $X =$ constant or $Y =$ constant consist of hyperbolic curves of the mth degree. If, further, $c_1 = c_2 = \quad . \quad . \quad . \quad = 0$, then either $X = 0$ or $Y = 0$ gives a reduced image consisting of m right lines drawn through the origin radiating at uniform angles. Either set may be taken as straight rigid walls of a boundary.

If $m = 0$ and $n = 1$, then $X =$ constant gives a system of circles tangent at d_1 to a line drawn parallel to the y-axis, and $Y =$ constant a system tangent at d_1 to a line drawn parallel to the x-axis. This tranformation may be used to approximately represent the motion in a funnel-shaped river of uniform depth whose sides are arcs of circles and which discharges into a sea.

Similarly for $m = 1$, $n = 1$.

If $m = 0$ and $n = 2$, then $X =$ constant and $Y =$ constant each give, of course, a system of curves of the fourth degree.

Let us next use the transforming equation

$$\varphi + i\psi = \log (X + iY) = \log \frac{(z - c_1)\ (z - c_2)\ (z - c_3)\ .\ .\ .}{(z - d_1)\ (z - d_2)\ (z - d_3)\ .\ .\ .}. \qquad (145)$$

Suppose $n = 0$; then $\varphi =$ constant gives a system of cassinoids whose foci are at $c_1, c_2, \quad . \quad . \quad . \quad$; $\psi =$ constant gives a system of hyperbolic curves of the mth order setting out from the points $c_1, c_2, \quad . \quad . \quad . \quad .$ For a cassinoid the product of the moduli of the m factors for any given point z is constant, while for an hyperbolic curve the sum of the arguments or angles of z reckoned from a fixed direction is constant.

If line sources or sinks of equal strength be placed at the foci $c_1, c_2, \quad . \quad . \quad . \quad .$, the curve system just described represents the flow in an infinite plane sheet.*

When n is not zero, we may suppose line sources at $c_1, c_2, \quad . \quad . \quad .$ and sinks at $d_1, d_2, \quad . \quad . \quad .$ or vice versa.

For $m = 1$, $n = 1$, $\psi =$ constant gives a system of circles all passing through the two points c_1, d_1. $\varphi =$ constant gives the orthogonal system. Here the boundary may be finite because we can consider by itself the area included between any two stream lines.

18. *The transformations by sine functions, etc.*

If $z = \sin Z$, $\cos Z$, $\sinh Z$, $\cosh Z$, $\sin kZ$, $\cos kZ$, $\quad . \quad . \quad .$ etc., the images of $X =$ constant, $Y =$ constant consist of a system of confocal ellipses intersected orthogonally by a system of confocal hyberbolas. Assuming the hyberbolas to be the stream lines, the transformation represents the flow through an opening two units in width in a straight partition extending to infinity in either direction. It also represents the motion between two capes or headlands whose outlines coincide with two of the hyperbolas. By observing such systems of curves drawn to scale, it will be seen that such a cape or headland must be quite slender in order that the velocity there be several times as great as at the center of the opening. Hence it often happens that at capes and headlands tidal streams are not sufficiently increased in velocity to become especially noticeable.

$$z = \frac{\varepsilon^{\varepsilon}(1 - \varepsilon)^{1 - \varepsilon}}{\sin \varepsilon \pi} \left[\left(e^{Z}\right)^{1 - \varepsilon} - \left(e^{-Z}\right)^{\varepsilon} \right] \qquad (146)$$

where ε is any real positive quantity ranging from $\frac{1}{2}$ to 0, represents the motion through an opening between two plane walls extending to infinity. The width of the

*Annals of Mathematics, Vol. IV (1892), pp. 77–80.

opening is 2 units, and the walls make angles $\varepsilon\pi$ with a line drawn perpendicularly through its center. The origin of coördinates is at the intersection of these two walls produced.*

19. *Transformation by elliptic functions.*

Let

$$\mathrm{cn}\,(z + K) = e^{iZ}. \tag{147}$$

By this transformation, $X = 0$ as y goes from $+\infty$ to $-\infty$, gives two sides of a square extending from the origin to $x = K, y = 0$, thence to the point $x = K, y = K$; $X = 90°$ gives the two remaining sides of the square. For $X =$ constant where $0 <$ constant $< 90°$, the images are lines, generally curved, extending from the origin to the opposite corner of the square. If at one of these corners of the square a line source be located and at the other a sink, the curves $X =$ constant will denote the stream lines. The curves will also represent the motion between any two of these stream lines, along which thin walls have been erected. As a possible application to nature, we can suppose a stream to broaden into a lake and again contract to its former width.

By using any modulus other than $\sqrt{\tfrac{1}{2}}$, we shall have a rectangle instead of a square.†

Transformation by the equation

$$z = \mathrm{sn}\, Z. \tag{148}$$

Taking the lines $Y =$ constant as stream lines, this transformation represents motion through two openings made through a wall along the x-axis extending to infinity in both directions. The openings are each $\left(\frac{1}{k} - 1\right)$ in width (k being the modulus) and are separated by a portion of the solid wall two units in length. By imagining thin walls erected along certain of these stream lines, we have the motion around an oval island lying between two capes.‡

20. *The vena contracta.*

The equation

$$\frac{-dz}{dw} = e^{w} + \sqrt{(e^{2w} - 1)}, \tag{149}$$

or

$$-Z = e^{w} + \int \sqrt{(e^{2w} - 1)}\, dw + \text{constant},$$

or

$$-Z = e^{w} + i\left(w - \frac{1}{2^2}e^{2w} - \frac{1}{2.4^2}e^{4w} - \frac{1.3}{2.4.6^2}e^{6w} - \cdots\right) + \text{constant}, \tag{150}$$

where

$$Z = x + iy,$$
$$w = \varphi + i\psi,$$

*See Annals of Mathematics, Vol. II (1901), p. 73; also Lamb, Hydrodynamics, pp. 82, 83.

†See C. S. Peirce, American Journal of Mathematics, Vol. II (1879), pp. 394–396, and Norbert Herz, Lehrbuch der Landkartenprojectionen, pp. 267–277.

‡See Annals of Mathematics, Vol. IV (1888), pp. 81–83.

transforms the parallel lines of the w-plane,

$$\psi = \text{constant},$$

into stream lines in the z-plane, the two bounding stream lines being taken to be $\psi = 0$, $\psi = \pi$. Along the free stream lines the pressure is constant, and so must be the velocity and so (since $-\frac{\partial \varphi}{\partial s} = \text{velocity}, = 1$ by properly choosing the units) $\varphi = -s +$ constant; or $\varphi = -s$ since the constant is arbitrary. This assumption makes φ negative.

For the line $\psi = 0$ the real part of the transforming equation becomes

$$-x = e^{-s} + \text{constant}.$$

If the origin of x be taken at the edge of the orifice where, of course, s is zero, the constant becomes -1;

$$\therefore x = 1 - e^{-s}$$

is the equation of the free stream line at this edge. For $s = \infty$, $x = 1$.

For the line $\psi = \pi$, the real part of the transforming equation becomes when $s = \infty$

$$x = 1 + \pi.$$

The width of the orifice is $2 + \pi$ and the width of the jet at infinity being π, the ratio $\frac{\pi}{2 + \pi} = 0{\cdot}611$ is the coefficient of contraction.

For three-dimentional motion the coefficient of contraction must, in general, be between $\frac{1}{2}$ and 1.

See Lamb, Hydrodynamics, pp. 27, 105.

21. *Difficulties in realizing two-dimensional motion.*

A steady motion such that the lines of motion of all water particles shall be horizontal and such that all those particles once in the same vertical line always remain in a vertical line, and so slow that the inertia of the water may be neglected, is not easily realized experimentally or in natural bodies of water. Yet such motion lends itself most readily to mathematical treatment. See §§ 16–19 for examples. Motion in a body of water of uniform depth does not generally approximate to this plane motion of mathematicians, for the motion is much retarded at the bottom and sides. Moreover, any sudden change of cross section or the presence of an angular projection into the body of water may cause the continuous stream-line motion to give way, unless the velocity be very slow, to discontinuous motion. There will be a comparatively swift stream bordered by masses of still water or countercurrents and eddies.

In two extreme cases there is a realization of, or tendency toward, the simple mathematical plane motion. One of these is where very thin sheets of liquid are used. Experiments have been made by H. S. Hele-Shaw, which show the stream lines in the motion past certain obstacles by aid of a colored liquid injected into the colorless liquid at certain points, thus dividing the whole sheet into distinguishable bands. Some account of his work is given in Nature, Vol. 57 (1898), p. 566; Vol. 58 (1898), pp. 34–36, 61, 467, 520, 535; Vol. 59 (1899), pp. 222–223. The other case is where the water is so deep that the motion is nearly alike from the top down to near the bottom, and where the velocity is not sufficient to cause discontinuous motion due to sharp edges or angles. As the bottom or sides are approached the motion will be characterized by eddies, because right at such boundaries the velocity is generally assumed to be zero. In channels, straits, etc., the tidal currents most nearly represent steady motion at the time of the greatest flood or ebb velocity. If at such times the velocity be not so great as to give rise to discontinuous motion attended with countercurrents, etc., the required motion will be partially realized. Of course, variations in the depth prevent any natural body of water from being a good illustration. Nevertheless, observations show that off certain angular capes the velocity is greater than the mean, while the lines of motion bend around such capes as theory would imply; for example, Cape de la Hague and Saint David's Head. Even in these cases eddies or countercurrents may occur behind headlands or in the smaller bays. (See Fig. 28.)

Two-dimensional motion can in some cases be approximately realized by using a vertical sheet of water contained in a tank with glass front and back. This vessel can be partitioned to suit numerous problems. The region to be studied is always supposed to be small in comparison with the area of the face of the tank; otherwise it would be difficult to approximately satisfy the conditions of any proposed problem.

It may be well to note how a slow two-dimensional motion corresponding to a given φ may possibly be approximately produced in the case of a very long channel or strip of very shallow water included between two given stream lines, provided that the element magnification (or the velocity) is about the same at each end of any equipotential line crossing the channel. Imagine a very shallow channel of uniform depth to lead from an inexhaustible supply of still deep water. Let the line of juncture be made to coincide with an equipotential line of the proposed motion. Let there be a slope along the given stream lines such that the velocity shall be that required in the proposed motion, or $-\frac{\partial \varphi}{\partial s}$. The velocity of a stream is constant at a given point and is under some conceivable conditions proportional to $\sqrt{\frac{\partial z}{\partial s}}$ or the square root of the slope. The required velocity would thus determine the slope of the stream lines at each point. The transverse slope is, by the above hypothesis, small in comparison to the slope along the stream lines. Having laid down the stream lines and curved the bottom to the right slope at each point, a level line can be drawn across them. Let this level line define the junction between the lower end of the channel and a deep body of water always maintained at a constant level. Now, by causing the surfaces of the two bodies of comparatively still water to be on slightly different levels, as determined above, the required steady flow may be approximately obtained. Were it in the nature of things possible for the slope of the bed to maintain at each point a velocity proportional thereto (a possibility, perhaps, for very slow motions), then the restriction as to velocities at the two opposite sides would be unnecessary. Then the contour or level lines would be lines of equal velocity-potential; the lines of equal slope would be lines of equal velocity, and the lines orthogonal to these would be lines of equal direction.

22. *Two-dimensional motion not applicable to the emptying or filling of reservoirs.*

Suppose that we have a large shallow reservoir of uniform depth. Let the water be drawn off through one or more small openings. At first sight it might seem that simple two-dimensional motion would be approximately realized, for the motion is nearly all horizontal, is nearly steady for a considerable interval of time, and is too slow to cause discontinuous motion and eddies. A few illustrations will show some of the difficulties as well as some of the distinguishing features of such motion. A long rectangular tank being emptied by openings consisting of perforations suitably scattered over one end is the simplest case. Let the horizontal velocity of the water (as shown by floats extending nearly to the bottom) in the tank at this end be denoted by c, and let L denote the tank's length. At the closed end the velocity is zero. The general expression for the velocity (for discharge) is, therefore,

$$v = -\frac{c(L-x)}{L}, = -\frac{\partial\varphi}{\partial x},$$

or

$$\varphi = -\frac{c}{2L}(L-x)^2 + \text{constant}. \tag{151}$$

That is, lines of equal velocity-potential are close together at the end where the tank discharges and far apart at the closed end. The lines of motion are of course straight lines parallel to the sides of the tank. But these lines and the system $\varphi =$ constant, where this constant takes equal increments, can not (save where x/L is small) form isothermal systems, although they are orthogonal. Had we taken a channel of uniform depth and having uniform velocity throughout its length, as a river, we might divide the surface into elementary squares instead of rectangles. Such lines would define approximately, were there no resistance at the sides, the flow of a river, as shown by vertical floats extending from the surface to near the bottom.

As another illustration of the present difficulty, let us assume a shallow circular tank with an opening at the center of the bottom, or having a small vertical pipe at the center, perforated in all directions. Let the average velocity at unit's distance from the center be c. Let L denote the radius of the tank, where $r = L$ the ve ocity is to be zero; then velocity at any distance r from the center is to the velocity at a (unit's) distance, r_1, as the area of annulus outside of r is to the area of the annulus outside the r_1 circle directly, and inversely as r is to unity. That is,

$$\text{Velocity (for discharge) at distance } r \text{ from center} = -\frac{cL^2 r_1}{r(L^2 - r_1^2)} + \frac{cr_1 r}{L^2 - r_1^2};$$

$$\therefore\ \varphi = \frac{cL^2 r_1}{L^2 - r_1^2}\log r - \frac{c}{2}\frac{r_1 r^2}{L^2 - r_1^2} + \text{constant}. \tag{152}$$

This formula is, of course, applicable to any sector of the circle; for, from the symmetrical character of the tank and opening, we know that all lines of motion must radiate from the center as straight lines. It has been shown in an example (§ 16) that the system of curves which would, with this system, divide the circle into squares is that obtained by omitting the second term in the above expression for φ. For small values of r the second term of (152) becomes relatively insignificant.

23. *Tidal streams are not generally due directly to a difference of level in the water's surface at two localities.*

In wave motions, whether progressive or stationary, the water flows half of the time uphill and half of the time downhill. There are indeed very few cases in nature where wave motion of the tides gives way to motion whose velocity depends directly upon the then existing difference of level between the surfaces of two bodies of water; a few very contracted straits are the only conspicuous examples. The acceleration, however, depends directly upon the slope of the surface as was noted in § 11.

Notwithstanding the fact that tidal streams are a part of some form of wave motion, their courses and relative velocities are mainly governed by the land, and so, in a measure, can be explained by aid of the preceding sections on continuous and discontinuous plane steady motion. See, for example, a chart of the Irish Sea, Fig. 28. In fact, the courses of tidal streams are governed by the land to a far greater extent than are those of permanent ocean currents.

Some cases where Torricelli's theorem applies will be noted in Chapter VIII.

CHAPTER III.

OSCILLATING AREAS.

24. This chapter treats of oscillations in sheets of water whose depths are small in comparison with their horizontal dimensions. The modes of oscillations obtained for a few simple areas have a much wider application than is at first evident; for, if a thin, vertical wall be put in the place of any line of motion, the character of the motion of the liquid thus partitioned will remain the same as before. For instance, the period of slowest oscillation for one of the pointed strips in Fig. 9, or of several adjacent strips, is the period for a canal whose length is equal to the edge of one of the smaller squares. Hence we might combine one-half of one of these pointed strips with one-half of the canal just mentioned, and the period would remain unaltered.

The problem before us is to solve the equation

$$\frac{\partial^2\zeta}{\partial t^2} = \kappa^2\left(\frac{\partial^2\zeta}{\partial x^2} + \frac{\partial^2\zeta}{\partial y^2}\right) \tag{153}$$

where $\kappa^2 = gh$ subject to the boundary condition

$$\frac{\partial\zeta}{\partial\nu} = 0. \tag{154}$$

A very general solution of this equation can be made up of a series of solutions each of the form

$$\varphi\,(l\kappa t + \mathrm{i}\; mx + \mathrm{j}\; ny) \tag{155}$$

where

$$l^2 = m^2 + n^2, \tag{156}$$

$$\mathrm{i},\ \mathrm{j} = \sqrt{1} = \pm 1. \tag{157}$$

and φ is an arbitrary function. Each of these solutions can generally be broken up into four others, viz., the 1-terms, the i-terms, the j-terms, and the ij-terms. These statements readily follow from the expansion of (155) in powers of $(\mathrm{i}\,mx + \mathrm{j}\;ny)$ by Taylor's theorem.*

Special case: If $n = 0$, then $m = l$,
we have

$$\varphi\,(\kappa t + x) \pm \psi\,(\kappa t - x) \tag{158}$$

as a solution of (153) or

$$\frac{\partial^2\zeta}{\partial t^2} = \kappa^2\,\frac{\partial^2\zeta}{\partial x^2}. \tag{159}$$

For harmonic motion we may put $\varphi =$ sine or cosine; if the motion be simply harmonic, the speeds $l\kappa$, $l'\kappa$, $l''\kappa$, . . . , of the various terms are each equal to $l\kappa$.

* Cf. Bull. Am. Math. Soc., Vol. V (1898), pp. 96–98.

We have, as solutions, any linear combinations of such terms as are contained in the following expressions:

$$\begin{aligned}
&\cos l\kappa t \cos mx \cos ny + \cos l'\kappa t \cos m'x \cos n'y + \cos l''\kappa t \cos m''x \cos n''y + \ldots, \\
&\cos l\kappa t \sin mx \sin ny + \cos l'\kappa t \sin m'x \sin n'y + \cos l''\kappa t \sin m''x \sin n''y + \ldots, \\
&\sin l\kappa t \sin mx \cos nz + \sin l'\kappa t \sin m'x \cos n'y + \sin l''\kappa t \sin m''x \cos n''y + \ldots, \\
&\sin l\kappa t \cos mx \sin nz + \sin l'\kappa t \cos m'x \sin n'z + \sin l''\kappa t \cos m''x \sin n''y + \ldots,
\end{aligned} \tag{160}$$

where

$$l^2 = m^2 + n^2,\ l'^2 = m'^2 + n'^2,\ l''^2 = m''^2 + n''^2, \quad \ldots \tag{161}$$

These terms may have any constant coefficients, and the angles may be increased or decreased by any arbitrary constants.

25. *Rectangular areas.*

Taking the origin at one corner and the axes along two of the sides we may write

$$\zeta = A \cos l\kappa t \cos mx \cos ny + A' \cos l'\kappa t \cos m'x \cos n'y + \quad \ldots \tag{162}$$

wherein

$$m,\ m',\ m'', \quad \ldots \quad = \frac{\mu\pi}{h_1},\ n,\ n',\ n'', \quad \ldots \quad = \frac{\nu\pi}{h_2}, \tag{163}$$

μ, ν being integers or zero, and h_1, h_2, the lengths of the sides of the rectangle. This value of ζ evidently satisfies the boundary conditions, which are simply

$$\frac{\partial\zeta}{\partial x} = 0 \text{ for } x = 0 \text{ and } x = h_1,\ \frac{\partial\zeta}{\partial y} = 0 \text{ for } y = 0 \text{ and } y = h_2.$$

Suppose $\mu = 1$, $\nu = 0$ in the first and only term; we have, because $l^2 = m^2 + n^2$

$$\zeta = A \cos\frac{\pi}{h_1}\kappa t \cos\frac{\pi}{h_1}x; \tag{164}$$

which may be written in the form

$$\zeta = A \cos l\kappa t \cos lx \tag{165}$$

$$\zeta = A \cos at \cos lx \tag{166}$$

where a, denoting the speed of the oscillation, is written in the place of the $l\kappa$ above, and so

$$a = \kappa l \text{ or } a^2 = ghl^2, \tag{167}$$

l being $\frac{\pi}{h_1}$ or $\frac{2\pi}{\lambda}$.

Suppose $\mu = 1$, $\nu = 0$ in the first term, and $\mu = 0$, $\nu = 1$ in the second; we have, because

$$l^2 = m^2 + n^2,\ l'^2 = m'^2 + n'^2,$$

$$\zeta = A \cos\frac{\pi}{h_1}\kappa t \cos\frac{\pi}{h_1}x + A' \cos\frac{\pi}{h_2}\kappa t \cos\frac{\pi}{h_2}y. \tag{168}$$

Since A and A' are arbitrary, it is seen to be possible to have at the same time two simple harmonic oscillations with any relative amplitudes in the same area, each being harmonic in distance as well as in time. Moreover, we can add any constant to the time angle of either term. Suppose the depth of the water to be such that the free period in the x-direction is a half lunar day, and in the y-direction a half solar. Suppose that at the time of syzygy the lunar oscillation reaches elongation in the x-direction at a certain lunar hour, and the solar oscillation reaches elongation in the y-direction at a certain solar hour. The amplitude of the combined vertical oscillation will not become a maximum until a time shall have elapsed equal to the difference between the times just mentioned multiplied by 30 and divided by $s_2 - m_2 = 1°\cdot0159$. In this way it is easy to see how the "age" or "retard" of the phase inequality under the above conditions might be several days, and be either positive or negative. It would be difficult to realize this condition in the tides of nature because (1) of the requisite dimensions for the free oscillations and (2) of the fact that lunar and solar days are too nearly equal in length for having one set of forces incite oscillation in one direction only. For a partial realization of this effect see § 78.

26. *Square areas.*

A square area can oscillate in an infinite number of ways while the period remains constant. For, given the period, or the speed $l\kappa$, then we may take as many terms of form (162) where $h_2 = h_1$ as we please, the only conditions being

$$l^2 = m^2 + n^2 = m'^2 + n'^2 = m''^2 + n''^2 = \quad . \quad . \quad . \quad . \tag{169}$$

These terms can, of course, have any constant coefficients and any epochs.

If $\mu = 1$, $\nu = 0$ in the first term and $\mu = 0$, $\nu = 1$ in the second, we have

$$\zeta = A \cos \frac{\pi\kappa t}{h_1} \cos \frac{\pi x}{h_1} + A' \cos \frac{\pi\kappa t}{h_1} \cos \frac{\pi y}{h_1}. \tag{170}$$

When $\zeta = 0$, this equation gives the nodal lines, along which there is neither rise nor fall. When ζ, or rather $\zeta \div \cos \frac{\pi\kappa t}{h_1}$, = constant, the equation

$$A \cos \frac{\pi x}{h_1} + A' \cos \frac{\pi y}{h_1} = \text{constant} \tag{171}$$

denotes a contour line. Let this be written for the moment

$$\Phi\,(x, y, c) = 0;$$

then

$$\frac{dy}{dx} = -\frac{\dfrac{\partial\Phi}{\partial x}}{\dfrac{\partial\Phi}{\partial y}}.$$

If the value within the parenthesis marks refer to an orthogonal trajectory,

$$\left(\frac{dy}{dx}\right) = -\frac{dx}{dy} = \frac{\partial\Phi}{\partial y} \div \frac{\partial\Phi}{\partial x} = -\frac{\partial\Psi}{\partial x} \div \frac{\partial\Psi}{\partial y}.$$

or

$$\frac{\partial\Psi}{\partial x}\frac{\partial\Phi}{\partial x} + \frac{\partial\Psi}{\partial y}\frac{\partial\Phi}{\partial y} = 0, \tag{172}$$

where Ψ refers to the trajectory, is the general condition of orthogonality. In the present case we have

$$\left(\frac{dy}{dx}\right) = \frac{A' \sin \frac{\pi y}{h_1}}{A \sin \frac{\pi x}{h}},$$

which gives upon integration

$$\frac{h_1}{\pi A'} \log \tan \frac{\pi y}{2h_1} - \frac{h_1}{\pi A} \log \tan \frac{\pi x}{2h_1} = \text{constant} \qquad (173)$$

for the lines of motion.

The lines of motion can be determined in another way:

Cover the square with a series of short arrows, all drawn parallel to the x-axis, whose lengths are proportional to $A \sin \frac{\pi x}{h_1}$ [eqs. (95), (96), (170)]; also with a

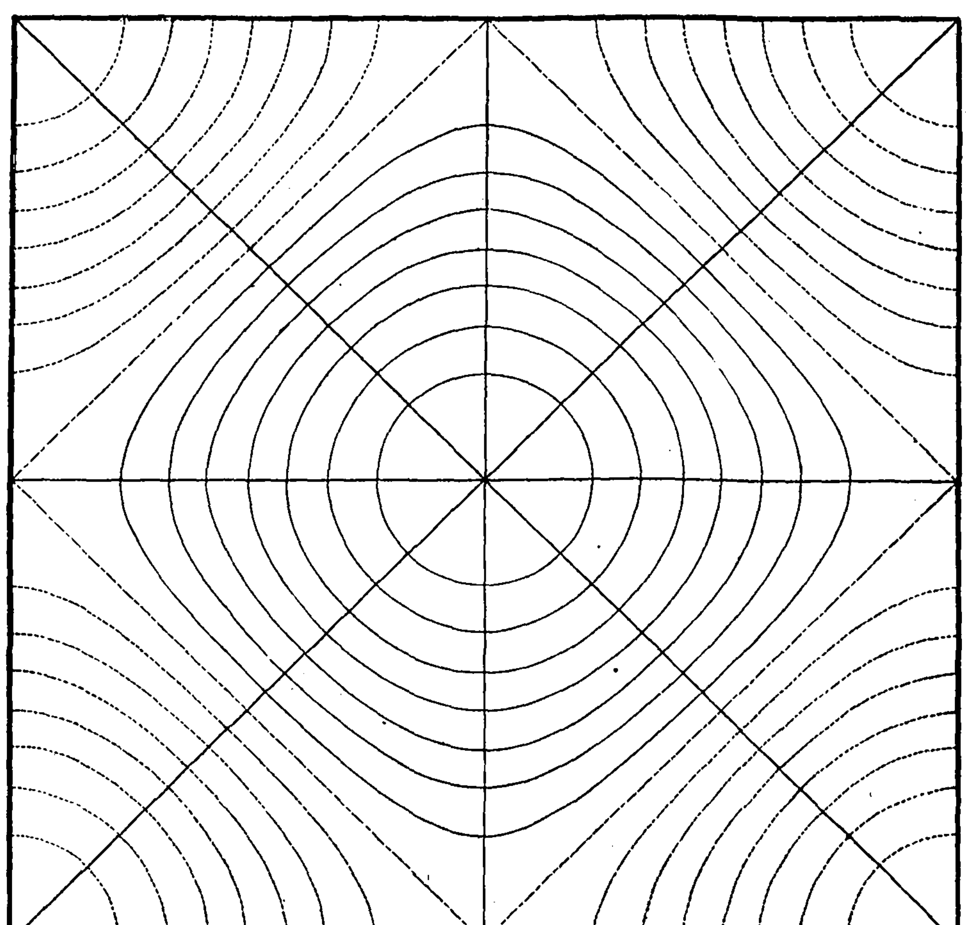


Fig. 8.

series parallel to the y-axis and whose lengths are proportional to $A' \sin \frac{\pi y}{h_1}$. These are proportional to the x- and y-displacements. The resultant displacement at a given point is the diagonal of a small rectangle and its direction coincides with that of the line of motion passing through the point.

If the initial phase of the time angle be different from zero in one of the terms, the particles will describe horizontal ellipses and the wave will no longer be stationary, but

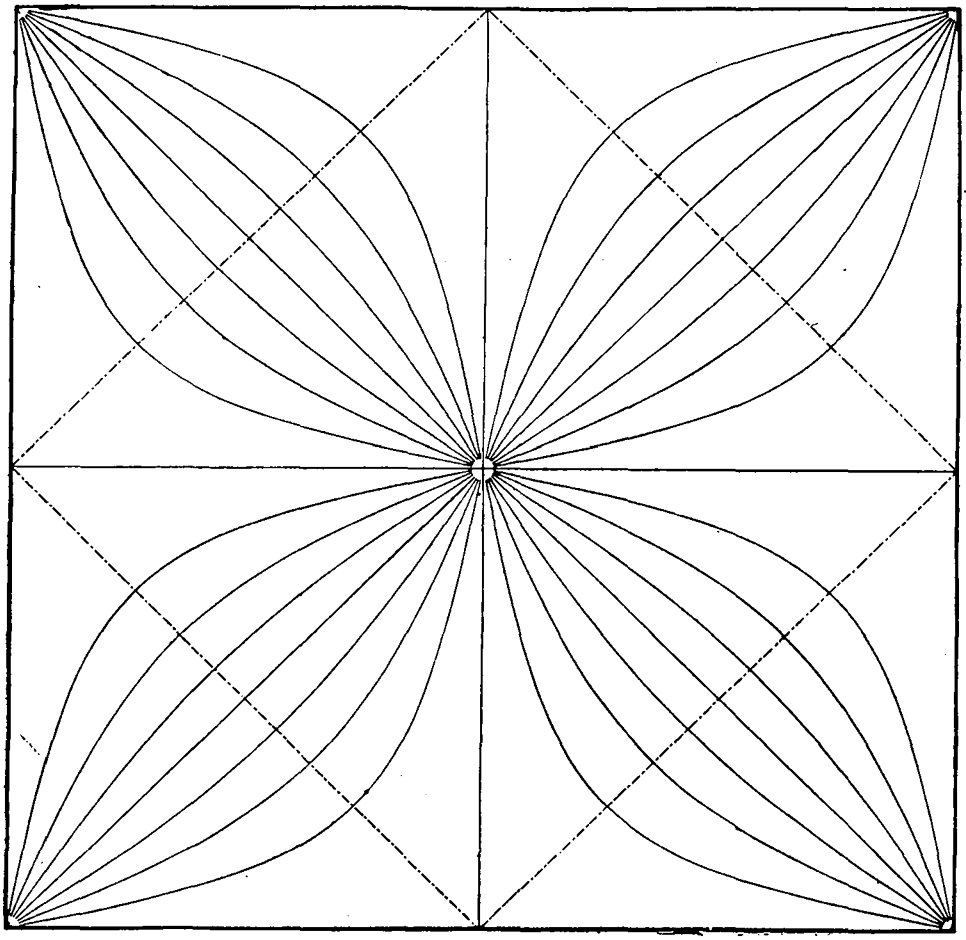
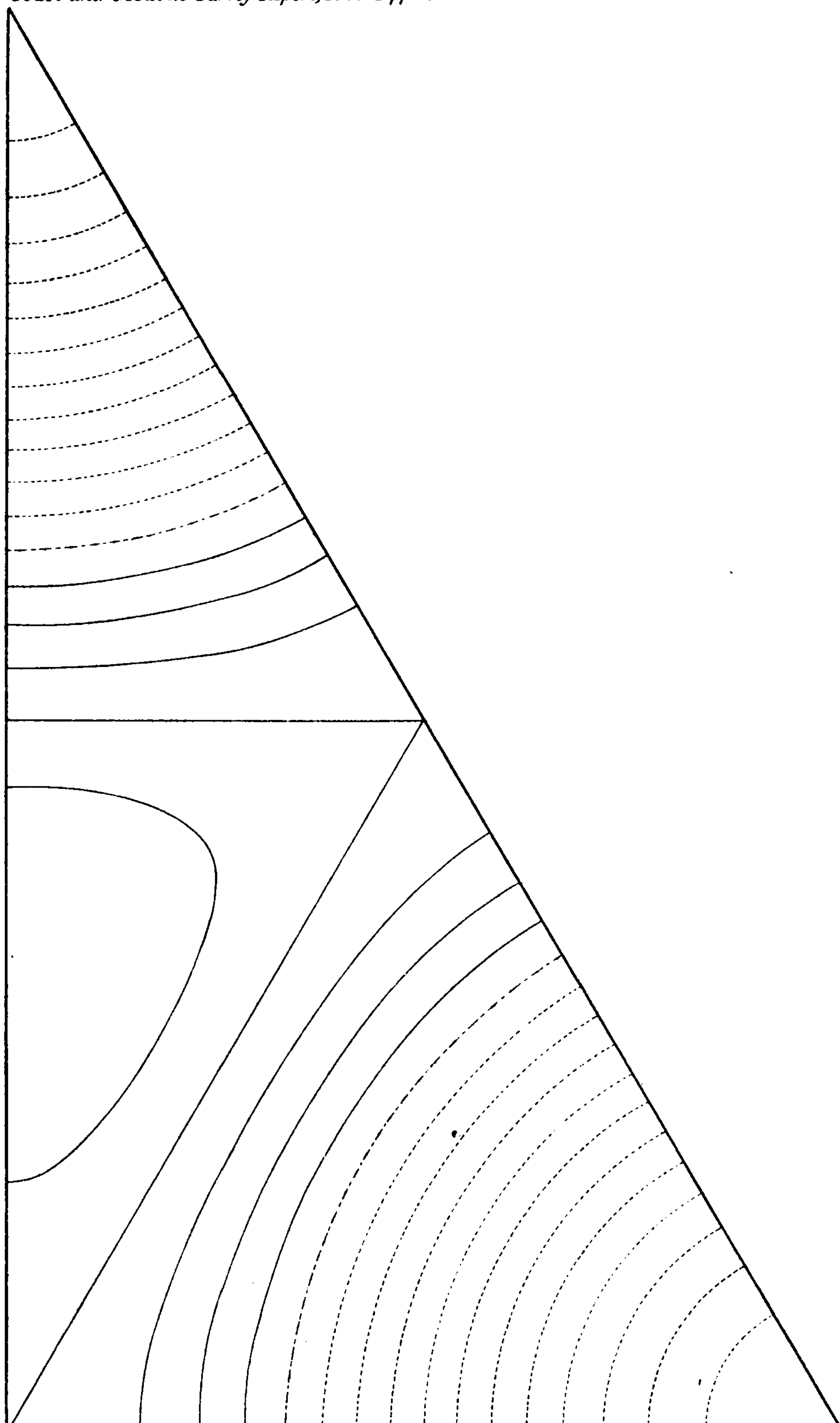


Fig. 9.

progressive around the center. Taking successive values of t and constructing an elementary rectangle for each case at any assumed point, a series of radiating arrows will be found which if reduced to the proper scale and placed end-to-end in the order of time will be the elliptical path described by the particle.

It is an easy matter to construct an apparatus which shall show the horizontal motion of the particles, the motion consisting of a simple harmonic oscillation in the



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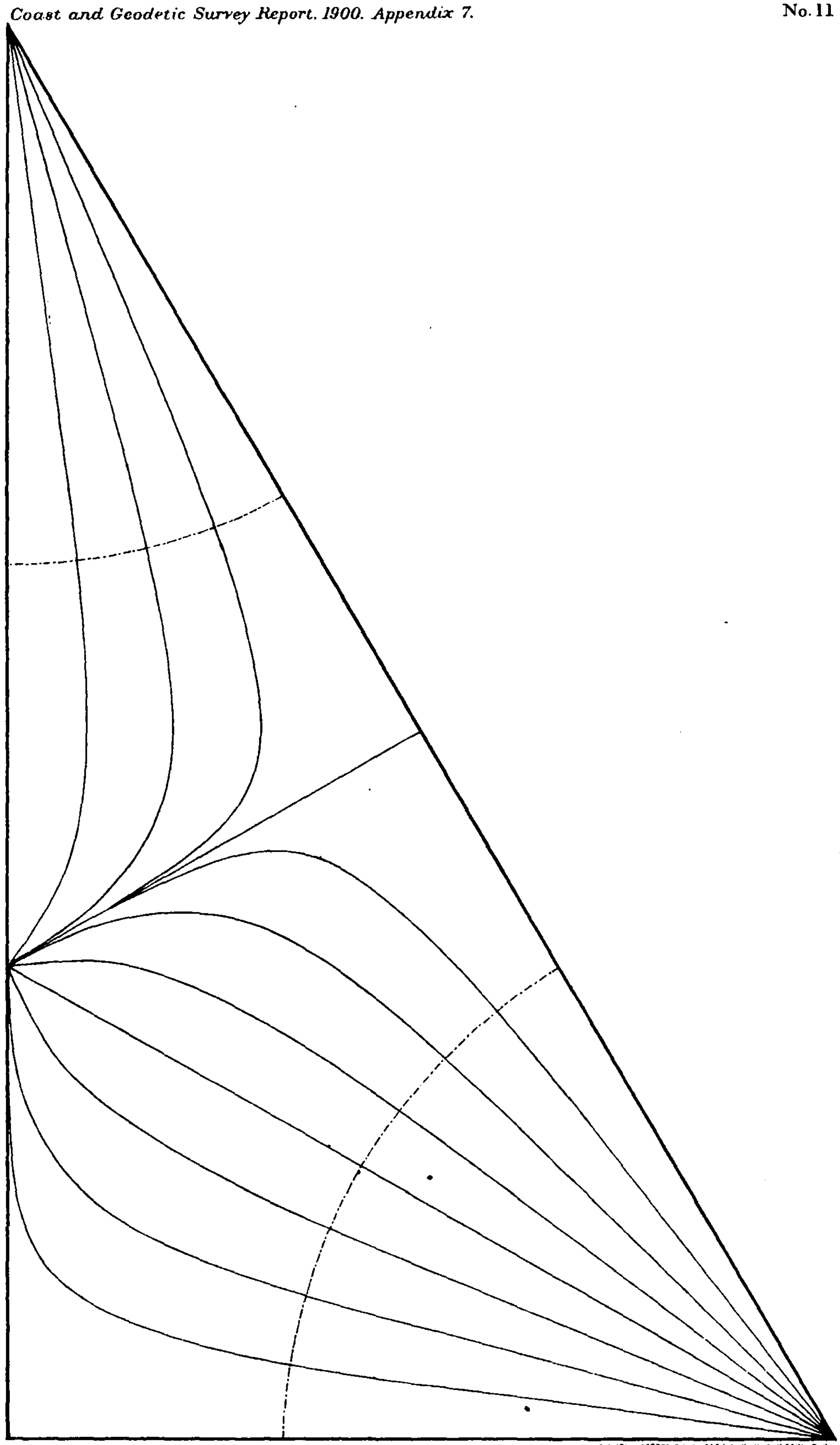

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x-direction and another in the y-direction. Imagine the square covered with narrow grooved slats each placed a short distance apart and running, say in the y-direction. Let these be connected by, or supported upon, elastic bands running transverse to them and terminating at the edge of the square. These bands are thickest at the center and gradually get thinner toward the edges; or short uniform bands might be used and their number might be made to so decrease as to bring about the same result. The law of the required thickness is given by (69), Part I. Now if a simple harmonic motion be imparted to the central slat, all others will have simple harmonic motion of like phase, but with amplitudes diminishing toward the sides of the square parallel to the slats. If the slats represent rows of water particles, their motion will truly represent the horizontal motion of an oscillation in the x-direction. Another set of grooved slats can be made to represent an oscillation in the y-direction.

The intersections of these two sets of grooves represent the horizontal motions of the water particles. The relative amplitude and phases of the two systems are taken at pleasure. The intersections may be marked either by pins, or by beams of light falling upon the apparatus.

The simple case of equal phases and amplitudes, that is where

$$\zeta = A \cos\frac{\pi\kappa t}{h_1}\cos\frac{\pi x}{h_1} + A\cos\frac{\pi\kappa t}{h_1}\cos\frac{\pi y}{h_1} \tag{174}$$

is illustrated in Figs. 8 and 9. The nodal lines consist of four right lines whose equations are

$$\frac{x}{h_1} \pm \frac{y}{h_1} = \pm 1. \tag{175}$$

The lines of motion, which are right lines, are

$$x = \pm h_1,\ y = \pm h_1,\ x = 0,\ y = 0,\ y = \pm x. \tag{176}$$

Thin rigid partitions may be erected along any of these last four lines, or along any part of their lengths, and the motion will remain as before.

27. *Triangular areas.*

Two modes of oscillation of a 45° triangle are shown in Fig. 8, one being seen in a half of one of the small squares, the other in a quarter of the large squares as divided by the lines $y = \pm x$. If we take these diagonals as the x- and y-axes, the foregoing values of ζ becomes

$$\zeta = 2A\cos\frac{\pi\kappa t}{h_1}\cos\frac{\pi x}{\sqrt{2}h_1}\cos\frac{\pi y}{\sqrt{2}h_1} \tag{177}$$

The oscillation of a 30° triangle, shown in Fig. 10, has for its equation

$$\zeta = 2A\cos\frac{\pi\kappa t}{h'}\cos\frac{\sqrt{3}\pi x}{2h'}\cos\frac{\pi y}{2h'} - A\cos\frac{\pi\kappa t}{h'}\cos\frac{\pi y}{h'}. \tag{178}$$

The relations

$$l^2 = m^2 + n^2 = m'^2 + n'^2$$

are evidently satisfied. So are the requirements

$$\frac{\partial\zeta}{\partial x} = 0 \text{ for } x = 0, \text{ and } \frac{\partial\zeta}{\partial y} = 0 \text{ for } y = 0.$$

That $\frac{\partial\zeta}{\partial\nu} = 0$* along the hypotenuse,

$$\frac{\sqrt{3}x}{2h'} + \frac{y}{2h'} = 1, \tag{179}$$

can be shown as follows:

$$\begin{aligned}\frac{\partial\zeta}{\partial\nu} &= \frac{\partial\zeta}{\partial x}\frac{dx}{d\nu} + \frac{\partial\zeta}{\partial y}\frac{dy}{d\nu} \\ &= \frac{\sqrt{3}}{2}\frac{\partial\zeta}{\partial x} + \frac{1}{2}\frac{\partial\zeta}{\partial y},\end{aligned} \tag{180}$$

the normal being supposed to increase outward.

$$\begin{aligned}\therefore \frac{\partial\zeta}{\partial\nu} = -A\frac{3\pi}{2h'}\sin\frac{\sqrt{3}\pi x}{2h'}\cos\frac{\pi y}{2h'} - A\frac{\pi}{2h'}\cos\frac{\sqrt{3}\pi x}{2h'}\sin\frac{\pi y}{2h'} \\ + A\frac{\pi}{2h'}\sin\frac{\pi y}{h'}\end{aligned} \tag{181}$$

where the time factor is omitted. This becomes zero if for x we substitute its value from (179). Here h' denotes the distance from the right angle to the hypotenuse.

Two such triangles having the short side in common form a triangle whose angles are 30°, 120°, and 30°. Two such triangles having the long side in common form an equilateral triangle. ζ has in each case the value (178).

If we put

$$\zeta = 2A\cos\frac{\pi\kappa t}{h'}\cos\frac{\sqrt{3}\pi x}{2h'}\cos\frac{\pi y}{2h'} + A\cos\frac{\pi\kappa t}{h'}\cos\frac{\pi y}{h'} \tag{182}$$

we obtain a mode of oscillation for a hexagon the center being the origin and the y-axis coinciding with one of its diagonals. Here h' denotes the length of the projection of the apothem upon an adjacent diagonal.

This expression represents an oscillation of any of the six equilateral triangles composing the hexagon; or of the twelve 30-degree triangles having their smallest angle at the center.

The nodal line

$$2\cos\frac{\sqrt{3}\,\pi x}{2h'}\cos\frac{\pi y}{2h'} + \cos\frac{\pi y}{h'} = 0 \tag{183}$$

is very nearly circular.

28. *Circular areas.*

In the simple harmonic oscillation already considered ζ has generally been of the form

$$\zeta = \cos l\kappa t\,[A\cos mx\cos ny + A'\cos m'\cos n'y + A''\cos m''x\cos n''y + \ldots] \tag{184}$$

where $l\kappa$ denotes the speed of the oscillation and is such that

$$l^2 = m^2 + n^2 = m'^2 + n'^2 = m''^2 + n''^2 = \ldots.$$

* $\partial\nu$ denoting an element of the normal has, of course, no connection with the preceding ν denoting an integer.

By properly choosing the arbitrary constants it seems reasonable to believe that an indefinite number of terms in the above ought to represent some of the modes of oscillation for a circle or almost any other area.

We have seen that for rectangular areas the ζ's are periodic in x and y. This ought to be the case, because for the parts of a common area made up of any number of like rectangles ζ resumes the same values at distances in the x- and y-directions equal to twice the respective lengths of the rectangles. In a circular area, ζ must either be free from the central angle θ or be a periodic function of it. Hence we must have for ζ one or more terms of the form

$$\zeta = f_s(r) \left.\begin{matrix}\cos \\ \sin\end{matrix}\right\} s\theta \cos l\kappa t \tag{185}$$

where $s = 0, 1, 2, \quad . \quad . \quad . \quad .$ If we denote this function $f(r)$ by $A_s J_s(lr)$, then l must be such that $\frac{\partial \zeta}{\partial r} = 0$ when $r = r_0$, the radius of the circle, and so such that $J'_s(lr_0) = 0$. Here and elsewhere

$$\text{speed} = \frac{\lambda}{\tau} \times \frac{2\pi}{\lambda} = l\frac{\lambda}{\tau} = l\kappa \tag{186}$$

If $s = 0$, ζ is independent of θ and so the motion has circular symmetry about the origin. The roots of $J'_0(lr_0) = 0$ are

$$lr_0 = 1{\cdot}2197\pi,\ 2{\cdot}2330\pi,\ 3{\cdot}2383\pi,\ \ldots \tag{187}$$

The virtual length of any sector is, therefore, $r_0/1{\cdot}2197 = 0{\cdot}820 r_0$, $2\,(r_0/2{\cdot}2330 = 0{\cdot}896 \times \frac{1}{2}r_0)$, $\quad . \quad . \quad . \quad .$ Corresponding to these values of l are a series of values of r or lr which reduce $J_0(lr)$, and so ζ, to zero; they are the radii of the nodal circles. Such values are

$$lr = 0{\cdot}7655\pi,\ 1{\cdot}7571\pi,\ 2{\cdot}7546\pi,\ \ldots$$
$$r = 0{\cdot}6276 r_0,\ 0{\cdot}7869 r_0,\ 0{\cdot}8519 r_0 \tag{188}$$

If $s = 1$, the motion no longer possesses circular symmetry, although it is symmetrical with respect to a certain diameter which coincides with a line of motion. l is determined by the equation

$$J_1'(lr_0) = 0 \tag{189}$$

This is satisfied by

$$lr_0 = 0{\cdot}586\pi,\ 1{\cdot}697\pi, \text{ and } 2{\cdot}717\pi. \tag{190}$$

The virtual length of a circular area is, therefore, $r_0/0{\cdot}586 = 0{\cdot}853 \times 2r_0$, $2\,(r_0/1{\cdot}697 = 0{\cdot}589 \times r_0)$, $\quad . \quad . \quad . \quad .$ For diagrams of this motion see Lamb, Hydrodynamics, pp. 308, 309.

By referring to (185) we see that if two oscillations of like period be superimposed, the result will be of the form

$$\zeta = A_s J_s(lr) \cos(l\kappa t \mp \theta s + \epsilon), \tag{191}$$

showing that the result is a wave traveling unchanged round the origin with an angular velocity $\frac{l\kappa}{s}$.

The foregoing are some of the most simple cases of oscillating areas, the boundaries being complete and the depth uniform. As will be shown in the chapter on experiments, a stationary wave can be readily formed between two parallel walls, one or both of the ends of the area thus defined being open. In other words, the oscillation of the entire body of water need not always be taken into account, as in cases like the preceding, but only such portions as lie between the two parallel walls and a little distance beyond their extremities. It is assumed that care has been taken to so place the walls in the body of water that the oscillation between them will not be interfered with from without.

29. *Definitions.*

As will be shown in Chapter VII, it is possible to divide the greater part of the ocean's surface into regions whose periods of free oscillation do not differ much from twelve lunar hours and in which it is possible for the tidal forces to incite a considerable tide. There are a few regions which have approximately twenty-four hours as one of their free periods.

By *oscillating area* we shall usually mean an area, comparatively simple in form, whose free period of oscillation, were its boundaries all rigid, would not differ much from twelve (or twenty-four) lunar hours.

All areas which oscillate together because of contiguity, form an *oscillating system.*

The division of the principal part of the ocean's surface into a few systems is not arbitrary. Whether or not we shall suppose these systems divided into more simple regions styled "areas" is a matter of expediency to be decided by the purpose in hand.

Generally areas partially inclosed by land resemble more or less an approximate rectangle, a right trapezoid, or a triangle. Areas having, or resembling, either of the first two forms, and sometimes even the third form, may be styled *simple* or *canal-like.*

A *fractional oscillating area* is an area having an oscillation, but which could not, because of its dimensions, oscillate in the required period were it completely surrounded by rigid walls.

The *axis* of a simple area is an imaginary central line drawn parallel to the sides.

A *nodal line* is a line within the area along which there is little or no rise and fall.

A *loop* is a portion of an area where the rise and fall is comparatively great.

In a rectangular area the distance between two nodal lines or loops is a *half-wave length*, and is denoted by $\frac{1}{2}\lambda$.

The *virtual length* of an area is the length of a rectangular area of the same depth and having the same free period; both areas are supposed to oscillate according to one of their simplest modes.

A boundary consisting of shore line may be spoken of as *rigid.* Such a boundary may be called *broken* if it is pierced by one or more considerable openings or consists of a chain of islands.

A boundary separating two areas that oscillate together, but along which there is generally a rise and fall, may be called *latent* or *imaginary.*

A boundary vaguely marking the outer limits of an area, and along which there is generally little rise and fall, may be styled *free.*

The movement belonging to an oscillating area or system may be spoken of either as an *oscillation* or as a *stationary wave.* The word "oscillation" is also used to denote the periodic movement; as, a certain body makes so many oscillations per minute.

Viewed from its assumed mode of oscillation, a simple area may be spoken of as a *half-wave area*, a *whole-wave area*, etc.

CHAPTER IV.

CONCERNING WAVES IN DEEP WATER, AND LONG WAVES WHERE THE DEPTH MAY VARY.

30. Let $\mathbf{x}$, $\mathbf{y}$, $\mathbf{z}$ denote the small displacements of a particle from its mean position x, y, z; then, as in § 17, Part I, it is easily shown that the equation of continuity for a three-dimensional element becomes

$$\left(1+\frac{\partial \mathbf{x}}{\partial x}\right)\left(1+\frac{\partial \mathbf{y}}{\partial y}\right)\left(1+\frac{\partial \mathbf{z}}{\partial z}\right)=1 \tag{192}$$

or, less accurately,

$$\frac{\partial \mathbf{x}}{\partial x}+\frac{\partial \mathbf{y}}{\partial y}+\frac{\partial \mathbf{z}}{\partial z}=0. \tag{193}$$

The dynamical equations for unit mass are

$$\frac{\partial^2 \mathbf{x}}{\partial t^2}=X+\frac{\partial}{\partial x}\left\{-g\zeta-\int_{z=z}^{z=h}\frac{\partial^2 \mathbf{z}}{\partial t^2}\,dz\right\}, \tag{194}$$

$$\frac{\partial^2 \mathbf{y}}{\partial t^2}=Y+\frac{\partial}{\partial y}\left\{-g\zeta-\int_{z=z}^{z=h}\frac{\partial^2 \mathbf{z}}{\partial t^2}\,dz\right\}, \tag{195}$$

where ζ denotes the surface value of $\mathbf{z}$.

In analogy to equations (26) (27), Part I, we write, for free waves, that is, waves where X and Y are zero,

$$\mathbf{x}=A\cosh lz\sin(at-lx+\alpha), \tag{196}$$

$$\mathbf{y}=B\cosh mz\sin(bt-my+\beta), \tag{197}$$

$$\mathbf{z}=A\sinh lz\cos(at-lx+\alpha)+B\sinh mz\cos(bt-mz+\beta). \tag{198}$$

These satisfy the equation of continuity, also the dynamical equations provided

$$a^2=gl\tanh lh, \tag{199}$$

$$b^2=gm\tanh mh. \tag{200}$$

These equations denote two series of waves, one propagated toward $+x$, the other toward $+y$, the depth being uniform.

31. *On two-dimensional standing waves.*

Writing z, $\mathbf{z}$ for y, $\mathbf{y}$, equations (26),(27), (57), (58), Part I, become

$$\mathbf{x} = A \cosh lz \sin (at - lx + \alpha), \tag{201}$$

$$\mathbf{z} = A \sinh lz \cos (at - lx + \alpha), \tag{202}$$

where

$$a^2 = gl \tanh lh,$$

$$\mathbf{x} + \mathbf{x}_r = -2A \cosh lz \sin [l(x - L)] \cos (at + \alpha - lL), \tag{203}$$

$$\mathbf{z} + \mathbf{z}_r = 2A \sinh lz \cos [l(x - L)] \cos (at + \alpha - lL). \tag{204}$$

Since the first pair of equations satisfy the equation of continuity and the dynamical equation, so do the second pair. Replacing $\mathbf{x} + \mathbf{x}_r$, $\mathbf{z} + \mathbf{z}_r$ by single letters $\mathbf{x}$ and $\mathbf{z}$, we note that the second pair of equations are suitable for expressing a plane standing wave in water of uniform depth in a rectangular tank, whose length is a multiple of a

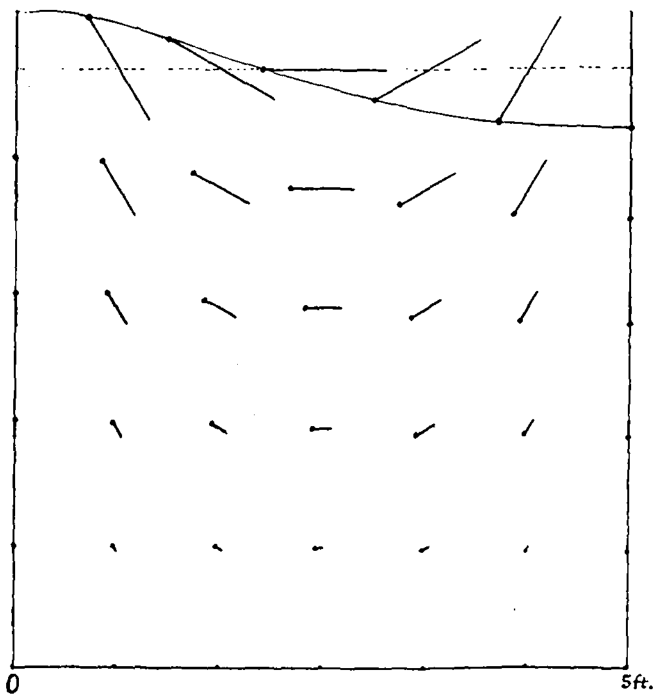

Fig. 12.

half-wave length, i. e., of $\frac{1}{2}\lambda$. For if lL is equal to $\pm$ an odd multiple of 90°, the horizontal displacement will become zero as x becomes equal to any odd multiple of $\pm 90° / l$. Here the space origin is at a nodal point of the bottom of the canal. If the origin be taken at the end whose x-coördinate is $-L$, the equations (203), (204) become

$$\mathbf{x} = 2A \cosh lz \sin lx \cos (at + \alpha - lL), \tag{205}$$

$$\mathbf{z} = -2A \sinh lz \cos lx \cos (at + \alpha - lL). \tag{206}$$

At any particular time, writing $A_{,}$ for $2A\cos(at+\alpha-lL)$, (207)

$$\mathbf{x}=A_{,}\cosh lz\sin lx, \tag{208}$$

$$\mathbf{z}=-A_{,}\sinh lz\cos lx, \tag{209}$$

and so

$$\mathbf{x}+i\mathbf{z}=A_{,}\sin l(x-iz). \tag{210}$$

From equations (205), (206) it is seen that the motion of each particle is rectilinear and simple harmonic. The tangent of the angle of inclination to the horizon is $\frac{\mathbf{z}}{\mathbf{x}}=-\tanh lz$ $\cot lx$. The paths are vertical where $lx=0$ or multiples of 180° and horizontal at points halfway between. See Fig. 12.

Since, to quantities of the second order,

$$\frac{\partial\mathbf{x}}{\partial t}=-\frac{\partial\varphi}{\partial x},\ \frac{\partial\mathbf{z}}{\partial t}=-\frac{\partial\varphi}{\partial z}; \tag{211}$$

and since the lines of motion ($\psi=$ constant), must cut the equipotential lines ($\varphi=$ constant) orthogonally,

$$\frac{\partial\varphi}{\partial x}\frac{\partial\psi}{\partial x}+\frac{\partial\varphi}{\partial z}\frac{\partial\psi}{\partial z}=0. \tag{212}$$

This will be satisfied if

$$\frac{\partial\varphi}{\partial x}=\frac{\partial\psi}{\partial z},\ \frac{\partial\varphi}{\partial z}=-\frac{\partial\psi}{\partial x}. \tag{213}$$

Hence

$$\varphi=\frac{g}{a}\,2\,A\tanh lh\cosh lz\cos lx\sin(at+\alpha-lL), \tag{214}$$

$$\psi=\frac{g}{a}\,2\,A\tanh lh\sinh lz\sin lx\sin(at+\alpha-lL); \tag{215}$$

or, at any particular time, writing $A_{,,}$ for $\frac{g}{a}\tanh lx\sin(at+\alpha-lL)$,

$$\varphi=-A_{,,}\cosh lz\cos lx \tag{216}$$

$$\psi=\quad A_{,,}\sinh lz\sin lx, \tag{217}$$

which equations may be written

$$\varphi+i\psi=-A_{,,}\cos l(x+iz). \tag{218}$$

Forced oscillation.—Suppose that we assume expressions for the displacements which satisfy the boundary condition imposed by the length of a tank where $2L=$ length $=\frac{\pi}{l}$, but whose period $\left(\frac{2\pi}{a'}\right)$ differs from the free period of the tank $\left(\frac{2\pi}{a}\right)$. Such expressions are

$$\mathbf{x}=\quad 2\,A\cosh lz\sin lx\cos(a't+\alpha-lL) \tag{219}$$

$$\mathbf{z} = -2A \sinh lz \cos lx \cos(a't + \alpha - lL). \tag{220}$$

The equation of continuity is satisfied.

By hypothesis, a'^2 does not equal $gl \tanh lh$; but $a'^2 = gl' \tanh l'h$, say, where l' differs from l. Hence the dynamical equation, where X is put equal to zero, is no longer satisfied. If, however, we make

$$X = 2A(a^2 - a'^2) \cosh lh \sin lx \cos(a't + \alpha - lL), \tag{221}$$

the dynamical equation will be satisfied wherein $a^2 = gl \tanh lh$. This shows that the oscillation is a forced one maintained by an external periodic force. The nearer a' approaches a the smaller may be the force X. If $a > a'$ the phase of the horizontal component of the oscillation is the same as the phase of the force X; if $a' > a$ the phases differ by 180°.

32. *On three-dimensional standing waves.*

Likewise we have for the diplacements when the motion is no longer confined to a vertical plane

$$\mathbf{x} = 2A \cosh lz \sin lx \cos(at + \alpha - lL), \tag{222}$$

$$\mathbf{y} = 2B \cosh mz \sin my \cos(bt + \beta - mM), \tag{223}$$

$$\begin{aligned}\mathbf{z} = &-2A \sinh lz \cos lx \cos(at + \alpha - lL)\\ &-2B \sinh mz \cos my \cos(bt + \beta - mM).\end{aligned} \tag{224}$$

These satisfy the equation of continuity, and the dynamical equations provided the relations (199) (200) obtain. They satisfy the boundary conditions of a rectangular tank whose sides are $2L\left(=\frac{\pi}{l}\right)$, $2M\left(=\frac{\pi}{m}\right)$ in length. For, $\mathbf{x}$ becomes zero if $x = 0$, or multiples of $2L$; and $\mathbf{y}$ becomes zero if $y = 0$, or multiples of $2M$.

Now let $b = a$, and so $m = l$; also let $M = L$, and write A', α', in the place of B, β. For simplicity suppose the time origin so taken that $\alpha - lL = 0$; then

$$\cos at = \frac{\mathbf{x}}{2A \cosh lz \sin lx},$$

which substituted in the expression for $\mathbf{y}$ gives

$$\mathbf{y}^2 - 2\mathbf{xy}\frac{A' \sin ly}{A \sin lx}\cos(\alpha' - lL) + \mathbf{x}^2\frac{A'^2 \sin^2 ly}{A^2 \sin^2 lx} = [2A' \cosh lz \sin ly \sin(\alpha' - lL)]^2. \tag{225}$$

This being the equation of an ellipse shows that the path of any liquid particle whose undisturbed position is x, y lies in the surface of a vertical cylinder whose trace upon a horizontal plane is in general elliptical. The cylinders become circular for points lying upon the vertical surface whose equation is $A \sin lx = \pm A' \sin ly$ provided $\alpha' \sim \alpha = 90°$.

If $\alpha' = \alpha$, the cylinder becomes a vertical plane, and we have

$$\frac{\mathbf{x}}{\mathbf{y}} = \frac{A \sin lx}{A' \sin ly}; \tag{226}$$

which shows that the path of any particle whose undisturbed position is x, y then lies in a vertical plane of which this is the equation. Again

$$\frac{\mathbf{x}+\mathbf{y}}{\mathbf{z}} = -\frac{A \cosh lz \sin lx + A' \cosh lz \sin ly}{A \sinh lz \cos lx + A' \sinh lz \cos ly}. \tag{227}$$

This is also the equation of a plane; consequently the path of the particle is a straight line, provided the two component horizontal displacements have the same or opposite initial phases.

33. *Standing waves derived from oscillations.*

From any solution of

$$\frac{\partial^2}{\partial(\kappa t)^2} = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \tag{228}$$

one for

$$\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} = 0 \tag{229}$$

can be obtained by replacing the κt by $\sqrt{-1}$ times x, y, or z and the x, y by the remaining two letters.

In the preceding chapter we have made use of the solution of (228)

$$\cos(l\kappa t + \mathrm{i}mx + \mathrm{j}ny). \tag{230}$$

Here we use the solution of (229)

$$\cosh(lz + imx + jny), \tag{231}$$

where $i, j = \sqrt{-1}$. Since t is now treated as a constant, it follows that

$$\varphi, = A \cosh lz \cos mx \cos ny + A' \cosh l'z \cos m'x \cos n'y + \ldots, \tag{232}$$

where each term may be multiplied by any time factor, is a solution, provided

$$l^2 = m^2 + n^2,\ l'^2 = n'^2 + n'^2, \ \ldots .$$

If the solution is to be simply harmonic in time, this factor must be some such function as $\cos at$. Now, this will be of the same general form as the ζ of the preceding chapter times $\cosh lz$ if we make $l' = l$, $l'' = l$, ...

At the free surface the pressure is uniform, and so for sufficiently small motions we may write (100) in the form*

$$\zeta = \frac{1}{g}\left[\frac{\partial\varphi}{\partial t}\right]_{z=h+\zeta} \tag{233}$$

or, approximately,

$$\zeta = \frac{1}{g}\left[\frac{\partial\varphi}{\partial t}\right]_{z=h} \tag{234}$$

Assuming the slope of the wave surface to be small, we have

$$\frac{\partial\zeta}{\partial t} = -\left[\frac{\partial\varphi}{\partial z}\right]_{z=h} \tag{235}$$

*See Lamb, Hydrodynamics, p. 371; Treatise on Fluid Motion, p. 187.

Eliminating ζ, we have

$$\frac{\partial^2\varphi}{\partial t^2} + g\frac{\partial\varphi}{\partial z} = 0 \tag{236}$$

where $z = h$. This condition becomes, for simple harmonic motion,

$$a^2\varphi = g\frac{\partial\varphi}{\partial z}; \tag{237}$$

$$\therefore\ a^2 = gl \tanh lh \tag{238}$$

for any simple-harmonic solution such that $\cosh lz$ is a factor. Such a solution of (229) can be obtained from any solution of (228) having $\cos l\kappa t$ as a factor, by the above-named substitution.

For instance, from the value of ζ for oscillations or long stationary waves in a circular area,

$$\zeta = f_s(r) \left.\begin{matrix}\cos\\ \sin\end{matrix}\right\} s\theta \cos l\kappa t, \tag{239}$$

we have

$$\varphi = \cosh lz\, f_s(r) \left.\begin{matrix}\cos\\ \sin\end{matrix}\right\} s\,\theta \cos at, \tag{240}$$

where

$$a^2 = gl \tanh lh.$$

In all cases of vertical walls as boundaries, the normal differentiation will be concerned only with x and y. Consequently the same xy-function used in the preceding chapter in expressions for ζ can be transferred to the φ of the same problem in water not shallow.

Given a tank of any shape having a horizontal bottom and vertical sides. Take a rectangular tank having the same depth of water and the same period of oscillation. The water in the two tanks will continue to oscillate together however the depths be altered, provided the (uniform) depth of water in the one be kept equal to the (uniform) depth in the other. See Table 52.

When the depth is not uniform, the problem of determining the free oscillations or standing waves in limited bodies of water is very difficult. It has been solved in but few instances. The reader is referred to Lamb, Hydrodynamics, p. 426.

34. *A canal closed at one end and having a critical length.*

In § 29, Part I, it was noted that a canal closed at one end and communicating with a sea whose tide is

$$\mathbf{z} = A \sinh lz \cosh (at - lx + \alpha) \tag{241}$$

has for its horizontal and vertical displacements

$$\mathbf{x} = \frac{A \cosh lz}{\cos lL} \sin [l(L - x)] \cos (at + \alpha), \tag{242}$$

$$\mathbf{z} = \frac{A \sinh lz}{\cos lL} \cos [l(L - x)] \cos (at + \alpha). \tag{243}$$

In most cases we are to suppose that the canal which communicates with the tided body of water is too small to have its motion much affect the character of the motion in the latter body. For canals a small fraction of λ in length, and for those whose length is $\frac{1}{2}\lambda$, or very nearly $\frac{1}{2}\lambda$, or some multiple of $\frac{1}{2}\lambda$, the horizontal motion at the mouth is comparatively small, and so no restrictions as to the relative size of the two bodies are necessary. On the other hand, the restriction becomes very important if the length of the canal is about $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, etc. To see this more clearly, imagine a rectangular sheet of water $\frac{1}{2}\lambda$ in length and of indefinite width. It will oscillate freely in a certain period τ. Now add a little to its length. It will still oscillate as before, except that its period will be lengthened somewhat. If we double or treble the original length (i. e., add $\frac{1}{2}\lambda$, λ, etc., to it), the original area will oscillate as before any such addition was made. If to the original length, $\frac{1}{2}\lambda$, we add $\frac{1}{4}\lambda$, the oscillation in or about in the original period will be completely destroyed. If the added area or canal $\frac{1}{4}\lambda$ in length were sufficiently small (i. e., shallow or narrow), the oscillation in the original area would not be destroyed, but it would be disturbed at and near the mouth of the canal. When $L = \frac{1}{4}\lambda$, or $lL = 90°$, $\mathbf{x}$ generally becomes large, especially at the mouth, where $x = 0$. $\mathbf{z}$ then generally becomes large, excepting near the mouth. At the mouth the magnitude and sign of the amplitude are indeterminate. For any length not too near a critical length, the profile of the stationary wave at any instant is a sine or cosine curve. Now, assume that as the critical length is approached, the nature of the profile is not seriously altered. Since the rise and fall realized in natural or artificial bodies is quite limited, even at the head of the canal, it follows that at the mouth the rise and fall must be almost zero. This being so, the horizontal, and not the vertical, displacement determines the phase of the oscillation of the canal relative to that of the oscillation outside. Suppose a tidal wave to be moving shoreward as if over a shoal at a rate due to depth. Its equations will be

$$\mathbf{x} = A \cosh lz \sin (at - lx + \alpha), \tag{244}$$

$$\mathbf{z} = A \sinh lz \cos (at - lx + \alpha). \tag{245}$$

Suppose that there is a rather shallow bay $\frac{1}{4}\lambda$ in length terminating i · water (generally shallow) where there is a propagation of the free wave. Let this mouth of the bay be taken as the origin of coördinates and the positive direction of x be toward the land. The requirements are, besides the dynamical equation and equation of continuity:

First, where $x = 0$,

$$\mathbf{x} = kA \cosh lz \sin (at + \alpha)$$

because we assume that the horizontal motion at the mouth is alike in both bodies of water, excepting that the oscillation is reinforced so that the displacement is k times as great in the small body. The amount of rise and fall at the mouth does not enter into these conditions.

Second, where $x = L$,

$$\mathbf{x} = 0;$$

for at the head of the bay no horizontal motion can take place.

If we write

$$\mathbf{x} = k \frac{A \cosh lz}{\sin lL} \sin [l(L - x)] \cos (at + \alpha - 90°), \tag{246}$$

$$\mathbf{z} = k\frac{A \sinh lz}{\sin lL} \cos [l(L - x)] \cos (at + \alpha - 90^\circ), \tag{247}$$

all of these conditions are fulfilled. From these we see that the phase of the rise and fall within the bay is 90°, or $\frac{1}{4}$ τ, behind the phase of the rise and fall just outside of the mouth.

At the mouth

$$\mathbf{z} = kA \sinh lz \cot lL \cos (at + \alpha - 90^\circ), \doteq 0, \tag{248}$$

as $lL \doteq 90^\circ$; and at the head

$$\mathbf{z} = kA \sinh lz \cos (at + \alpha - 90^\circ). \tag{249}$$

As pointed out in § 27, Part I, high water corresponds to a condensation in a sound wave, and low water to a rarefaction. If now a jar or resonator $\frac{1}{4}$ λ deep be held with its open end toward a source of sound, but not very near to it, the phase of the condensation within the jar will be $\frac{1}{4}$ τ behind the phase of the condensation around the mouth of the jar. The horizontal displacements of the particles at the mouth may be many times that in the progressive wave at the same distance from the source of sound. This will depend upon the degree of perfection of the jar for the purpose in hand.

35. *A uniform canal connecting two bodies of water.*

In order to treat this question as one of wave motion, we shall assume that the maximum horizontal displacement of any one of the particles is small in comparison with the length of the canal. In other words, we are to assume that in any expression it is immaterial whether we suppose the coördinates of a point to pertain to its mean or to its true position. In order to ascertain whether or not this is the case, we find expressions for the x-displacements satisfying the vertical displacements at the ends, as well as the equations of continuity and equal pressure. The value of any horizontal displacement as thus computed can then be compared with the length of the canal. Probably this ratio should not exceed $\frac{1}{8}$, or $\frac{1}{4}$ at most.

If the vertical displacements at the two ends be

$$\mathbf{z}_{,} = A_{,} \sinh lz \cos (at + \alpha_{,}), \ \mathbf{z}_{,,} = A_{,,} \sinh lz \cos (at + \alpha_{,,}), \tag{550}$$

then

$$\mathbf{x} = -\frac{A_{,} \cosh lz}{\sin lL} \cos l\,(L - x) \cos (at + \alpha_{,}) + \frac{A_{,,} \cosh lz}{\sin lL} \cos lx \cos (at + \alpha_{,,}) \tag{251}$$

$$\mathbf{z} = \frac{A_{,} \sinh lz}{\sin lL} \sin l\,(L - x) \cos (at + \alpha_{,}) + \frac{A_{,,} \sin lz}{\sin lL} \sin lx \cos (at + \alpha_{,,}) \tag{252}$$

satisfy all the required conditions.

For the time of high or low water at any point of the canal, we have from $\frac{\partial \mathbf{z}}{\partial t} = 0$

$$\tan at' = -\frac{A_{,} \sin l\,(L - x) \sin \alpha_{,} + A_{,,} \sin lx \sin \alpha_{,,}}{A_{,} \sin l\,(L - x) \cos \alpha_{,} + A_{,,} \sin lx \cos \alpha_{,,}}. \tag{253}$$

$$\frac{dt}{dn} = \frac{l}{a} \frac{A_{,} A_{,,} \sin lL \sin (\alpha_{,} - \alpha_{,,})}{A^2_{,} \sin^2 l\,(L - x) + A^2_{,,} \sin^2 lx + 2\,A_{,} A_{,,} \sin l\,(L - x) \sin lx \cos (\alpha_{,} - \alpha_{,,})}; \tag{254}$$

this is the velocity of propagation of the wave along the canal. If $0 < x < L$, this expression can not change; that is, the velocity is always either positive or negative throughout the canal according as $\alpha_{,} - \alpha_{,,}$ lies between 0 and 180° or 180° and 360°.

If the tide of the canal end of the inner body owes its existence to the wave propagated through from the outer, then if the canal is not too long, the initial phase $\alpha_{,}$ is greater than the initial phase $\alpha_{,,}$. In other words, $\alpha_{,}-\alpha_{,,}$ is a rather small positive angle. A small angle $\alpha_{,}-\alpha_{,,}$ causes the velocity of propagation to be positive.

The above expression for $\mathbf{z}$ gives for the amplitude of the tide

$$\frac{\sinh lz}{\sin lL}\left\{ A^2_{,} \sin^2 l(L-x) + A^2_{,,} \sin^2 lx + 2\, A_{,} A_{,,} \sin l(L-x) \sin lx \cos(\alpha_{,}-\alpha_{,,}) \right\}^{\frac{1}{2}}, \tag{255}$$

a result evident from (5), Part I.

When $\mathbf{z}=0$, the particles have their mean position. The time when this occurs is, obviously, given by the equation

$$\tan at'' = \frac{A_{,} \cos l(L-x) \cos \alpha_{,} - A_{,,} \cos lx \cos \alpha_{,,}}{A_{,} \cos l(L-x) \sin \alpha_{,} - A_{,,} \cos lx \sin \alpha_{,,}}. \tag{256}$$

The amplitude of the horizontal displacement is

$$\frac{\cosh lz}{\sin lL}\left\{ A^2_{,} \cos^2 l(L-x) + A^2_{,,} \cos^2 lx - 2\, A_{,} A_{,,} \cos l(L-x) \cos lx \cos(\alpha_{,}-\alpha_{,,}) \right\}^{\frac{1}{2}}. \tag{257}$$

If one of the seas have no tide, say if $A_{,,}=0$, then

$$\tan at' = -\tan \alpha_{,}$$

or

$$at' = -\alpha_{,} \tag{258}$$

neglecting multiples of π. But $t=-\alpha_{,}/a$ renders $\cos(at+\alpha_{,})$ a maximum; and so it is high water throughout the canal at the time of high water at the mouth where tide occurs. The amplitude reduces to

$$\frac{A_{,} \sinh lz}{\sin lL} \sin l(L-x). \tag{259}$$

For the time when $\mathbf{x}=0$, we have

$$\tan at'' = \cot \alpha_{,}$$

or

$$at'' = 90^\circ - \alpha_{,}$$

neglecting multiples of π. The amplitude of the horizontal displacement, $\mathbf{x}$, is

$$\frac{A_{,} \cosh lz}{\sin lL} \cos l(L-x). \tag{260}$$

This displacement, and so the velocity, is greatest where $x=L$, i. e. where the canal joins the tideless sea.

Referring to the expression for $\mathbf{x}$ we note that, $A_{,,}$ being zero, the particles are at their elongation toward $-x$ at the time of high water outside.

The above results are given in Airy's Tides and Waves, Arts. 311–314. For some applications to nature see §§ 102, 103, 113 beyond. To most straits this theory is but partially applicable if, indeed, at all. The reason for this is the fact that for some distance out from one or both ends of the strait, the shoaling causes a considerable horizontal motion to the wave propagated from deep water. This may interfere with the motion in the strait defined by the vertical movements at the two ends. In order to have this theory apply well, the two external bodies should be deep up to the ends of the strait. The particles oscillating to and fro near either end of the strait can then have their theoretical motion, because this is the only motion then involved, and so the external waters offer no opposition.

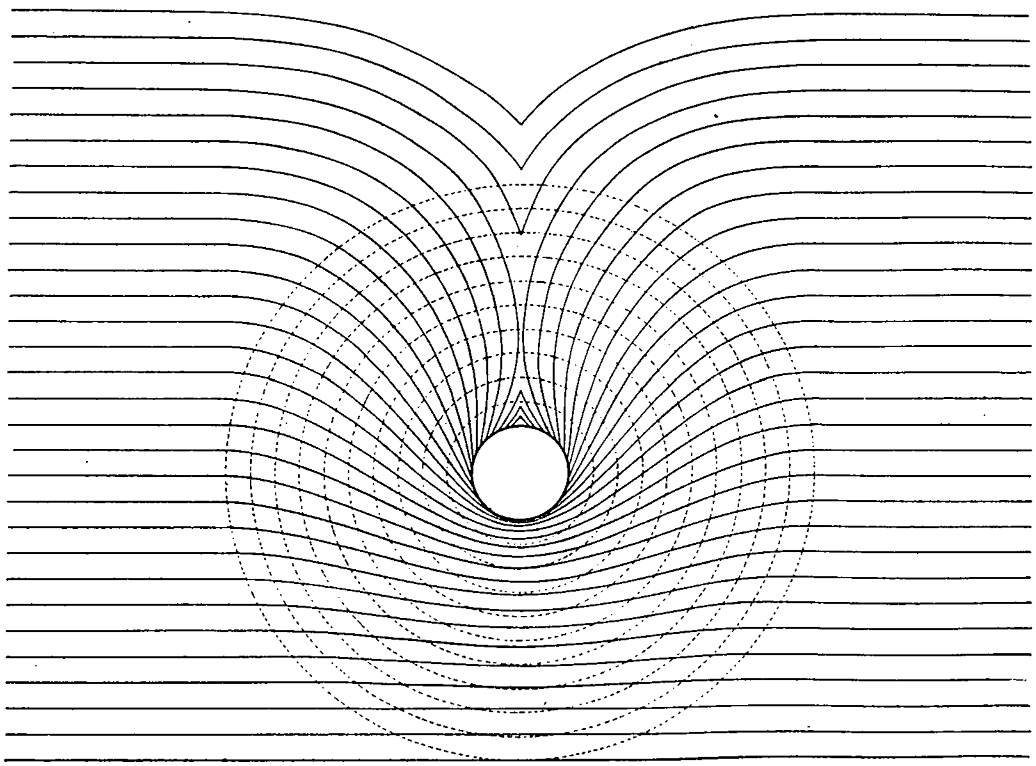

Fig. 13.

36. *Construction of cotidal lines on the assumption that the crest of the wave advances at the rate due to depth.*

Suppose we have a map upon which are shown the contours of equal depth. Take a slender triangular or wedge-shaped piece of paper whose width at each point represents, according to the scale of the map, the distance passed over by a free wave in, say, 0·1 or 0·2 of an hour for some definite depth. Let various depths in even tens and hundreds of feet or fathoms be written across the wedge-shaped piece at proper distances from the vertex. Assuming that the crest of the wave at a given instant extends along a given or arbitrary line, its positions at subsequent intervals of 0·1 or 0·2 of an hour are readily laid down by means of the scale just described.

Fig. 13 shows the effect of a circular island upon the cotidal lines. The diameter of the island is supposed to be 40 nautical miles; from its coast the sea bottom is supposed to slope uniformly for a distance of 100 miles to the depth of 1 000 feet. The broken lines represent 100-foot contours; the constant time interval is one-tenth of an hour.

Fig. 14 represents the progress of a wave up a broad depression or valley 40 miles wide at the bottom and 240 at the top, the depth at the center being 1 000 feet.

Had the valley been only a few miles in width, the rate of propagation at any point would have been $\sqrt{gh'}$ where h' is the average depth at the cross section, it being assumed that the area of the cross section, wherever taken, is constant, and that its form changes but slowly from point to point.

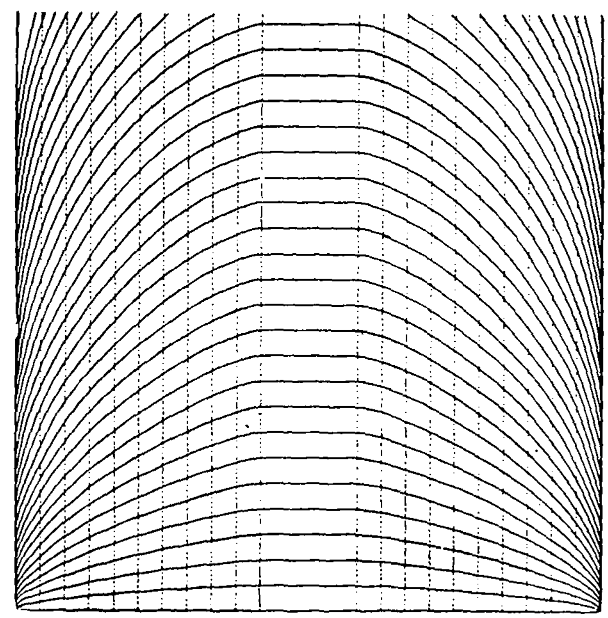

Fig. 14.

For, the vertical and transverse accelerations being negligible, the dynamical equation [(23), Part I, or (92), Part IV]

$$\frac{\partial^2 \xi}{\partial t^2} = -g\frac{\partial \zeta}{\partial x} \tag{261}$$

still remains true, and the equation of continuity

$$\zeta = -h'\frac{\partial \xi}{\partial x} \tag{262}$$

is readily derived upon considering a displacement of a small volume and such that all particles once in the same cross section always remain in it [c f. (21), Part I]. This rule applies to most tidal rivers where reflecting ends, or narrows, or great irregularities in shore line and depth, do not occur.

37. *A wave moves over a uniformly sloping bottom; required, the average velocity of advance.*

Let the slope be denoted by h_o/L; then the depth is

$$h = \frac{h_o}{L}(L - x). \tag{263}$$

The general formula for the velocity at any point is

$$v = \sqrt{gh}.$$

The average velocity is $\sqrt{g} \times$ average value of $\sqrt{h}$, or

$$\sqrt{g}\frac{h_o^{\frac{1}{2}}}{L^{\frac{1}{2}}x'}\int_{x=o}^{x=x'}(L-x)^{\frac{1}{2}} = \tfrac{2}{3}\frac{\sqrt{gh}}{L^{\frac{1}{2}}x'}\left[L^{\frac{3}{2}} - (L-x')^{\frac{3}{2}}\right]$$

$$= \sqrt{gh_o}\left(1 - \tfrac{1}{4}\frac{x'}{L} - \frac{1}{24}\frac{x'^2}{L^2} - \frac{1}{64}\frac{x'^3}{L^3} - \frac{1}{128}\frac{x'^4}{L^4} - \cdots\right), \tag{264}$$

$$= \tfrac{2}{3}\sqrt{gh_o} \tag{265}$$

when $x = L$. Thus it is seen that a long wave requires 1.5 times as much time for traveling to the shore over a bottom uniformly sloping to no depth as it would for traveling over the same distance with a depth constantly equal to that where the shoaling or time of reckoning began. Compare 1·5 with 1·306 of the next section.

Of course the results of this section and the preceding one do not accurately apply to the tide wave, but rather to such a disturbance as an earthquake sea wave. We must not suppose that Figs. 13 and 14 represent cotidal lines which would in all respects harmonize with the theory of wave motion. For in this section, and in the construction of Figs. 13 and 14, no attention was paid to the possibility of such motion.

38. *Long waves or oscillations in canals of variable widths and depths.*

The equation of continuity may be written

$$\zeta = -\frac{1}{w}\frac{\partial}{\partial x}\left(S\xi\right), \tag{266}$$

where w denotes the width at the surface; or, denoting the mean depth over this width by h',

$$\zeta = -\frac{1}{w}\frac{\partial}{\partial x}\left(h'w\xi\right). \tag{267}$$

This taken in connection with the dynamical equation (261) gives

$$\frac{\partial^2\zeta}{\partial t^2} = \frac{g}{w}\frac{\partial}{\partial x}\left(h'w\frac{\partial\zeta}{\partial x}\right). \tag{268}$$

Suppose the canal to communicate with a sea whose tide is

$$\zeta = A'\cos(at + \alpha). \tag{269}$$

Suppose the canal to be of constant depth but gradually tapering to a point at a distance L from the mouth, so that $w = (L - x) \times$ const. The solution of (268) satisfying the given conditions is

$$\zeta = A'\frac{J_0[l(L-x)]}{J_0(lL)}\cos(at + \alpha), \tag{270}$$

where

$$l^2 = a^2/gh \tag{271}$$

For the case of constant width, but with a depth decreasing to zero at the head, the solution is

$$\zeta = A'\frac{J_0[2\,\kappa^{\frac{1}{2}}(L - x)^{\frac{1}{2}}]}{J_0(2\,\kappa^{\frac{1}{2}}\,L^{\frac{1}{2}})}\cos(at + \alpha), \tag{272}$$

where

$$\kappa = a^2\,L/gh_0. \tag{273}$$

In the first case, the amplitude of the oscillation is increased, while the wave length is practically constant as we proceed up the canal. In the second, the amplitude increases, while the wave length diminishes.

A rectangular body of water of length $2L$, whose depth is zero at the two ends and h_0 at the center, has as the free period of its slowest mode of oscillation not $4\,L/\sqrt{gh_0}$ but $1{\cdot}306 \times 4\,L/\sqrt{gh_0}$, or a period 1·3 times as long as the period of a canal of uniform depth h_0, or 0·923 times the period of a canal of uniform depth $\frac{1}{2}\,h_0$. For further particulars see Lamb, Hydrodynamics, pp. 291–296.

CHAPTER V.

EXPERIMENTS WITH MODERATELY LONG WAVES.

39. In order to obtain a fair representation of a tide wave or seiche, it is necessary to have the horizontal dimensions of the body of water experimented with large in comparison with its depth. But on account of the limited size of the artificial body, we are obliged to make use of a depth considerably out of the true proportion. For bodies of uniform depth and vertical side walls, this difficulty is easily overcome in the manner outlined in § 33. Table 52, which gives the periodic times (τ) for various values of undisturbed depth (h) and half-wave length ($\frac{1}{2}\lambda$), is of almost constant service in work of this kind.

It is important to measure the depths as carefully as possible. This can be accomplished fairly well by means of a slender scale showing inches and tenths of inches, read by aid of a small mirror held partly immersed close by. But generally more accurate results are obtained by comparing the period of oscillation of any given body of water with a rectangular body of precisely the same depth and of nearly the same period. This can be accomplished by having movable partitions, all of which remain in the tank of water during the experiment, so that the depth does not vary. The timing can be done with the second hand of a watch. An interval of observation should generally be two, three, or four minutes. The vertical amplitude of the oscillation should be kept as small as possible and still subserve the purpose in hand—it should not exceed, say, one-eighth part of the depth.

Some experiments upon stationary waves have been made by Frederick Guthrie; the results are published in the Philosophical Magazine, Vol. 50 (1875), pp. 290–302, 377–388. In these the depths are generally great, and the results agree reasonably well with those obtained theoretically. Some references to other wave experiments may be found in Part I of this manual.

In this chapter we shall be chiefly concerned with oscillations or stationary waves in limited masses of water, and which may be set up and sustained by an external periodic force acting along one direction. A tank of water placed upon a bench or table which admits a limited amount of spring or sway will, when crowded back and forth in suitable periods, soon be found to oscillate according to some of its simpler modes. In triangular and most other shaped bodies the direction of the motion of the water particles at any given instant varies from point to point. Consequently, if the unidirectional force which sets up or sustains the oscillation acts favorably in one part of the body or area, it may act unfavorably in others. It is for this reason that a rectangular area $\frac{1}{2}\lambda$ long gives, when acted upon by the external force, an oscillation whose amplitude is much greater than that for an area, say, $\frac{3}{4}\lambda$ long. In fact, no oscillation could be set up by this force in an area of uniform depth λ long, for the force would then destroy as much motion as it would create.

If the vibration of a pendulum is sustained by an impulse imparted at the time when the velcoity of the bob is a maximum in the direction in which the force acts, the periodic time will not be altered. An oscillation in a tank is best sustained by causing the slight motion of the vessel due to the periodic external force to be a maximum at the instant when the velocity of the water particles is a maximum in the same direction.

Generally speaking, it is difficult to produce such permanent oscillations as theory would require in most bodies of water, because the direction of the line of motion at any given point does not generally agree with the direction of the external periodic force. In other words, we can not very well arrange a series of forces acting along the various lines of motion. Again, suppose that we have determined from theory, as in Chapter III, the form of the surface of the water at the time of elongation of the particles. Suppose that we construct out of some rigid material a surface which when lowered upon the water would cause its surface to take the theoretical elevations and depressions. If now this rigid surface could be suddenly annihilated or removed without disturbance of any kind, a perfect or theoretical oscillation would be the result. There seems to be no way of accomplishing this.

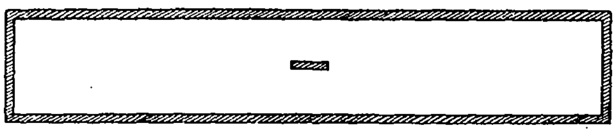

Fig. 15.

40. Suppose we have about 2 inches of water in a rectangular tank or trough 12 inches wide and several feet long. Suppose this to be placed upon a stand or table. Now by periodically crowding back and forth the table upon which the vessel rests, we can, after a little, establish a fairly good oscillation across the tank; the half-wave length ($\frac{1}{2}\lambda$) will be 12 inches. If this generating and sustaining force be discontinued, the oscillation will go on for one or two minutes, but the amplitude will gradually become smaller. Hence the free oscillation can be timed with considerable precision. In most experiments it is best to continue to sustain the oscillation by imparting a very small periodic force to the moving particles, as already explained. An experiment extending over two or three minutes will generally give the period to about the nearest fiftieth of a second, as a comparison with results obtained from Table 52 will show.

41. Next, suppose that we place an obstruction 4 or 5 inches long in the center of the trough (Fig. 15) and begin to generate the oscillation or stationary wave as before. For a little while the attempt will succeed fairly well at the ends of the trough; but before long, on account of the obstacle, the character of the motion will be altered almost beyond recognition. At first sight this would tend to discourage one from attempting to explain the tides in any natural body of water by the theory of nearly free oscillations generated and sustained by the periodic actions of the moon and sun; for, islands occur in almost any large body of water, and the shore line is often very uneven. The saving feature of the case lies in the fact that but few successive actions go to produce the tide; perhaps none are felt after the lapse of three days. Consequently the obstacles have not time to alter the character of the oscillations to the extent indicated in the experiment. In other words, the lines of motion which theory would give to the rather complicated body of water are set aside, and there is at first established over the body an imperfect oscillation, which would be a mode of oscillation were the body simplified to its general and not its actual form.

42. Suppose that we next try to obtain an oscillation extending lengthwise of the trough, the depth of water being about 2 inches. Great difficulty will be experienced in setting up so long an oscillation, which shall approach the simple and stationary

character required. If one end be raised or lowered, a progressive wave will be seen traveling back and forth for a short time after the disturbance subsides. But a good oscillation whose half-wave length is the length of the trough will not be thus obtained. Next, so put in a board as to form one sloping end wall. Now elevate and lower one end of the trough one or more times, and then leave the body to itself. The water will oscillate in the free period of the body, and, strange to say, the motion will continue to be sensible and well defined for two minutes or more after all indications of the progressive part have died out. For a bottom 45·7 inches long and a free surface 66·7 inches long, and a depth of 2·3 inches, three sets of observations, continued about two minutes each, gave 4·77 seconds as the length of the period of free oscillation. That is, the period is the same as that of a trough of uniform depth (2·3 inches) 71·0 inches long, instead of 66·7 inches.

43. Suppose that we partition off an L-shaped strip about 3 inches wide running along one end and one side of the trough. An external periodic force acting across the trough will incite motion to the end section of the L; this motion will soon cause the whole L-area to oscillate, provided the length of the longer branch be taken as some multiple of the shorter. Experiment will, however, show that distances defining wave lengths or half-wave lengths should be measured along the center line of the L-shaped strip partitioned off. In other words, the virtual lengths of the right trapezoidal strips involved are very nearly their mean geometrical lengths. The more half-wave lengths added to the longer branch, the smaller will be the amplitude of the oscillation, because the transverse branch or area is the only one upon which the external forces can act.

44. Suppose in the next place that we build a partition nearly but not quite across the trough. Let a narrow and shallow canal extend from where the partition ends along the side of the trough and terminate abruptly. This can be easily arranged by suitable partitioning. An oscillation set up across the main portion of the trough will cause the water in the small canal to oscillate in the same period. Nodes will occur at odd multiples of $\frac{1}{4}\lambda$ from the head of the canal. If there are two nodes, high water is simultaneous at both ends of the canal; if there is one node, it is low water at the head when it is high water outside; if the canal is less than $\frac{1}{4}\lambda$ in length, high water inside is simultaneous with high water outside. Should a node fall close to the mouth of the canal, the character of the motion in the main body of the trough will be considerably altered, and no very satisfactory results will be obtained; or rather, the motion in the canal depends on other considerations. (See § 34.)

45. By means of a movable partition it is easy to obtain a rectangular sheet of water whose depth shall be zero at one side and several inches at the other. Such a sheet 5·5 inches across and 3·3 inches deep on the deep side was found from a 3-minute observation to have a free period of $\left(\frac{180}{310}=\right)$ 0·58 second. A fairly good node was observed at about 3·2 inches from the deep side. The period for a rectangular sheet 5·5 inches across and uniformly 3·3 inches deep is, by Table 52, 0·433 second. The ratio of these two periods is therefore 0·75. The period for the rectangular sheet 1·65 inches deep is, by Table 52, 0·492 second. Thus we see that the free period of a body of water of variable depth may be greater than the period of a body of like horizontal dimensions with a uniform depth equal to the average depth of the first body. (Cf. §§ 38, 33, end, and 55.)

46. For the experiments about to be described, it is assumed that we have mounted upon a table a rectangular tank whose horizontal dimensions are about 4 by 6 feet. In connection with this, we are assumed to have some 15 or 20 bricks, some boards, and other materials for partitioning it off as may be desired.

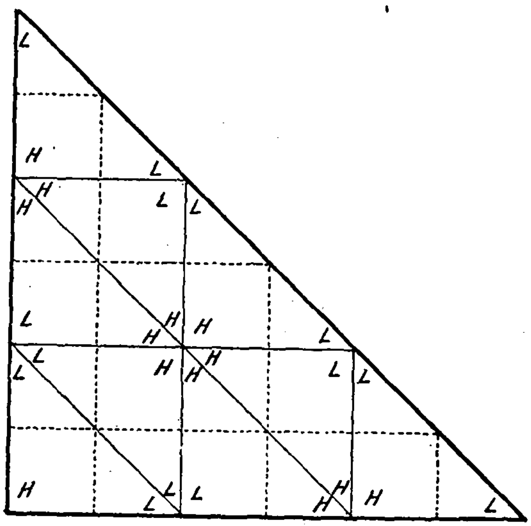

Fig. 16.

In the first place, suppose all partitions removed and the tank to contain 2 inches of water. Let this be gently crowded in such periods of time as will set up oscillations. The mass of water will be an odd multiple of half-wave lengths across, because the external force would have no resultant effect upon a sheet whose width is an even multiple. The ridges and furrows will extend lengthwise the tank. The width of the tank being 48·4 inches, observations (covering 3 or 4 minutes in each case) gave as the periodic time when three half-wave lengths were formed, 1·19 seconds; when five were formed, 0·76 second; and when seven, 0·57. Table 52 gives 1·19, 0·74, 0·56.

An even number of half-wave lengths, say 2, can be obtained by making the area of one of the half-wave lengths much shallower than that of the other. Of course its length will be decreased in accordance with Table 52. When force is imparted to the water, the oscillation will be governed by the deeper and longer half-wave length.

47. When a few irregularities are introduced in the shore line or bottom of a broad and moderately shallow tank of water, it is surprising to see how almost any impulses of reasonable period imparted to the body of water by crowding or slightly swaying the tank or its supports, will set up wave motion which will be maintained for a short time. The amplitude of such oscillations, excepting in angles or bays, will not generally be as great as the amplitude of the stationary waves just described; nor will the oscillations long continue. They are often badly mixed up with progressive waves, so that the particular barriers which gave rise to them may not be easily discerned. Along the edges or shores the oscillation has its greatest amplitude and regularity. This state of affairs is probably not unlike that of

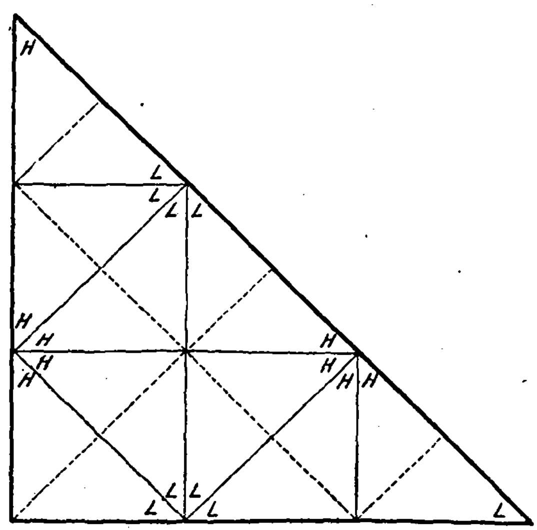

Fig. 17.

OBLIQUE BOUNDARY BETWEEN CALIFORNIA AND NEVADA

Showing arrangement of Topographic Sheets, the Random Line, Von Schmidt Line, Scheme of Triangulation and Profile.

Map B.
PROFILE OF THE RANDOM LINE
Vertical scale is ten times the horizontal
Colorado River
Sea Level
N E V A D A
C A L I F O R N I A
ARIZONA
VON SCHMIDT LINE 1873
NEEDLES
Statute Miles
OBLIQUE BOUNDARY BETWEEN
CALIFORNIA AND NEVADA
Showing arrangement of Topographic Sheets, the Random Line,
Von Schmidt Line, Scheme of Triangulation and Profile.
Field work executed between the years 1893 and 1899 by C.H. Sinclair,
W.B. Fairfield, A.L. Baldwin, H.F. Flynn and F.W. Edmonds, Assistants,
U.S. Coast and Geodetic Survey.

the Pacific Ocean, where there is a broad expanse of water upon which the tidal forces acting in almost any direction may produce agitation, and where the motions are not as much constrained or defined by the shore lines as in smaller bodies, nor are they as easily explained.

48. Right-triangular areas are easily formed by placing a straight partition across one corner of the tank. Oscillations of certain modes can be produced by a periodic force acting in one direction. Those of other modes will be produced with difficulty if at all by this means. Figs. 16, 17 illustrate this in the case of 45° triangles acted upon by a force parallel to one side. Suppose for the moment that a rigid wall formed the hypotenuse of the small right triangle occupying the right angle of Fig. 16. A glance at the lines of motion drawn in Fig. 9 will show that a large part of the force acts with the motion and a very small part against it. Now suppose this wall removed and the oscillation shown in Fig. 16 to be produced. The whole area divides itself into 9 triangles (oscillating areas). The force acts with the motion in the case of 6 of these triangles and against the motion in case of the remaining 3. The excess of 6 over 3, or 3, represents the number of triangles to which the force which produces the oscillation in the 9 triangles is really applied. In other words, the force acts only $\frac{1}{3}$ as advantageously as in the case of the single small triangle just referred to.

A 45° triangle formed by partitioning off a corner of the tank, each leg being 42·4 inches, was made to oscillate as in Fig. 16. With a depth of 2·07 inches, the number of oscillations from a 3-minute observation interval was found to be 79 per minute and so $\tau = 0{\cdot}76$ second. Theory gives $\tau = 0{\cdot}755$ second. For, the virtual length of each triangle is the distance of the right angle from the hypotenuse, or 10 inches. See Table 52.

Another mode of oscillation is that where the nodal lines run parallel or perpendicular to the hypotenuse. The virtual length of each triangular area is the length of one of the sides. A force parallel to one side will incite an oscillation throughout the area, but it will not act upon the water particles in the same manner as in the preceding case where the nodal lines were parallel to the sides. But in this case the nodal lines might be made parallel and perpendicular to the direction of the force by turning the tank so that its sides make angles of 45° with the edges of the table.

The oscillation of a 30° triangle, shown in Figs. 10, 11, is readily produced by having the shorter side parallel to the direction of the external force.

49. An isosceles triangle whose base was 4 inches and altitude 8 inches, the latter lying in the direction of the impressed force, was found to make 113 oscillations per minute and to be isochronous with a rectangular area of altitude 6·77 inches, the depth of the water being 2·25 inches. This comparison with a rectangle makes the virtual length of the triangle about 0·85 times the altitude. From the preceding chapter it appears that the virtual length of an equilateral triangle is 0·866 times the altitude, and from the symmetrical mode of the circle it follows that the virtual length of a very slender triangle is 0·82 times the altitude. Thus it would appear that for a perfect oscillation in a triangle of the above dimensions the virtual length should be somewhat greater than 0·82 times the altitude. A nodal line was noticed running nearly parallel to the base and roughly about $3\frac{1}{4}$ inches above it, which is 0·4 of the altitude. In a slender triangle theory places the node 0·372 of the altitude above the base.

50. To ascertain the free periods of a circular area, it is convenient to make use

of a brass hoop 3 or 4 inches broad and 1 or 2 feet in diameter. This is to be laid upon the bottom of the broad, shallow tank. Should it not be circular it can be made so by placing bricks or other weights around the outside. With a depth of 2 or 3 inches no difficulty will be experienced in setting up the first two unsymmetrical modes of oscillation by the usual unidirectional force, and they will be fairly in accordance with theory, as to period, lines of motion, relative amplitudes, etc.

Elliptical areas of various shapes can be formed out of the hoop, provided elliptical outlines, each having the same perimeter as the circle, be traced upon the bottom. By means of weights or tacks the hoop, distorted into an ellipse, can be held in place.

For a circle having a diameter of 13·48 inches the period of oscillation, according to its slowest mode, the depth being 2·22 inches, was found from a 4-minute observation to be $\left(\frac{60}{71}=\right)$ 0·85 second. The theoretical value is $\tau=0·831$ second.

For a circle having a diameter of 26.2 inches, the period of oscillation, according to its slowest mode, the depth being 2·24 inches, was found from a 4-minute observation to be $\left(\frac{240}{151}=\right)$ 1·59 seconds. The theoretical value is $\tau=1·545$. With the same hoop and depth, a 4-minute observation gave for the period of oscillation according to the next unsymmetrical mode, $\tau=\left(\frac{240}{402}=\right)$0·60 second. The theoretical value is 0·589 second.

Oscillation according to the odd symmetrical modes can be obtained in a sector whose angle is, say, 30°. The central radius of the sector should, of course, coincide with the direction of the force.

51. Let us next consider an L-shaped area 3 inches broad and 2 × 14 inches in length along the outer side, and so 2 × 12½ inches along the central line or axis. Let one arm lie parallel to the external force and the other lie perpendicular to it. The period of oscillation, the depth being a trifle more than 2 inches, was found from a 3-minute observation to be $\left(\frac{60}{67}=\right)$ 0·90 second. Upon partitioning off the dependent arm, thus leaving a rectangle 3 inches broad and 14 long, the period of oscillation was found to be $\left(\frac{60}{60}=\right)$ 1·00 second. From Table 52 the periods corresponding to the lengths 12½ and 14 are as 0·93 to 1·04 = 0·90 : 1·00, very nearly. This experiment goes to show that the virtual length of a right trapezoidal area is very nearly the mean geometrical length.

52. Let us next consider a deep canal closed at one end and communicating with an oscillating area. Let an opening be made in the middle one of the lateral partitions for the mouth of the canal which extends perpendicularly to the lines of motion of the main area. The depth of the canal is supposed to be the same as the depth outside. Suppose that we so time the periodic force that three half-wave lengths extend across the tank. The mouth of the canal will then fall at a loop of the oscillation. If the length of the canal be some multiple of $\frac{1}{2}\lambda$, the oscillation in the main area will not be disturbed (save slightly reduced in amplitude) although an oscillation of equal amplitude in the canal or dependent area will be sustained. If the length of the canal be about $\frac{1}{4}\lambda$ or a little less, great disturbance will be noted in the main area. The oscillation

in the canal will be poor and the amplitude at the mouth small. If the length of the canal lie between $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$, and its width be a considerable fraction of $\frac{1}{2}\lambda$, the oscillation in the canal will be fairly good; for we can imagine it to extend sufficiently far into the main area for approaching the length $\frac{1}{2}\lambda$. There will be a node $\frac{1}{4}\lambda$ from the head of the canal, and the amplitude will there be greater than at the mouth if the length of the walls of the canal are less than $\frac{1}{2}\lambda$.

53. Near the nodes of oscillating areas the lateral boundaries (i. e., boundaries following lines of motion) may be cut out for some distance, and the oscillation will go on nearly the same as it would were all boundaries complete. That is, the period, amplitude, and character of the motion will be very nearly alike in the two cases. An

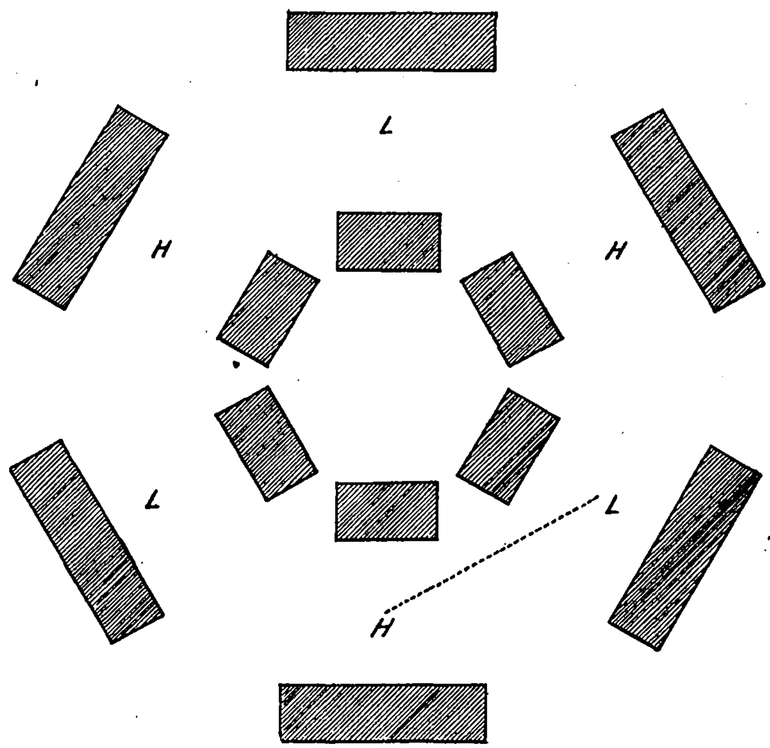

Fig. 18.

experiment upon two rectangular areas of like dimensions and placed side by side in the tank will convince one of the truth of this statement. The reason why the motion is unaltered by the opening is that the level on the inside of it is practically the same as that on the outside, and all lines of motion follow and do not cross the line of the partition and opening.

If the lateral boundaries are entirely removed, so that only the two ends of the rectangular area remain, the period will be a trifle but not much shorter than that for the closed rectangle. The amplitude will be considerable near the centers of the end walls, but small near their extremities; the motion will be noticeable at a considerable distance beyond the positions formerly occupied by the lateral walls. Experiments upon a square area indicate that the period is diminished somewhat when both lateral walls are removed and by a less amount when one is removed. But the results were discordant, indicating a dependence upon boundaries exterior to the region considered. Experiments show that unless the end walls be at least about $\frac{1}{4}\lambda$ in length no considerable oscillation will be set up between them. When there is one lateral wall, the end walls need be only one-half as long as when both sides are open.

Suppose, now, that we have simply two parallel end boundaries, and suppose one of them to be several times longer than the other. An experiment upon an inclosed area 8·5 inches square, the depth of water being 2·3 inches, gave as its period 0·62 second. Theory makes it 0·633 second. Upon removing the lateral walls of this square the period was found to be 0·58 second. This result may be unreliable and dependent upon boundaries exterior to the region. On the long end the rise and fall was seen to extend about $\frac{1}{4}\lambda$ beyond the limits defined by the opposing short end.

If in a broad tank a skeleton hexagon, like that shown in Fig. 18, be constructed, it will be possible, by crowding the tank back and forth as usual, to set up an oscillation whose loops will be supported by the rigid walls. This is so because more of the force impressed upon the water goes to sustaining the oscillation than to destroying it. With a depth of 2·38 inches the period of the hexagon shown was found, from observations extending over four minutes, to be 0·706 second. The virtual length of each area is therefore, by Table 52, 9·83 inches; which is very nearly equal to the length (10 inches) of the dotted line shown in the figure.

54. It has already been noted that the virtual length of areas tapering toward the ends is less than the extreme geometrical length. E. g., the virtual length of a slender triangular half-wave area is, by § 28, 0·820 times the extreme length; for a whole-wave area it is 0·896 times the extreme length. The virtual length of half-wave areas tapering at both ends may be much less than the extreme length. (See § 26.) On the other hand, it is easily shown that the virtual length of a half-wave area broadening at both ends may be greater than its extreme geometrical length. For instance, it was found from experiment that a rectangular 17·3 inches long and 6 inches wide, the water being about 1·9 inches deep, has for its period 1·32 seconds. With the same length, and with the same depth of water, an area 6 inches wide at either end and 2·2 in the middle gave for its period 1·64 seconds.

More difficulty will be experienced in the production of oscillations in an area much contracted at the center than in one whose shape is rectangular or oval.

55. Let us next consider a case of variable depth. Suppose we have a rectangular area 8·98 inches across. Let the depth at each end be 2·63 inches; let it gradually slope up in going toward the central line where the depth is but 0·75 inch. A 3-minute observation gave as the period of oscillation $\left(\frac{180}{206}=\right)$ 0·87 second. The depths 2·24, 0·36 and 2·03, 0·15 inches gave as periods $\left(\frac{180}{168\cdot5}=\right)$ 1·07 and $\left(\frac{180}{126}=\right)$ 1·43 seconds, respectively. For a rectangle of uniform depth equal to the mean depth in each of the above three cases, we have as periods, according to Table 52, 0·742, 0·829, 0·896 second, respectively. Thus we can infer that a half-wave area has its period much increased by a ridge across the center. Observation shows that the velocity of the water particles situated over the ridge is comparatively great; also that the amplitude of the rise and

fall, even at the ends, is much less than would have been produced by forces of the same intensity acting upon the body cleared of this obstruction.

56. Progressive derived waves can be produced in the following manner: Box off in the tank a convenient half-wave area, but let one of the end walls, or a portion of one, extend not quite to the surface. Beyond this wall or opening and outside of the area let the water continue to be as shallow as on the crest of the submerged wall. A stationary wave in the area will give rise to a progressive derived wave. In the shallow region we can put weights of square, circular, or any other cross section and observe the behavior of the progressive wave as it is interrupted by them, just as if they were islands in the midst of a shallow sea.

57. Suppose that we have an area entirely surrounded by a rigid wall except a small opening at one of the loops of the oscillation. The water in this opening will behave as if in a strait communicating with a tideless sea. At the time of high water at the loop, the particles in the strait will be at their maximum elongation toward the oscillating area. But this will not be the case unless the narrow strait be of some considerable length in comparison with the lengths of the orbits of the particles lying in the strait. If the small strait be of practically no length, as if a gap cut through a thin partition, then Torricelli's theorem applies. In order that this hydrostatic effect may be too small to be of consequence, it is probable that the length of the strait should be at least 4 times the amplitude of the horizontal oscillation in its strait.

58. There are other ways of obtaining oscillations of bodies of water. Imperfect results can be obtained by periodically agitating the water to near the bottom with a large paddle. The proper period of a body and in a given direction can thus be approximated to. Pools in brooklets form natural bodies of suitable size. Artificial reservoirs of various shapes and sizes are readily excavated along the banks of streams whence they can be supplied with water. Canals with and without end barriers can be dug at pleasure. If shallow in comparison with the pool, their motion may be regarded as dependent or derived.

59. Suppose that we construct a reservoir which represents accurately a nearly inclosed gulf or bay together with all its tidal tributaries. It is not necessary that the vertical scale be the same as the horizontal; the only requirement is that the depth shall always be a small fraction of a wave length when the period is fixed in the manner stated below. Now by any suitable artificial means, as by periodically immersing a float in a pool suitably constructed outside the miniature bay, aim to reproduce the observed tidal phenomena just outside of the real bay. The period should be found by trial—observation having shown just what fraction of a period the time of tide at one point of the bay precedes or follows that at some other. With such an arrangement carefully constructed the tide and tidal streams throughout the bay and its tributaries would become known, and so a mechanical solution of the problem obtained. We see that it must be true here, because the portion of the tide period required for any solitary disturbance to pass between any two assumed points of the bay is the same in the model as in the original.

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CHAPTER VI.

SMALL OSCILLATIONS SUSTAINED BY PERIODIC FORCES.

60. *Time of elongation of a compound pendulum.*

If to a compound pendulum whose resistance is proportional to its velocity, a series of simple harmonic forces having periods equal to the free period of the pendulum be applied, and a permanent state established, then must the time of elongation be simultaneous with the time when the moment of the external periodic forces with respect to the axis of suspension becomes zero. This is also the time when the virtual work of the external periodic forces upon the system becomes zero.

Denoting the elementary masses of the pendulum by m_1, m_2, ... and their distances from the axis of suspension by λ_1, λ_2, ... , we have as the effective horizontal force of the body (sometimes spoken of as minus the force of inertia) the expression

$$(m_1\lambda_1 + m_2\lambda_2 + \quad . \quad . \quad . \quad)\frac{\partial^2\theta}{\partial t^2}. \tag{274}$$

The moment of this force relative to the axis of suspension is

$$(m_1\lambda_1^2 + m_2\lambda_2^2 + \quad . \quad . \quad . \quad)\frac{\partial^2\theta}{\partial t^2}, \tag{275}$$

which may be written

$$M\lambda'^2\frac{\partial^2\theta}{\partial t^2} \tag{276}$$

where M denotes the entire mass and λ' the radius of gyration.

The impressed forces are of the three kinds mentioned below:

(1) The *external forces*, which are periodic and horizontal and of the form

$$F_1 \cos(at + \alpha_1),\ F_2 \cos(at + \alpha_2), \quad . \quad . \quad . \quad , \tag{277}$$

F_1, F_2, ... denoting maximum values or amplitudes. The range of the subscript is generally quite different from that pertaining to the mass elements.

(2) The *natural forces of restitution*, which are

$$-g\theta\,[m_1 + m_2 + \quad . \quad . \quad . \quad]. \tag{278}$$

(3) The *forces of resistance*, which may be written in the form

$$-C'\,[c_1\lambda_1 + c_2\lambda_2 + \quad . \quad . \quad . \quad]\frac{\partial\theta}{\partial t} \tag{279}$$

if we assume the resistance to be as the first power of the velocity. C' is a general coefficient dependent upon the medium, and $c_1, c_2, \ldots$ special coefficients dependent upon the shape and nature of resisting surface of the mass elements.

The moment equation is therefore of the form

$$M\lambda'^2 \frac{\partial^2\theta}{\partial t^2} = \sum_\nu F_\nu\lambda_\nu \cos\,(at+\alpha_\nu) - Mg\bar{\lambda}\theta - C''\check{\lambda}^2 \frac{\partial\theta}{\partial t} \qquad (280)$$

where $\bar{\lambda}$ denotes the distance of the center of gravity from the axis of suspension, and $\check{\lambda}$ the distance of the center of resistance.

D'Alembert's principle combined with the principle of virtual work leads, of course, to the same equation. For these principles assert that the aggregate of the forces, impressed and reversed effective, acting upon a material system, and each multiplied by the displacement of its point of application in the directions x, y, z, when an arbitrary motion takes place in accordance with the connections of the system, must be zero. That is,

$$\Sigma\left[\left(X - m\frac{\partial^2 x}{\partial t^2}\right)\delta x + \left(Y - m\frac{\partial^2 y}{\partial t^2}\right)\delta y + \left(Z - m\frac{\partial^2 z}{\partial t^2}\right)\delta z\right] = 0. \qquad (281)$$

In the present instance $\delta y = \delta z = 0$ and $\delta x = \lambda\delta\theta$, and so $\delta\theta$ comes out as a factor. At the axis of suspension λ, and so $\lambda\delta\theta$, becomes zero. Hence we are not obliged to take further account of the reactions of the supports than to note that they are finite.*

Let A' denote the amplitude of the oscillation at a point distant λ' from the axis of suspension; let the time be reckoned from the instant when the particle is at elongation toward $-x$. Then

$$\lambda'\theta = -A'\cos at, = A'\cos\,(at + 180°), \qquad (282)$$

$$\lambda'\frac{\partial\theta}{\partial t} = A'a\sin at, \qquad (283)$$

$$\lambda'\frac{\partial^2\theta}{\partial t^2} = A'a^2\cos at. \qquad (284)$$

The moment equation (280) becomes

$$A'Ma^2\lambda'^2\cos at = \lambda'\sum_\nu F_\nu\lambda_\nu\cos\,(at+\alpha_\nu)$$
$$+ A'Mg\bar{\lambda}\cos at - A'C''a\check{\lambda}^2\sin at. \qquad (285)$$

This equation may be written in the form

$$P\cos at + Q\sin at = 0. \qquad (286)$$

Since this must be a true equation for all values of t, the coefficient of $\cos at$ and that of $\sin at$ must each be zero. If we make $P = 0$ and $Q = 0$, the α's are completely determined (for any assigned value of a), because each α differs from a given α, say α_1, by a known and fixed amount. Were the α's thus determined, the moment equation (285) would, of course, be satisfied for all values of t.

$P = 0$ gives

$$A'Ma^2\lambda'^2 = \lambda'\Sigma_\nu F_\nu\lambda_\nu\cos\alpha_\nu + A'Mg\bar{\lambda}, \qquad (287)$$

and $Q = 0$ gives

$$\lambda'\sum_\nu F_\nu\lambda_\nu\sin\alpha_\nu + A'C''a\check{\lambda}^2 = 0. \qquad (288)$$

* Cf. Routh, Rigid Dynamics, Part I, p. 285.

Here we are not concerned about the determination of the α's in general, but only those corresponding to a certain value of a. Suppose the α's such that (285) or (286) shall be satisfied at the times of elongation, viz., when $at = 0$ or $180°$. The only restriction necessary for bringing this about is that $P = 0$. P will be equal to zero if

$$F_1 \lambda_1 \cos \alpha_1 + F_2 \lambda_2 \cos \alpha_2 + \ . \ . \ . = 0. \tag{289}$$

and if

$$a^2 \Lambda'^2 = g\bar{\lambda}. \tag{290}$$

If all F's are zero, the latter condition alone is sufficient for making the corresponding P equal to zero. Hence we know that this must be the relation between the speed and lengths of the free compound pendulum. This gives for the complete period of the vibration

$$\tau = 2\pi\sqrt{\left(\frac{\lambda'^2}{g\bar{\lambda}}\right)} = 2\ \pi\sqrt{\left(\frac{\lambda}{g}\right)} \tag{291}$$

where τ replaces $2\pi/a$ and λ is the length of the simple equivalent pendulum.

But (290) must be also true for the sustained oscillation because, by hypothesis, the motion is alike whether free or sustained.

The displacement of the point of application of F_ν is $\lambda_\nu\ d\theta$; the value of the force in the same direction is at the time of elongation proportional to $F_\nu \cos \alpha_\nu$. Hence the above equation (289) expresses the fact that the virtual work of the external periodic forces is zero at the time of elongation, or that the moment of three forces with respect to the axis of suspension is then zero. Q. E. D.

If $\nu = 1$, that is, if there be but one external periodic force, and if a satisfies (290), $P = 0$ and $Q = 0$ give $\alpha_1 = 270°$. That is, the phase of the oscillation $(at + 180°)$ is $90°$ behind the phase of the force $(at + \alpha_1)$. When $t = 0$, and the pendulum bob is at its elongation to the left, the force must be zero if it sustain the vibration without alteration.

If the forces of resistances contain powers of $\frac{\partial\theta}{\partial t}$ higher than the first, the moment equation can not be satisfied by assuming θ to be a simple harmonic function of t. For, this resistance would then require that there be other terms in (285) having for arguments multiples of at. Conversely, if the resistance be proportional to the first power of the velocity, θ being by hypothesis a periodic function in at, must be a simple harmonic function of at. For, suppose θ then contain terms whose arguments are multiples of at. By hypothesis the resistance is proportional to $\frac{\partial\theta}{\partial t}$. The sine or cosine terms in θ, having such arguments, give cosine or sine terms in $\frac{\partial\theta}{\partial t}$ and sine or cosine terms in $\frac{\partial^2\theta}{\partial t^2}$. The entire coefficient of such a term, when the equation is transposed to one side, must in each case be zero; this can be so only when the coefficients of such terms in θ are zero.

61. *Free period of the pendulum not equal to the period of the forces.*

In this case the period of the actual vibration is that of the forces, because the initial conditions of the free vibration must have disappeared through resistance, however small. In the preceding case we had

$$a^2 \lambda'^2 = g\bar{\lambda}, \quad \text{or} \quad a^2 \lambda = g,$$

a being the "speed" or "frequency" of the external forces as well as of the free vibration. a' will here denote the speed of these forces, while the speed of the free vibration will still be denoted by a, i. e., $a^2 \lambda'^2 = g\bar{\lambda}$ or $a^2 \lambda = g$. The moment equation (285) is of the same form as before, excepting that a is replaced by a'. Writing $a'^2 = (a'^2 - a^2) + a^2$ we have from (287), (288)

$$A'M\lambda'(a'^2 - a^2) = \sum_\nu F_\nu \lambda_\nu \cos \alpha_\nu, \tag{292}$$

$$\lambda' \sum_\nu F_\nu \lambda_\nu \sin \alpha_\nu + A'C''a'\bar{\lambda}^2 = 0. \tag{293}$$

Since the pendulum is a rigid body, it is obvious that all of the periodic external forces acting upon it may be replaced by one such force without altering the character of the motion. When $\nu = 1$ we have

$$\cos \alpha_1 = \frac{A'M(a'^2 - a^2)\lambda'}{F_1 \lambda_1}, \tag{294}$$

$$\sin \alpha_1 = -\frac{A'C''a'\bar{\lambda}^2}{F_1 \lambda' \lambda_1}, \tag{295}$$

$$A' = -\frac{F_1 \lambda' \lambda_1 \sin \alpha_1}{C''a'\bar{\lambda}^2}, \tag{296}$$

$$\tan \alpha_1 = \frac{C''a'\bar{\lambda}^2}{M(a^2 - a'^2)\lambda'^2}. \tag{297}$$

From these equations the following results are readily obtained:

If $a' < a$ the phase of the force agrees with that of the vibration, there being practically no friction; when there is friction, the vibration lags behind the force by an amount lying between 0 and 90°.

If $a' > a$ the phase of the force differs from the phase of the vibration by 180°, there being practically no friction; when there is friction, the vibration is in advance of the force by an amount lying between 180° and 90°.

If $a' = a$ the phase of the force is 90° greater than the phase of the vibration; i. e., the force is 90° in advance of the vibration.*

Suppose there to be no friction; that is, let $C'' = 0$, then $\alpha_1 = 0$ or 180° according as $a' \lessgtr a$. From (296) we have

$$A' = \pm \frac{F_1 \lambda_1}{M(a'^2 - a^2)\lambda'} = \pm \frac{F_1 \lambda_1 \lambda'}{M(a'^2 - a^2)\lambda'^2} = \pm \frac{F_1 \lambda_1 \lambda'}{M a'^2 \lambda'^2 - Mg\bar{\lambda}} \tag{298}$$

since $a^2 \lambda'^2 = g\bar{\lambda}$.

Next suppose that a is very great in comparison with a'; that is, that the force is much slower than the free pendulum. We have

$$A' \doteq -\frac{F_1 \lambda_1 \lambda'}{Mg\bar{\lambda}}. \tag{299}$$

If $\lambda_1 = \lambda' = \bar{\lambda} = \lambda$,

$$A' \doteq -\frac{F_1 \lambda}{Mg} \text{ or } F_1 \doteq -\frac{A'Mg}{\lambda} \doteq -Mg\theta', \tag{300}$$

*See Rayleigh, Theory of Sound, Vol. I, Ch. III; Routh, Rigid Dynamics, Part I, Ch. IX; Ibid., Part II, Ch. VII.

where θ' denotes the magnitude of the angular direction of the pendulum at elongation. From (300) and (278) we see that $F_1 \cos (a't + \alpha_1)$ is simply the force or restitution with its sign changed. In other words, the pendulum is, because of the long period of the force, always in a state of statical equilibrium with this force and the force of gravity.

62. *Time of elongation of the water particles in a canal $\frac{1}{2}\lambda$ long.*—If to the particles of water in a canal of uniform cross section half a wave length long wherein the resistances are proportional to the velocities of the particles, a series of simple harmonic forces having for period the free period of the body of water be applied and a permanent state established, then must the time of elongation be simultaneous with the time when the virtual work of the external periodic forces upon the system becomes zero.

The kind of oscillation here contemplated is harmonic with respect to both time and distance, and so the displacement of any slice-element may be written

$$\xi_\nu = -A \sin lx_\nu \cos at = A \sin lx_\nu \cos (at + 180^\circ), \tag{301}$$

or simply

$$\xi = -A \sin lx \cos at$$

if the impressed forces either vanish or can be specified by a function of x. Here the left end of the canal is the origin of x, and t is reckoned from the time of elongation to the left. A narrow canal may be either curved or straight; x is distance measured along the canal.

In applying D'Alembert's principle in conjunction with the principle of virtual work for the purpose of obtaining an equation between all forces, both impressed and effective, it is to be remarked that any set of infinitesimal displacements throughout the system corresponding to an infinitesimal change dt in t are (because the oscillation is harmonic) severally proportional to, though much smaller than, $\xi_1, \xi_2, \ldots$; and these finite displacements may be substituted for the very small ones because all terms in the equation will be affected by the same factor. We have, putting $f_\nu m_\nu \cos (at + \alpha_\nu)$ for the force X_ν,

$$\sum_\nu m_\nu \xi_\nu \frac{\partial^2 \xi_\nu}{\partial t^2} = \sum_\nu f_\nu m_\nu \xi_\nu \cos (at + \alpha_\nu) + \sum_\nu ghm_\nu \xi_\nu \frac{\partial^2 \xi_\nu}{\partial x_\nu^2} - \sum_\nu C' m_\nu \xi_\nu \frac{\partial \xi_\nu}{\partial t}. \tag{302}$$

Here f_ν denotes the amplitude of the intensity of the force upon the slice whose characteristic is ν. The terms in g on the right-hand side of this equation represent the natural forces of restitution on the slice-elements each multiplied by its displacement ξ_ν. For, $p = g\zeta$, and by (262) the equation of continuity is

$$\frac{\zeta}{h} + \frac{\partial \xi}{\partial x} = 0; \tag{303}$$

$$\therefore -\frac{\partial p}{\partial x} = gh\frac{\partial^2 \xi}{\partial x^2}. \tag{304}$$

Substituting for ξ_ν its value, we have

$$Aa^2 \sum_\nu m_\nu \sin^2 lx_\nu \cos at = \sum_\nu f_\nu m_\nu \sin lx_\nu \cos (at + \alpha_\nu)$$

$$+ Aghl^2 \sum_\nu m_\nu \sin^2 lx_\nu \cos at - AC'a \sum_\nu m_\nu \sin lx_\nu \sin at. \tag{305}$$

This equation may be written in the form

$$P \cos at + Q \sin at = 0. \tag{306}$$

If the α's are such that $P = 0$, this equation will be satisfied by $at = 0$ or $180°$. $P = 0$ requires that

$$Aa^2 \sum_\nu m_\nu \sin^2 lx_\nu = \sum_\nu f_\nu m_\nu \sin lx_\nu \cos \alpha_\nu + Aghl^2 \sum_\nu m_\nu \sin^2 lx_\nu, \tag{307}$$

which will be the case if

$$\sum_\nu f_\nu m_\nu \sin lx_\nu \cos \alpha_\nu = 0, \tag{308}$$

and if

$$a^2 = ghl^2.$$

If all f's are zero, the latter condition alone is sufficient for causing the corresponding P to vanish. Hence we know that this must be the relation between the speed and length $\left(=\frac{2\pi}{l}=\lambda\right)$ of the stationary wave. This gives for the complete period of the oscillation

$$\tau = \frac{2\pi}{l\sqrt{(gh)}} = \frac{\lambda}{\sqrt{(gh)}} \tag{309}$$

where τ replaces $2\pi/a$. $a^2=ghl^2$ will be true for the sustained wave also, because, by hypothesis, the character of the motion is not altered by the sustaining forces.

The displacement of the point of application of the force acting upon the slice-element whose characteristic is ν, is proportional to $\sin lx_\nu$. The force itself is, at a time of elongation, proportional to $f_\nu m_\nu \cos \alpha_\nu$. Hence the above equation (308) expresses the fact that the virtual work of the external periodic forces is zero at the time of elongation of the particles, i. e., at the time of high or low water. Q. E. D.

In effecting the above-indicated summations, x or x_ν goes from 0 to $\frac{1}{2}\lambda$ and the number of slices (i. e., values ν) into which this length is divided is supposed to be very great; whereas, in the case of the pendulum the number of points to which forces are applied may be very few.

§ 63. *Extension to a canal whose length is some multiple of $\frac{1}{2}\lambda$.*

To extend the above fundamental equation (305) to canals more than one-half wave-length long, an additional subscript ranging through a few values 1, 2, 3, ... , i. e., the number of half wave-lengths considered, must be written alongside of ν. Moreover, h and C' will take this new subscript when the depths of the various half wave lengths differ. Since this new subscript is always a small integer, we may actually write out its various values 1, 2, ... The equation $P = 0$ requires that

$$Aa^2 \sum_\nu m_{\nu,1} \sin^2 l_1 x_{\nu,1} + Aa^2 \sum_\nu m_{\nu,2} \sin^2 l_2 x_{\nu,2} + \quad . \quad . \quad .$$

$$= \sum_\nu f_{\nu,1} m_{\nu,1} \sin l_1 x_{\nu,1} \cos (at + \alpha_{\nu,1}) + \sum_\nu f_{\nu,2} m_{\nu,2} \sin l_2 x_{\nu,2} \cos (at + \alpha_{\nu,2}) + \quad . \quad . \quad .$$

$$+ Agh_1 l_1^2 \sum_\nu m_{\nu,1} \sin^2 l_1 x_{\nu,1} + Agh_2 l_2^2 \sum_\nu m_{\nu,2} \sin l_2 x_{\nu,2} + \quad . \quad . \quad . \quad , \tag{310}$$

which will be the case if

$$\sum_\nu f_{\nu,1} m_{\nu,1} \sin l_1 x_{\nu,1} \cos \alpha_{\nu,1} + \sum_\nu f_{\nu,2} m_{\nu,2} \sin l_2 x_{\nu,2} \cos \alpha_{\nu,2} + \quad . \quad . \quad . = 0, \tag{311}$$

and if

$$a^2 = g h_1 l_1^2,\ a^2 = g h_2 l_2^2, \quad . \quad . \quad . \quad . \tag{312}$$

But these latter are true relations between period and wave length for the various half wave lengths considered. The other relation expresses that the virtual work of the external periodic forces upon the system is then zero.

64. *Areas of uniform depth.*

If to the particles of water in a given oscillating system, each area of uniform depth, and wherein the resistances are proportional to the velocities of the particles, a series of simple harmonic forces having for period the free period of the body of water be applied and a permanent state established, then must the time of elongation be simultaneous with the time when the virtual work of the external periodic forces upon the system becomes zero.

Let us suppose that we have drawn upon any given oscillating area of uniform depth a set of normal coördinates consisting of lines of motion and contour lines. Since we may erect vertical partitions ad libitum along the lines of motion, we may consider separately the strips formed by two such neighboring lines, distinguishing one strip from another by an additional subscript μ.

Let ρ_ν denote the amplitude of the horizontal displacement at the part of the strip characterized by the subscript ν; because the motion is harmonic in time the virtual displacement dr will be proportional to ρ, and the component virtual displacements will be proportional to ξ, η. From equations (281), (97) we have an equation resembling (302) with terms in η and in ξ and η added. For the moment let $\xi = -\varphi(x, y)$ $\cos a\, t$, $\eta = -\psi(x, y) \cos a\, t$ and so

$$\frac{\partial^2 \xi}{\partial t^2} = -a^2 \xi, \quad \frac{\partial^2 \eta}{\partial t^2} = -a^2 \eta. \tag{313}$$

In the first place suppose the oscillation to be free; then $P = 0$ gives an equation from which all subscripts and summation signs can be omitted, and the resulting equation will be true. In fact, the chief use of the subscripts is to allow an arbitrary distribution of the disturbing forces over the areas. Making use of (91), (97), and (313), we obtain from $P = 0$ a differential eqation in ζ and x, y; and this is known to be true for harmonic oscillations because it can be readily derived from (94) if in the latter ζ is assumed to be harmonic.

Now on the assumtion of sustaining forces, the corresponding $P = 0$ gives, by virtue of the differential relation just mentioned,

$$\sum_\nu \sum_\mu \bar{f}_{\nu,\mu}\, m_{\nu,\mu}\ \varphi(x_{\nu,\mu}, y_{\nu,\mu}) + \sum_\nu \sum_\mu \bar{\bar{f}}_{\nu,\mu}\, m_{\nu,\mu}\ \psi(x_{\nu,\mu}, y_{\nu,\mu}) = 0. \tag{314}$$

But this is proportional to the virtual work of the external periodic forces upon the oscillating area when $at = 0$ or $180°$. Hence the theorem.

If we have given the contour lines and lines of motion of an area, we can find the horizontal displacements. The connection between ρ and ζ is

$$\frac{\partial^2 \rho}{\partial t^2} = - g \frac{\partial \zeta}{\partial r} \tag{315}$$

or

$$\zeta = - \frac{1}{g} \int \frac{\partial^2 \rho}{\partial t^2} dr. \tag{316}$$

If ζ be expressed in terms of x, y, then ξ, η become known through the equations

$$\frac{\partial^2 \xi}{\partial t^2} = - g \frac{\partial \zeta}{\partial x}, \frac{\partial^2 \eta}{\partial t^2} = - g \frac{\partial \zeta}{\partial y}, \tag{317}$$

and ρ is the resultant of the two.

65. To apply the general rule given at the beginning of the last section to an oscillating system in nature, we imagine the force diagrams (Fig. 1) to be scattered along the lines of motion of the areas of the system, e. g., along the axis of a canal-like body of water. Let us begin with any Greenwich component hour. The local component hour corresponding to the numbering on the force diagram is found by subtracting the longitude in time from the assumed Greenwich hour if the longitude be west and adding the longitude if it be east. Project the force arrow belonging to the assumed time in each diagram upon the line of motion passing through it. The aggregate of the elementary masses, each multiplied by the intensity of the tidal force in the direction of the displacement of the element, and again by a quantity proportional to the value of the maximum displacement (since the oscillation is harmonic), must be zero at the time of high or low water. The algebraic sum of these products for any given hour should be plotted as an ordinate at that hour. Where the curve thus constructed crosses the time axis denotes the time of high or low water.

In some simple cases the results can be seen at once. We thus have the following:

66. *Semidiurnal oscillations.*

In an east-and-west canal half a wave length long, it is high water at the east end at the component hour 0 or 12, the time meridian being understood to be the meridian of the middle point of the canal.

This rule also applies to any curved canal half a wave length long lying symmetrically with respect to the central meridian.

In an east-and-west canal one wave length long, it is high water at both ends at the component hour—3 or 9, the time meridian being understood to be the meridian of the middle point of the canal.

This rule also applies to any curved canal a wave length long lying symmetrically with respect to the central meridian.

In the meridional canal half a wave length long it is high water at the south or north end, according as the greater part of the canal lies north or south of the equator, at the component hour 3.

In a meridional canal one wave length long, whose center lies between 45° south and 45° north latitude, it is high water at both ends at the component hour 9; if the center lies beyond these limits, the component hour of high water at the ends is 3.

67. *Diurnal oscillations.*

In an east-and-west canal half a wave length long situated in north latitude, it is high water at the east end at the component hour 0 or 24, the time meridian for diurnal, as well as semidiurnal, oscillations being understood to be the meridian of the middle point of the canal.

For a similar canal situated in south latitude it is high water at the east end at the component hour 12.

These rules also apply to any curved canal half a wave length long lying symmetrically with respect to the central meridian.

In a meridional canal half a wave length long, whose center lies between 45° south and 45° north latitude, it is high water at the north end at the component hour 6; if the center lies outside of these limits, the component hour for high water at the north end is 18.

In a meridional canal a wave length long whose center lies north of the equator, it is high water at the ends at the component hour 18; if the center lies south of the equator, the component hour for high water at the ends is 6.

68. *Tides in a short canal of any length.*

Since the canal is supposed to be short and straight, we can regard the external periodic force as being the same throughout its whole extent. For this reason no subscript is necessary and the periodic force, or X, may be written $f\cos(at+\alpha)$. Ignoring friction, equation (302) gives

$$\frac{\partial^2\xi}{\partial t^2} = f\cos(a't+\alpha) + gh\frac{\partial^2\xi}{\partial x^2} \tag{318}$$

Here a' denotes the speed of the force. If a have reference to the period of the canal we have

$$a^2 = ghl^2,$$

where $l = 2\pi/\lambda$, λ denoting a wave length; also

Period of slowest free mode $= \dfrac{4L}{\sqrt{(gh)}} = \dfrac{2\pi}{a}$, $2L$ denoting the length of the canal.

If we write

$$\xi = \frac{2f}{a'^2\cos\dfrac{a'L}{\sqrt{(gh)}}}\sin\frac{a'x}{2\sqrt{(gh)}}\sin\frac{a'(2L-x)}{2\sqrt{(gh)}}\cos(a't+\alpha), \tag{319}$$

$$\zeta = \frac{hf}{a'\sqrt{(gh)}\cos\dfrac{aL}{\sqrt{(gh)}}}\sin\frac{a'(x-L)}{\sqrt{(gh)}}\cos(a't+\alpha), \tag{320}$$

equation (318) is satisfied, also the terminal conditions $\xi = 0$ for $x = 0$ and $x = 2L$; and also the equation of continuity (303). According as the period of the force, $2\pi/a'$, be greater or less than the slowest free period of the body, the coefficients of the displacements are positive or negative, and so the phase of the oscillation will be the same as that of the force in the one case and opposite in the other. If $\alpha = 180°$, the time origin is the time of maximum force to the left instead of to the right, as implied in $\alpha = 0$. If the force period much exceed the oscillation period the displacements approach their equilibrium values.

$$\xi = \frac{f}{2\,gh}(2\,L - x)\cos(a'\,t + \alpha), \tag{321}$$

$$\zeta = \frac{f}{g}(x - L)\cos(a't + \alpha), \tag{322}$$

a result which would follow from (318) by there making the inertia term zero.

Friction may be taken into account by subtracting a term proportional to $\frac{\partial \xi}{\partial t}$ from the right-hand member of (321). The solution embracing this problem is given by Airy, Tides and Waves, Article 337. It will be noted that when his m is zero, as our problem requires, there is a nodal line crossing at the middle of the canal. In this connection see also Ferrel, Tidal Researches, Chapter IV.

CHAPTER VII.

A PARTIAL EXPLANATION OF THE TIDES.

69. In approaching the question of the actual causes of the tides, upon which so much labor has been expended and concerning which so much has been written, one may well surmise that the subject does not admit of accurate or complete treatment. It is therefore natural to consider, in the first place, only those sources which would seem to account for the dominant tides in any given region under consideration, and to postpone, perhaps indefinitely, the consideration of those sources whose importance in the production of tides must be relatively small. Considering the actual distribution of land and water, a few computations upon hypothetical cases will suffice to convince one that as a rule the ocean tides, as we know them, are so great that they can be produced only by successive actions of the tidal forces upon oscillating systems, each having, as free period, appoximately the period of the forces, and each perfect enough to preserve the general character of its motion during several such periods were the forces to cease their action. This greatly simplifies matters; for, having once for all constructed a set of force diagrams for the various latitudes, we have only to discover those regions which have a free period of oscillation about equal to the period of the forces, and to then ascertain at what time the particles should be at elongation in their nearly rectilinear paths. The paths of the particles being practically fixed and determined by the boundary conditions, it becomes possible to disregard the forces arising from the earth's rotation, and which vary with the component velocities of the moving particles.

Since some of the natural boundaries of any oceanic region may be indefinite, imperfect, or altogether wanting, serious difficulties arise when we attempt to actually mark out areas or systems of areas which shall have the required period of free oscillation, and in which it is possible for the tidal forces to incite a considerable tide. This is believed to be the first attempt to approximately locate areas which seem to account for the principal ocean tides, having regard to the difficulties just referred to, and to connect the possible motions of the water with the tidal forces.

The writings of Plato, Galileo, Newton, Bernoulli, Euler, Young, and Fitz Roy show that these philosophers regarded nearly free oscillations of large bodies of water, oscillations analogous to vibrations of pendulums, as important factors in causing or modifying the tides. Their ideas regarding the requirements of such motions were somewhat confused. Airy is the first writer who treats, with success, stationary waves under several conditions. Ferrel's treatment of tides in east-and-west canals, closed at both ends, is of special importance. He suggests that the large semidiurnal tides of the North Atlantic are due mainly to an east-and-west oscillation of its northern portion. In Chapters VIII and XI of his Hydrodynamics, Lamb gives an excellent treatment of forced and free oscillations. Chapters III–V of Rayleigh's Theory of Sound; and Chapter IX, Vol. I, and Chapter VII, Vol. II, of Routh's Dynamics, have an important bearing upon the subject.

70. Chapter I, Part IVA, this manual, treats of the tidal forces, also of the equilibrium theory, which is applicable to some landlocked bodies of water. The definitions of several terms of frequent occurrence are given in Chapter III. The law connecting the forces with the oscillations of the water is given in Chapter VI.

Before attempting to point out possible oscillating areas, one should establish certain lemmas pertaining to the motion in question. A number of these are given here; but it is to be remarked that several which might have been given are really contained in Chapter VIII, "On the classification of rivers, straits, bays, etc."

(1) Generally, with such initial displacements as are likely to occur in nature, a landlocked body of water has one (proper) period of (free) oscillation, and perhaps several such periods. This is evidenced by the phenomenon of the seiches.

(2) When all boundaries are rigid, the oscillating area may be very narrow and contain curves or bends. E. g., Lake Geneva for seiche oscillations.

(3) When the two straight ends constitute the only rigid portion of the boundary, the width of the area should be at least about $\frac{1}{4}\lambda$ in order to produce a sensible stationary wave. It should be still wider if the length be a multiple of $\frac{1}{2}\lambda$ (§ 53).

(4) If one side wall of the area be land, then the necessary width is only one-half as great as in the preceding case.

(5) The virtual length of a right trapezoidal area is approximately its mean geometrical length (§ 51).

(6) A tapering or narrowing toward the end of a canal increases the frequency of oscillation; i. e., the actual or extreme length is greater than the virtual length (§§ 26–28, 47–50). The reverse is true for a gradual shoaling toward the shore or end of the area, provided we use the undiminished depth in making our estimates (§§ 38, 42, 45).

(7) A broadening at both ends, or a contracting at the middle, of a half-wave area decreases the frequency of oscillation; i. e., the actual or extreme length is less than the virtual length, $\frac{1}{2}\lambda$ (§ 54). The same is true for a shoaling at the middle, even if we use the mean depth in making the comparison (§ 55).

(8) The axis of a simple area may be bent at a loop whenever the outer side of the loop is well supported (§ 53).

(9) In a half-wave simple area having no transverse ridge dividing it into two or more physical bodies, i. e., in an area whose depths continuously decrease toward the end boundaries, the motions of the particles are simultaneous (i. e., not progressive) even up to the shallow ends (§ 38).

(10) If the depth of water suddenly becomes reduced as a shoal is approached to a small fraction of its general depth, the submerged shore line will act nearly the same as an ordinary shore line in producing the tides; a derived wave will, circumstances permitting, progress onward across the shoal area (§ 56). E. g., the extensive shoaling near the meridian 180° west.

(11) If an oscillation is caused by two opposing straight walls of different lengths, the rise and fall upon the longer will not be confined to the region lying opposite the shorter wall, but will extend some distance beyond (§ 53).

(12) Suppose a stationary oscillation to exist in a canal communicating with a tided sea; let the length of the canal lie between o and $\frac{1}{4}\lambda$, then at the time of high water outside it is high water throughout the canal (e. g., many Alaskan canals). If the length lie between $\frac{1}{4}\lambda$ and $\frac{3}{4}\lambda$, it is low water for a distance of $\frac{1}{4}\lambda$ from the head at the time it is high water outside (e. g., Irish Sea, node at Courtown; English Channel, node at Christchurch). If the length be equal or nearly equal to $\frac{1}{4}\lambda$, then the horizontal motion at the mouth, instead of the vertical motion, determines the time of tide within. This tide will be three hours, or $\frac{1}{4}\tau$, later than the tide outside: e. g., the Gulf of Maine (§§ 34, 44).

(13) Consider next a canal whose depth is nearly equal to that of the sea. If the landlocked portion (i. e., the canal proper) happens to be about $\frac{1}{4}\lambda$ in length and narrow, the rise and fall of the adjacent sea tide will be seriously interfered with by the tendency of the stationary wave to have little rise and fall, but comparatively great current velocities, at the junction of the canal and sea. The obvious way out of the difficulty for a broad canal is to imagine the same extended seaward until its length becomes quite different from $\frac{1}{4}\lambda$ and approaches $\frac{1}{2}\lambda$, then the rise and fall at this imaginary mouth does in no wise conflict with that of the sea at the same place; e. g., Bay of Bengal (§ 52).

(14) Whenever a rise and fall apparently necessitates a discontinuity in height, as at an incomplete boundary, a wave will generally be propagated outward, with velocity due to depth, from the discontinuity; or a dependent (stationary) oscillation will be set up in and beyond the openings.

(15) If we can see that a reflected wave must travel in a direction nearly opposite to that of the direct wave, then there must result a more or less considerable stationary wave dependent upon the degree or amount of the reflection. (§ 28, Part I.)

(16) A good reflection occurs where the cross section changes much within a small fraction of a wave length.

(17) If the region adjacent to an oscillating area consists of a bay or gulf, with numerous branching arms of different dimensions, and if it has various depths or has openings into other bodies of water, the wave will be almost wholly progressive, at least for a considerable distance up; for, no large regular reflected wave will return resembling the direct wave as it entered. E. g., Chesapeake Bay.

(18) A circular or a square area may have a progressive wave due to the superposition of two stationary waves whose phases are not equal. The horizontal paths of water particles common to any two non-simultaneous areas are elliptical. (§§ 26, 28, 32.)

(19) If one portion of an extended shore line of considerable range of tide, i. e., a shore line near the middle of a loop, recede from the portion where the range is greatest, then from this locality a derived wave will proceed along the shore. For, the reflections, caused by such shore line, of a disturbance from any assumed point or center cannot generally take a direction opposite to that of the disturbance, as a stationary wave requires. Similarly for a shore line oblique to the axis of an area, provided that the configuration is such that the range of tide is there considerable. E. g., southern Guinea, Senegambia, western Europe, southeastern Patagonia, for the semidiurnal wave; perhaps western Australia for the diurnal wave.

(20) In a strait, not too short, connecting a deep ocean with a sea which has neither tides of its own nor tides induced from without, the tide wave is stationary in its character. (§§ 35, 103.)

(21) In estimating the time of high water of a loop of a stationary wave having a broken boundary, we should consider the tide at points situated some distance within the boundary; that is, not too near the openings. As the openings are approached the time becomes later, supposing the wave to be freely transmitted beyond, either into an infinite sea or into one which does not reflect. The larger the opening the greater this delaying effect. E. g., Cape Horn, Iceland Channel, Baffin Bay, southwestern Africa, and off Senegambia.

(22) For an island situated in an oscillating area, but not too near a nodal line, it may be high or low water upon the side facing the nodal line earlier than in the sea surrounding the island. Similarly for a cape extending far into the area. E. g., Kahului, Maui Island, Hawaii; Apia, Samoan Islands; Cape Farewell, Greenland. (Cf. § 112.)

(23) If the amplitude of one wave be much, or even slightly, greater than that of a second wave of like period, the times of the resultant maxima and minima will be approximately given by those of the first. (§§ 4, 10, Part III, and Tables 15, 16.)

(24) Near the nodes or near the free boundaries of an oscillating area, the times of the tides may not be governed by the times of high and low water of the oscillation of the area. In such cases the tides are not easily explained because they arise from some other source or sources.

(25) If there are two not too distant non-simultaneous high-water regions, the cotidal lines will change gradually from one value to the other; i. e., the wave will seem to progress, but not as a free wave at a rate due to depth. (Cf. §§ 26, 28.) E. g., off Liberia and in the axis of the narrowest part of the Atlantic the cotidal hour is VI while at Madeira and the Canary Islands it is I or II; therefore the cotidal lines must be numbered from VI to I or II in this distance. Similarly for the region from Ecuador to Chile, and Chile to Cape Horn; Greenland to the United States; Hawaiian Islands to the Fiji and New Hebrides Islands; also the coast line between Halifax and the Bay of Fundy. Between regions nearly separated by land the change may be rapid. E. g., through Muskeget Channel, Vineyard Sound, and Fire Island Inlet. (Cf. §§ 102–106.)

Between two simultaneous regions, not too far apart, the tide is simultaneous.

71. In dividing the ocean's surface into oscillating systems and areas, charts of depths (Figs. 19, 20), Table 51, and a terrestrial globe at least 6 inches in diameter are of constant service. The directions of lines drawn upon the globe can be ascertained by a small semicircular protractor of, say, 0·6 inch radius. Besides outlining areas upon a globe, a more careful drawing should be made upon a Mercator's projection of the world. Great circles on this projection are easily drawn by means of a system of curves drawn upon a transparent sheet and representing great circles crossing the equator in two opposite points; these are cut orthogonally by a system representing small circles or distance lines. Generally speaking, the axis, if the area is simple, should be drawn perpendicularly to the ends. The lateral boundaries, if free, should be drawn from capes and headlands of the end boundaries where the shore line suddenly takes another trend. The values of lunar and solar wave lengths, expressed in degrees of a great circle, as well as in miles, are given in Table 51. For simple or canal-like areas, the depth may generally be assumed to be constant over each half-wave length; for areas less simple in form, the depth can generally be assumed to be constant throughout.

After the areas have been outlined, the forces are applied in accordance with the rules given in the last chapter. As a first approximation (and it is often about as satisfactory as the result o further effort) the application of the force diagrams may be limited to the localities of the nodal lines. If it is found that from hour to hour the curves representing the resultant virtual work have, for the system under consideration, a very small amplitude in comparison with the amplitude belonging to other systems, it is probable that no considerable oscillation will be set up, and the tentative system should be abandoned, even if its dimensions be such that its period of free oscillation should agree fairly well with the periods of the tidal forces. (Cf. § 39.)

With the foregoing considerations kept in view, two charts (Figs. 23, 24) have been constructed—one for the semidiurnal systems and one for the diurnal. The Roman numerals indicate, unless otherwise stated, the cotidal hours; i. e., the Greenwich lunar times of semidaily or of daily high water as the case may be. These charts are supposed to show the times of high water as given by the assumed cause. When a locality is covered by two systems, the time belonging to each is given, and so the time of the real tide would be inferred to be intermediate between the two. Again, when a locality is covered by no system, or is quite near a node, the possibility of a derived progressive wave or of a dependent fractional area must be considered.

Many results of observation can be seen upon referring to Berghaus's cotidal chart of the world (Fig. 25); to a table given under §79 extracted from the Admiralty and the Coast Survey Tide Tables; to a table given under § 97 based upon harmonic constants; to Van der Stok's charts of the East Indian Archipelago (Figs. 29, 30); and to numerous items taken from charts, coast pilots, etc. It is to be noted that the cotidal hours given by Berghaus, or obtained from the Admiralty Tide Tables, refer to the lunitidal intervals at full and change, whereas the cotidal hours derived from harmonic constants, or extracted from the Coast Survey Tide Tables, refer to mean lunitidal intervals. Generally speaking, the numbering of the cotidal hours dependent upon the intervals at full and change must be diminished by about 20 minutes to make them comparable with cotidal hours referring to mean intervals. The theoretical cotidal hours always refer to mean intervals.

The principal systems for the semidaily tide may be designated thus: 1. North Atlantic; 2. South Atlantic; 3. North Pacific; 4. South Pacific; 5. North Indian; 6. South Indian; 7. South Australian (solar).

72. The North Atlantic system is in the form of a broad band extending from the northeastern coast of Brazil northeasterly $\frac{1}{2}\lambda$, thence northwesterly $\frac{1}{2}\lambda$ to Greenland and Baffin Bay. This system may be regarded as a bent area λ in length or, preferably, on account of the depths, as two trapezoidal areas each $\frac{1}{2}\lambda$ in length. In a free oscillation of a right trapezoid the rise and fall in the acute angle is much greater than elsewhere. Hence we should expect to find the range of tide great at Morocco, Spain, and Portugal and rather small at the Azores, especially at the most western islands of the group. The tides of northern Portugal, Spain, and France (and therefore Great Britain), are increased by the fact that this continental coast line in a general way opposes the American coast extending from Newfoundland to Cape Farewell by way of Davis Strait, the distance between the two coasts being about $\frac{1}{2}\lambda$.

The area thus defined really forms a part of the North Atlantic system; otherwise it would be too narrow to permit any considerable oscillation (lemma 3).

By making use of the force diagrams (Fig. 1) in the manner already stated, noting that the depth of the northern area is less than that of the southern, also that the motion should be greater on the eastern side of the trapezoidal areas than on the western, because the acute angle lies along that side in both instances, we find that the cotidal hour at each American end should be about VIII and off Morocco and Portugal it should be about II.

According to lemma 19 a derived progressive wave should move up the western coast of the British Isles, and thence into the Arctic seas.

The results of observation can be seen upon consulting the data just referred to.

In reality there is probably no well-defined nodal lines in the northern area because of the great progressive wave just referred to; but there is an approach to one. See Admiralty Tide Tables under "Tides around Ireland." In the southern area the nodal line is obliterated because the South Atlantic system has a loop between Cape Verde Islands and Brazil.

73. The South Atlantic system bears a fanciful resemblance to a branching tree, the trunk very broad and $\frac{1}{2}$ λ in length, extending from the Antarctic Continent to about latitude 27° S. One branch extends northeasterly $\frac{1}{2}$ λ to Baluchistan and India; another branch extends northwesterly λ to the Atlantic coast of the United States; a third branch extends about west-northwest $\frac{1}{2}$ λ to the eastern coast of Brazil.

By making use of the force diagrams we find that for the Antarctic Continent, the coast of Baluchistan (save for the effect of the Indian systems), and Brazil, the cotidal hour should be VI. For the vicinity of South Africa (save for the effect of the south Indian system), and for the east coast of the United States, the hour should be XII.

According to lemma 19 a derived progressive wave should move northward from off the western coast of southern Africa along the shores of the Gulf of Guinea, thence westward until it is masked by other tides. Because the loop west of Morocco and Portugal belongs to the North Atlantic system while the loop east and north of eastern Brazil belongs to the present system, the cotidal hours should, according to lemmas 19 and 25, change rapidly from the Cape Verde Islands to the Madeira Islands.

Three of the nodal lines should be capable of some verification by observation; one sets out from near Guadeloupe Island, another passes near Ascension, another we suppose to pass north of Bouvet Island.

To compare with observation, consult the sources of information already referred to in § 71, and bear in mind the preceding lemmas. No observations have yet been made along the Antarctic Continent.

This theory explains why it is that the observed semidiurnal tides are very small in the Caribbean Sea, thus causing the total tide to be largely diurnal.

74. The North Pacific system consists of two parts; a triangular region between North America and Asia, and a trapezoidal one extending from the southern side of the triangle to the coast of Chile, a distance about equal to λ. The acute angles of the triangle fall at Colombia and the Philippine Islands; the obtuse angle at Alaska. If regarded as consisting of two right triangles, the right angles may be supposed to fall south of the Hawaiian Islands. According to the theory (§ 27) of the oscillation of a plane right triangle whose oblique angles are 30° and 60°, the rise and fall at these angles should be three times as great as that at the right angle or at the middle point

of the hypotenuse. The nodal lines divide the hypotenuse into three equal parts. The virtual length is the distance from the right angle to the hypotenuse.

The theoretical cotidal hours for the entire system (triangles and trapezoid together) are not far from III and IX, as indicated on the chart (Fig. 23).

Along the imaginary boundary shown by a heavy line drawn from the Aleutian Islands to Japan, the rise and fall, from what has just been said, should be small in comparison with that of the Gulf of Alaska. From this imaginary boundary a derived wave should, according to lemma 15, proceed into the Okhotsk and Bering Seas, the range of tide in the Bering Sea should be somewhat reduced because of the proximity of a nodal line. The American end of this nodal line should be obscured by the presence of the South Pacific system. The openings in the rigid boundary between Luzon and Japan should, according to lemma 21, cause the observed tide to be somewhat delayed beyond its theoretical hour.

The southern boundaries of the triangles are, of course, somewhat uncertain. The heavy line is supposed to be drawn about where the range of the direct tide or oscillation becomes comparatively small. But by lemma 25 (latter part) there should be a good tide at the Galapagos Islands. The region around the right angles has an effectual or virtual boundary in the canal or trapezoidal area extending to Chile, a distance about equal to λ. The nodal line extending from near Acapulco to the Society Islands ought to be observable, especially at its northern end. The nodal lines drawn southeast of Japan would probably be obscured because of the irregularity of the shore line.

If the shores of California and those of Japan were more extended and more squarely opposing each other, theory would give VIII. 5 as the cotidal hour for the ends of this strip and II. 5 as that for the middle. It is possible that the effect is slightly felt under existing conditions. If so, it would tend to obscure the nodal line just mentioned.

As in the preceding cases, the above statements can be compared with observation. The agreement appears to be reasonably satisfactory; but more observations are needed to prove or disprove the existence of the nodal lines. This last remark has special reference to the eastern Ladrone Islands, the Caroline Islands, the (outer side of the) western Aleutian Islands, and Clipperton Island.

75. The South Pacific system comprises a belt extending from southern Chile and Graham Land westerly and northwesterly a distance nearly equal to λ, thence northeasterly a distance nearly equal to λ to the coast of southern and Lower California. If we add to the L-shaped figure just described the space inclosed between it and the American coast, we have, roughly speaking, a sector of a circle. The free period of a circular sector is obtained by using for λ about 0·90 of the radius. The center may be placed at 180° W. and 20° S. The two nodal circles have for radii 0·34 and 0·79 of the radius of the sector. The rise and fall at the center of a circle should be more than thrice that at the circumference. While it is not probable that the sector is perfect enough to be very satisfactory, there being no rigid walls along the radial boundaries, it seems likely that it does modify the positions of the nodal lines of the L-shaped figure and lengthen the period of oscillation; also that it helps to explain the considerable range of tide north of New Zealand. It is probable that a sector truncated along the 180th meridian would be a better representative than the sector just described.

The principal support of the western loop of this system is the shoaling which approximately coincides with the 180th meridian (Fig. 20). Again, there is a shoaling which extends from the Fiji Islands northwesterly. It lies at a distance of about λ from the opposing North American coast, the latter extending from Alaska to Mexico (§ 53). The indefinite character of the supports of this loop adds to the uncertainty of the nodal lines of the system.

The cotidal hour for the extremities and angle of the L should be VI. Between the nodal lines (or circles), other causes aside, the hour should be XII.

Tierra del Fuego and Graham Land form an incomplete boundary through which, according to lemma 14, a large derived wave should be propagated. Since the eastern coast of Patagonia is remote from any oscillating area of the Atlantic, and is so situated that no derived wave of that ocean can be considerable, one can reasonably infer that the tides of this coast should be due to a wave propagated from the South Pacific system through the opening south of Cape Horn. The tides on either side of the opening should be somewhat belated (lemma 21).

From the angle of the axis of the L, a wave (lemma 10) should progress toward Australia at the rate due to depth. Moreover, because eastern New Zealand is not far from a node, the wave progressing down its western coast should proceed up the eastern coast; this wave should also govern the tides at Chatham Islands.

A loop of this system being opposite the Hawaiian Islands should cause the tides to be earlier on the southeastern shore of Hilo Island than at Oahu or islands farther west.

Observations are roughly in accord with the preceding statements, as can be seen upon consulting the sources of information referred to in § 71.

76. The North Indian system consists of a simple or canal-like area extending from the northwestern coast of Australia, a distance λ to the coast of Somali and Arabia. By theory, the cotidal line at either end should be III, and between the nodal lines it should be IX. Moreover, the Bay of Bengal being a dependent fractional area whose length lies between $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$, the cotidal hour above the nodal line should, by lemma 13, be III.

On account of the extensive shoal off the northwestern coast of Australia, the range of tide should there be considerable. Moreover, a derived progressive wave should proceed toward and into the shallow Arafura Sea, and often with increased range. The great depths of the Banda Sea and the nature of its boundaries would prevent the derived wave from there occasioning any great rise and fall. Because the eastern boundary of the North Indian system is very oblique to the axis of the area, and because of the opening eastward it seems probable that the nodal line south of Sumatra would not be very well defined. But the nodal line drawn from Ceylon to Babie Island should be tolerably perfect. The gradual shoaling of the Bay of Bengal considerably increases its virtual length as estimated by its mean depth (§ 38). The presence of an area (between Hindostan and Mozambique) belonging to the South Atlantic system (and South Indian system), should probably obscure the nodal line drawn through the Laccadive Islands.

For comparing these statements with observation, consult the sources of information referred to in § 71; especially consult Van der Stok's M_2 chart of the East Indian Archipelago (Fig. 29). To obtain the Greenwich cotidal hour from his M_2 chart, divide the values given by 30 and diminish the result by 7·1 h., the east longitude of Batavia. See Berghaus' cotidal chart (Fig. 25).

The time required for a free wave to travel from Timor Island to the Pacific Ocean at Gilolo and Molucca passages is perhaps six hours. Conformably to theory, the M_2 cotidal hour is about III for the southern body of water, and moreover the range of tide is considerable, as is shown in an exaggerated form at Port Darwin, Australia; also we should expect, what observation shows, that the semidiurnal tide should be small around Gilolo and Molucca passages. Hence the wave should progress from the southern body of water northward to the Pacific Ocean. The cotidal hour at these passages should be about III + 6, or IX. According to Van der Stok's chart, the wave progresses northward.

77. The South Indian system consists of a simple area extending from the south coast of Australia southwesterly $\frac{1}{2}\lambda$ to where it is supported by the Antarctic Continent; thence northwesterly $\frac{1}{2}\lambda$ to Madagascar and South Africa. The cotidal hour, at either end, should be III.

On account of the narrowness of this area and its general lack of lateral boundaries, the oscillation set up by the tidal forces should not be as great as in most other areas (lemma 3). For this reason one would expect to find the tide around Tasmania, except at its northwestern corner, governed by the comparatively large derived wave which sets out from the angle of the South Pacific system. The nodal line falling near Cape Leeuwin should prevent there being any sensible semidiurnal tide from the South Indian system on the western coast of Australia, say at Freemantle (§ 53). For a similar reason this coast should have no great tide from the North Indian system.

Because of the western nodal line, the range of tide at the Crozet Islands should be small.

Some comparison with observation can be had from consulting Berghaus's cotidal chart of the world and tables of cotidal hours already referred to. In addition to this, see map of southeastern Australia (Fig. 34) and the chart of depths (Fig. 20). It is important that tides be observed upon the Antarctic Continent in longitude about 80° or 85° east; also at Crozet Islands.

78. The South Australian system consists of a simple area extending from the Antarctic Continent, a distance of about $\frac{1}{2}\lambda$ (solar), to the south coast of Australia. The solar cotidal hour for the north end should be VI and for the south end XII.

If the tides of the South Indian system were wholly lunar, then at a station on the south coast of Australia the epoch of the solar wave should exceed that of the lunar by about 90°. But the tides of the South Indian system being partially solar, as is almost always the case elsewhere, this difference would be diminished somewhat.

To compare observation with theory, it is necessary to know the amplitude and epoch or interval of the solar wave. The tides at Port Adelaide have been harmonically analyzed, and the results are in accord with what has been stated. But such an analysis should be made for some station on the Great Australian Bight; also for a station on the Antarctic Continent in longitude about 130° east.

79. *Observed intervals, ranges, cotidal hours, etc., for the semidaily tide systems.*

In the following table the tidal values are taken either from the Admiralty or the Coast Survey Tide Tables. Intervals taken from the former relate to the time of full and change; those taken from the latter are mean intervals. (See § 71.) The table given under § 97 should be consulted in connection with the one given here whenever the region in question contains stations at which harmonic analyses have been made. This can be ascertained by referring to the charts of tide stations (Figs. 21, 22).

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH ATLANTIC SYSTEM (BRAZILIAN END).	° ′ South.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Aracati	4 28	37 45	2 31	6 00	....	....	8	6	8·32
Ceara	3 42	38 31	2 34	5 35	....	....	8¼	....	7·97
Jericoacoara	2 48	40 32	2 42	5 15	....	....	8	6	7·77
Tutoia Anch	2 46	42 21	2 49	5 13	....	....	12¾	....	7·86
Santa Anna Rfs	2 16	43 36	2 54	5 45	....	....	13	....	8·46
Maranham, San Luiz	2 30	44 19	2 57	7 00	....	....	16½	10¾	9·71
Manoel Luiz Rf	0 52	44 14	2 57	5 00	....	....	12	....	7·78
San Joao Is	1 17	44 55	3 00	6 24	....	....	14	....	9·18
	North.								
Conani R	2 50	50 53	3 24	6 38	....	....	19	....	9·81
Cape Cachipour	3 49	51 01	3 24	5 52	....	....	7–10	....	9·07
Cayenne R	4 56	52 20	3 29	4 37	....	....	5–7	....	7·94
Salut Is	5 17	52 35	3 30	4 26	....	....	6–10	....	7·78
Maroni R	5 45	54 00	3 36	5 00	....	....	9	6	8·43
Surinam	6 02	55 13	3 41	6 00	....	....	9–10	5–6	9·48
Nickerie R	5 58	57 02	3 48	4 30	....	....	9½	....	8·15
Cappename R	5 50	55 57	3 44	5 30	....	....	8	....	9·04
Corentyn R	6 00	57 08	3 49	5 10	....	....	8½	5½	8·81
Berbice	6 17	57 30	3 50	4 30	....	....	8–10	6	8·18
Demerara R	6 49	58 11	3 53	4 28	....	....	9	6	8·20
Orinoco R., entr	9 02	60 50	4 03	6 00	....	....	3	....	9·85
Trinidad, Maracas B	10 45	61 26	4 06	3 30	....	....	5	4	7·48
Boca Mono	10 42	61 41	4 07	3 50	....	....	4	2½	7·82
Boca Grande	10 40	61 47	4 07	3 30	....	....	4	2½	7·50
Carenage	10 41	61 37	4 06	4 20	....	....	4	2½	8·29
Port of Spain	10 39	61 31	4 06	4 08	....	....	3¾	3	8.09
San Fernando	10 17	61 28	4 06	4 38	....	....	5	3	8·58
Icacos Pt	10 03	61 56	4 08	4 33	....	....	7½	4½	8·53
Guayaguayare B	10 09	61 02	4 04	4 25	....	....	7	4	8·34
Tobago	11 10	60 42	4 03	3 00	....	....	4	2	6·95
Grenada, St. George Hr	12 04	61 45	4 07	2 40	....	....	1½	¾	6·70
Grenadines	12 40	61 20	4 05	3 00	....	....	1½	....	7·99
St. Vincent, Kingstown	13 10	61 13	4 05	3 00	....	....	1½	1	6·98
Barbados, Carlisle B	13 07	59 36	3 58	3 00	....	....	3	1½	6·87
NORTH ATLANTIC SYSTEM (ANGLE).									
Ferro, Canary Is	27 46	17 53	1 12	0 30?	....	....	9?	....	1·68
Palma Is	28 40	17 45	1 11	0 30?	....	....	9?	....	1·66
Gomera Is	28 06	17 07	1 08	0 45?	....	....	9?	....	1·86
Santa Cruz, Tenerife	28 28	16 15	1 05	1 30	....	....	8	6	2·53
La Luz, Gran Canaria	28 09	15 25	1 02	0 52	....	....	10	....	1·87
Fuerteventura	28 42	14 01	0 56	1 00?	....	....	9?	....	1·90
Lanzarote Is	28 57	13 33	0 54	1 00?	....	....	8	....	1·87
Agadir or Santa Cruz	30 29	9 35	0 38	0 45	....	....	9	....	1·36
Mogador	31 31	9 43	0 39	1 18	....	....	10–12	....	1·91
Mazighan	33 15	8 31	0 34	1 33	....	....	9¾–13	....	2·07
Rabat	34 04	6 46	0 27	1 46	....	....	9–12	....	2·16
El Araish	35 11	6 05	0 24	1 30	....	....	9–12	....	1·85
Tangier	35 47	5 48	0 23	1 42	....	....	8¼	5	2·02
Fayal, Azores	38 32	28 38	1 55	11 45	....	....	4	....	1·27

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH ATLANTIC SYSTEM (ANGLE)—continued.	° ′ *North.*	° ′ *West.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Terceira, Azores	38 38	27 14	1 49	0 32			4½		2.34
St. Michael, Azores	37 49	25 08	1 41	0 30			6		2.16
Funchal B., Madeira	32 38	16 55	1 08	0 48			7		1.90
Porto Santo B	33 05	16 22	1 05	0 50			7		1.88
Gibraltar, new mole	36 07	5 21	0 21	1 47			3¼	2½	2.07
Algeciras	36 07	5 25	0 22	1 49			4	2½	2.13
Tarifa	36 00	5 36	0 22	1 46			6	3½	2.08
Conil	36 17	6 15	0 25	1 18			12	7½	1.68
Cadiz	36 31	6 19	0 25	1 12			12¾	8½	1.58
Rota	36 37	6 21	0 25	1 24			12½	8	1.77
Salmedina Rks	36 42	6 26	0 26	1 10			10	6½	1.56
Bonanza	36 48	6 20	0 25	2 15			10	6½	2.59
Port of Huelva	37 08	6 50	0 27	1 54			10	7½	2.29
Guadiana R	37 10	7 19	0 29	1 57			12		2.36
Lagos	37 07	8 38	0 35	2 07			13		2.62
Setubal	38 31	8 45	0 35	2 30			11½	7	3.00
Cascaes B	38 42	9 24	0 38	1 51			10½		2.42
Lisbon (Belem)	38 41	9 06	0 36	2 15			12	9	2.77
Peniche	39 20	9 23	0 38	1 54					2.47
Mondego (bar), Figueira	40 09	8 52	0 35	1 59			12½	8	2.50
Oporto	41 09	8 41	0 35	2 30			10	8	3.00
Miño R	41 52	8 50	0 35	2 30			7		3.00
Vigo	42 15	8 41	0 35	3 15			13		3.48
Arosa B	42 28	9 01	0 36	3 00			11	7½	3.50
Cape Finisterre	42 53	9 16	0 37	3 00					3.52
Camariñas Port	43 08	9 09	0 37	2 33			13	11	3.08
Coruña	43 23	8 24	0 34	2 41			13	11	3.16
Ferrol	43 29	8 16	0 33	3 00			13¾	9½	3.45
Cedeira	43 39	8 05	0 32	3 00			11	8	3.43
Vivero	43 41	7 32	0 30	3 00			15		3.40
NORTH ATLANTIC SYSTEM (NORTH AMERICAN END).									
Vestmannaeyjar	63 22	20 23	1 22	4 50			11		6.04
Reykjavik	64 12	21 50	1 27	5 21			14½		6.62
Hvamnesvig				5 40			14½	8	
Grundar fiord	65 00	23 18	1 33	4 45			14½	8	6.14
Stykkisholm	65 05	22 42	1 31	5 45			12	6¼	7.08
Patrix fiord	65 35	24 00	1 37	5 25			10¾	8	6.82
Svend Seyre	65 37	23 48	1 35	6 15			12?		7.62
Bildal, Arnar fiord	65 41	23 35	1 34	6 30			10		7.85
Dyra fiord	65 55	23 45	1 35	6 30			9–10	5–6	7.86
Flateyre, Onundar F.	66 03	23 30	1 34	6 15			11?		7.61
Skutils fiord	66 05	23 05	1 32	7 32			8		8.81
Nennortalik	60 08	45 16	3 01	6 00			8¼		8.82
Julianshaab	60 42	45 54	3 04	5 06			7	5	8.00
Arsuk	61 12	48 27	3 14	6 25			12	9	9.43
Frederickshaab	62 00	49 37	3 18	6 22			9	5	9.45
Godthaab	64 12	51 44	3 27	7 00			12		10.21
Holsteinborg	67 00	53 42	3 35	6 30			10		9.86

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH ATLANTIC SYSTEM (NORTH AMERICAN END)—c't'd.	° ′ *North.*	° ′ *West.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Eclipse Hr	59 50	64 10	4 17				5		
Nachvak B	59 05	63 20	4 13	7 08			5	3¾	11·11
Nain	56 34	61 44	4 07	7 09			6½		11·03
Ford Hr., Paul I	56 27	61 13	4 05	6 46			6½	4	10·62
Hopedale	55 25	60 20	4 01	5 38			7	4	9·46
Aillik B	55 09	59 05	3 56				7		
Webeck	54 54	58 02	3 52	6 21			7	4	10·01
Holton Hr	54 34	57 14	3 49	6 44			5¾	4	10·33
Ice Tickle	54 28	57 15	3 49	6 20			7	4	9·94
Run-by-guess	54 28	57 18	3 49	7 05			5¾		10·66
Pomeroy Inlet, Indian Hr	54 30	57 30	3 50	6 20			7	4	9·95
Rigoulette	54 11	58 25	3 54	7 37			4	3½	11·26
SOUTH ATLANTIC SYSTEM (SOUTH AFRICA, ETC.).	*South.*	*East.*							
Simons B	34 11	18 27	1 14	2 44			5¼	3½	1·41
Hout B	34 06	18 20	1 13	2 20			5		1·03
Table B	33 54	18 25	1 14	2 40			5	3½	1·35
Saldanha B	33 05	17 58	1 12	2 30			5	3½	1·22
St. Helena B	32 45	18 08	1 13	2 30			6		1·20
Roodewall B	30 27	17 21	1 09	2 30			6¼		1·27
Hondeklip B	30 19	17 16	1 09	2 30			5¼		1·27
McDougall Hr	29 17	16 53	1 08	2 30			5¾		1·29
Port Nalloth	29 15	16 51	1 07	2 35			5¼	3½	1·38
Elizabeth B	26 51	15 11	1 01				5–6		
Angra Pequena	26 40	15 12	1 01	2 30			8		1·40
Ichabo I	26 18	14 58	1 00	1 00			6	4	−0·03
Spencer B	25 43	14 53	1 00	10 50			5–6		9·47 (?)
Port d' Ilheo	23 20	14 28	0 58	3 00			8–10		1·93
Walfisch B	22 55	14 30	0 58	3 20			5½	3¾	2·25
Great Fish B	16 40	11 52	0 47	3 00			5	3½	2·12
Port Alexander	15 49	11 52	0 47	3 00			5		2·12
Little Fish B	15 10	12 10	0 49	2 30			5–6?		1·60
Benguela	12 34	13 23	0 54	3 00?			4½	3¼	2·00
		West.							
Tristan da Cunha	37 10	12 15	0 49	Noon.			4–6		0·82
St. Helena Id	15 54	5 44	0 23	3 11			3		3·46
		East.							
Dyer I	34 41	19 25	1 18	2 50			5		1·44
Cape Agulhas	34 50	20 01	1 20	2 50			5		1·41
St. Sebastian B., Port Beaufort	34 24	20 51	1 23	3 08			6		1·65
Mossel B	34 11	22 09	1 29	3 30			6		1·90
Knysna Hr	34 05	23 04	1 32	3 30			6–7		1·85
Plettenberg B	34 03	23 28	1 34	3 10			6		1·49
Cape St. Francis	34 12	24 53	1 40	3 34			5		1·77
Algoa B., P. Elizabeth	33 58	25 37	1 42	3 20			5¼	4	1·52
Bird I	33 50	26 18	1 45	4 00			4–5		2·11
Kowie R., P. Alfred	33 36	26 53	1 48	3 50			4–5	3	1·90
Waterloo B	33 29	27 11	1 49	4 00			6		2·04
East London, Buffalo R	33 02	27 55	1 52	3 47			5	3¾	1·79
St. John R	31 36	29 34	1 58	4 08			5¼		2·02

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH ATLANTIC SYSTEM (SOUTH AFRICA, ETC.)—c't'd.	° ′ *South.*	° ′ *East.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Port Natal	29 53	31 04	2 04	4 30	....	....	6	....	2.28
Delagoa B., P. Melville	25 59	32 54	2 12	4 30	....	....	15	....	2.15
Shefeen I	25 54	32 43	2 11	4 40	....	....	12	....	2.33
Lorenzo Marques	25 58	32 34	2 10	5 20	....	....	12	....	2.98
Limpopo R	25 12	33 31	2 14	4 20	....	....	11	....	1.96
Innambán R	23 45	38 32	2 34	5 38	....	....	11	7	2.87
Bazaruto B	21 40	35 20	2 21	4 26	....	....	12	....	1.93
Chiluán I	20 40	34 56	2 20	4 49	....	....	18½	13	2.32
Sofala R	20 12	34 42	2 19	4 00	....	....	19	....	1.54
Pungue R. entr	19 52	34 48	2 19	4 22	....	....	17	....	1.90
Zambezi R. entr	18 47	36 30	2 26	4 30	....	....	12–15	....	1.92
Kilimán R. entr	18 02	36 58	2 28	4 20	....	....	12¼	7½	1.72
Macuse R	17 44	37 12	2 29	4 20	....	....	14	12	1.71
Angoche R	16 15	39 55	2 40	4 00	....	....	10–12	....	1.19
Antonio R	16 00	40 08	2 41	3 15	....	....	13	10	0.46
Mozambique Hr	14 58	40 44	2 43	4 15	....	....	12	....	1.39
Almeida B	13 40	40 32	2 42	4 10	....	....	12–15	....	1.33
Pomba B	12 56	40 28	2 42	4 15	....	....	15	11	1.41
Ibo Hr	12 18	40 32	2 42	4 15	....	....	11	....	1.41
Kero Nyuni pass	11 35	40 40	2 43	4 15	....	....	13	8	1.39
Ras Msangi	11 11	40 30	2 42	4 10	....	....	14	9	1.33
Tunghi B	10 45	40 38	2 43	4 05	....	....	14	9	1.23
Keonga B	10 34	40 32	2 42	4 10	....	....	12	....	1.33
Rovuma B	10 26	40 30	2 42	4 10	....	....	12	....	1.33
Msimbati Chan	10 17	40 24	2 42	4 00	....	....	11	....	1.16
Mto Mtwara	10 18	40 10	2 41	3 45	....	....	12	....	0.94
Mikindani	10 13	40 12	2 41	3 45	....	....	12	....	0.94
Mgan Mwania Mungulho	10 05	40 00	2 40	3 45	....	....	12	....	0.95
Lindi R. entr	10 00	39 44	2 39	4 05	....	....	11	....	1.30
Mchinga B	9 43	39 45	2 39	4 00	....	....	12	....	1.21
Kiswere Hr	9 25	39 36	2 38	4 25	....	....	12	....	1.64
Kilwa Kisiwani	8 56	39 34	2 38	3 45	....	....	12	7½	0.99
Chole B. Mafia I	7 56	39 47	2 39	4 00	....	....	15	10	1.21
Dar-es-Salaam	6 49	39 19	2 37	4 20	....	....	14	9	1.57
Latham I	6 55	39 56	2 40	4 00	....	....	12	....	1.19
Zanzibar Chan	6 25	39 15	2 37	4 20	....	....	15	10	1.57
Zanzibar	6 09	39 11	2 37	4 15	....	....	15	10	1.49
Kokotoni Hr	5 50	39 17	2 37	4 10	....	....	15	....	1.41
Pangani R	5 26	38 59	2 36	4 15	....	....	15	10	1.51
Pemba I. Mchengangazi	5 07	39 51	2 39	3 43	....	....	11	7¾	0.94
P. Cockburn, Pemba I	5 10	39 45	2 39	4 00	....	....	12	8	1.21
Tauga B	5 05	39 05	2 36	4 00	....	....	12	7	1.26
P. Mombasa	4 05	39 40	2 39	4 00	....	....	12	8	1.21
Kilifi	3 37	39 51	2 39	4 00	....	....	12	8	1.21
Malindi	3 07	40 11	2 41	4 05	....	....	12½	9¼	1.27
Ozi Anch	2 40	40 40	2 43	4 08	....	....	10¾	6½	1.27
Lamu Hr	2 20	40 55	2 44	4 40	....	....	11	7	1.77
Manda B	2 15	41 00	2 44	4 00	....	....	10	7	1.13
Patta B	2 12	41 03	2 44	4 30	....	....	10	8½	1.62
Port Durnford	1 13	41 55	2 48	4 25	....	....	12	9	1.47
Kisimayu B	0 23	42 33	2 50	4 00	....	....	10	6	1.03

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH ATLANTIC SYSTEM (SOUTH AFRICA, ETC.)—c't'd.	° ′ South.	° ′ East.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
P. Nievre, Diego Suarez B	12 15	49 30	3 18	3 33	....	....	6½	4½	0 13
Port Ambavarane	12 26	49 32	3 18	4 15	....	....	5¾	....	0·93
Port Leven	12 45	49 45	3 19	3 30	....	....	7½	....	0·06
Andrava B	12 58	49 53	3 20	3 30	....	....	7	....	0·06
Antongil B., P. Choiseul	15 29	49 50	3 19	4 00	....	....	5	....	0·54
Tangtang Hr	16 45	49 45	3 19	4 30	....	....	6	....	1·03
Madame I., St. Mary Hr	16 55	50 00	3 20	4 00	....	....	5	....	0·53
Fenerive	17 25	49 25	3 18	....	....	....	3½	....	....
Tamatave	18 08	49 26	3 18	4 18	....	....	8	....	0·86
Vatomandri	19 18	49 04	3 16	4 20	....	....	7¾	....	0·92
Fort Dauphin	25 01	47 01	3 08	4 30	....	....	4-5	....	1·22
Cape St. Mary	25 38	45 04	3 00	4 30	....	....	10–12	....	1·35
St. Augustine B	23 34	43 46	2 55	5 50	....	....	10½	7¼	2·72
Tulléar Anch	23 20	43 43	2 55	5 53	....	....	8¼	4¼	2·76
Ranobe P	23 08	43 38	2 55	6 00	....	....	9	....	2·88
Nosi Hao	22 05	43 10	2 53	5 00	....	....	8¼	5½	1·95
Morombé C	21 46	43 20	2 53	6 00	....	....	12½	8½	2·92
Ampasilava B	21 11	43 45	2 55	5 00	....	....	14¼	9¾	1·91
Morondava	20 20	44 18	2 57	4 36	....	....	14¼	10¼	1·49
Barren Is	18 20	43 46	2 55	4 45	....	....	12	....	1·67
Maintirano (Kivinja)	18 09	44 03	2 56	4 45	....	....	16¼	11¼	1·66
Boyanna B	16 05	45 20	3 01	4 33	....	....	10¾	7¼	1·38
Makambi	15 43	45 55	3 04	4 27	....	....	11	7¾	1·23
Bombetoke B., Mojanga	15 50	46 21	3 05	4 45	....	....	12½	8¾	1·51
Mahajamba B	15 15	47 03	3 08	4 30	....	....	11¾	8	1·22
Moramba	14 55	47 20	3 09	3 53	....	....	11¾	8¼	0·60
Nosi Lava	14 33	47 36	3 10	4 20	....	....	11¾	8¼	1·02
Maravaay	....	....	....	7 00	....	....	11¾	8¼	....
Port Radama	14 15	48 05	3 12	4 40	....	....	13	....	1·31
Nosi Bé	13 15	48 15	3 13	4 38	....	....	14	8¾	1·26
Minow Is	12 55	48 35	3 14	5 00	....	....	15	10	1·60
Ampamonti B	12 30	48 50	3 15	4 23	....	....	10½	....	0·99
Courrier B	12 15	49 08	3 17	4 21	....	....	10	....	0·92
P. Liverpool	12 05	49 15	3 17	4 17	....	....	8	....	0·86
Glorioso Is	11 35	47 25	3 10	5 00	....	....	10?	....	1·66
SOUTH ATLANTIC SYSTEM (HINDOSTAN, ETC.).	North.								
Jashk B	25 40	57 50	3 51	9 30	....	....	9	....	5·33
Khor Rabij	25 25	59 15	3 57	10 10	....	....	9½	3	5.87
Chahbár B	25 16	60 30	4 02	9 30	....	....	9	....	5·15
Gwatar B	25 10	61 30	4 06	9 30	....	....	8–9	....	5·08
Gwádar B	25 10	62 20	4 09	9 30	....	....	8–9	....	5·03
Sonmiyáni Hr	25 25	66 35	4 26	9 00	....	....	9?	....	4·27
Karachi, Manra Pt	24 47	66 58	4 28	10 19	....	....	9½	5-6	5·50
Indus R., Gisri entr	24 47	67 04	4 28	9 45	....	....	7–10	....	4·95
Píti R. entr	24 40	67 08	4 29	10 05	....	....	9	....	5·26
Kúdi or Coondee R	24 35	67 09	4 29	9 50	....	....	10	....	5·02
Dubba R. "	24 20	67 15	4 29	10 10	....	....	8	....	5.34
Hajamro R. "	24 06	67 18	4 29	10 19	....	....	9–10	....	5·49
Keti	....	....	....	0 00?	....	....	....	....	....
Sir R. entrance	23 40	68 08	4 33	10 30	....	....	11	....	5·59

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semidiurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH ATLANTIC SYSTEM (HINDOSTAN, ETC.)—continued.	° ′ North.	° ′ East.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Sir R. Juggi	24 00	68 23	4 34	1 30	....	....	6	....	8·88
Kediwara mouth	24 02	67 30	4 30	10 19?	....	....	9–10	5– 8	5·47
Khori creek bar	23 33	68 20	4 33	10 19	....	....	8½–12	6– 7	5.42
Lakhpat	23 30	68 25	4 34	0 15	....	....	12	....	7·67
Goia Cr	23 15	68 35	4 34	11 19	....	....	8½–12	6– 7	6·36
Mandvi Rd	22 50	69 22	4 37	11 33	....	....	15	11	6·54
Rupenbandar	22 15	68 57	4 36	10 30	....	....	10	7	5·54
Porbandar	21 38	69 35	4 38	9 59	....	....	8½	6½	5·01
Navibandar	21 26	69 47	4 39	10 17	....	....	8	6½	5·29
Mangról Bandar	21 06	70 06	4 40	10 30	....	....	7	5	5·47
Verával Rd	20 53	70 22	4 41	10 27	....	....	9	7½	5·42
Mandwa B	20 45	71 00	4 44	0 00	....	....	8	6	7·27
Diu Hr	20 42	71 00	4 44	11 00	....	....	6	4½	5·90
Bassein creek	19 19	72 48	4 51	11 49	....	....	11½–15½	8½–11	6·57
Vesava	....	....	....	11 42	....	....	14	8½	....
Bombay Apollo Bandar	18 55	72 50	4 51	11 35	....	....	14¾	11¾	6·34
Chaul	18 33	72 56	4 52	11 00	....	....	11¼	8	5·76
Rajpuri R. entr	18 18	72 56	4 52	10 47	....	....	14	8–10	5·55
Bankot or Savitri R	17 59	73 03	4 52	10 37	....	....	9½	7¼	5·39
Dabhol R	17 35	73 10	4 53	10 40	....	....	8	5½	5·42
Boria B	17 22	73 12	4 53	10 00	....	....	10	8	4·78
Jaigarh	17 18	73 14	4 53	10 16	....	....	8¾	7¼	5·04
Ratnagiri	16 59	73 18	4 53	10 40	....	....	6¼	4½	5·42
Rajapur R. entr	16 37	73 20	4 53	10 45	....	....	6½	4½	5·51
Rajapur town	16 40	73 29	4 54	0 20	....	....	7	....	7·42
Viziadrug	16 33	73 20	4 53	10 16	....	....	6¾	4¾	5·04
Deogarh Hr. entr	16 23	73 22	4 53	10 13	....	....	8¼	6¾	4·99
Angria Bk	....	....	....	10 30	....	....	9	....	....
Malwan	16 03	73 29	4 54	10 01	....	....	7½	6	4·77
Vengurla	15 51	73 39	4 54	11 13	....	....	6¾	5½	5·94
Aguada (Goa) B	15 28	73 48	4 55	10 39	....	....	6⅓	5⅙	5·37
Murmagoa	15 25	73 48	4 55	10 33	....	....	....	....	5·27
Karwar B	14 48	74 06	4 56	10 36	....	....	6¾	4½	5·31
SOUTH ATLANTIC SYSTEM (AFRICO-BRAZILIAN LOOP).	South.	West.							
Ascension I	7 55	14 25	0 58	5 30	....	....	2	....	6.28
	North.								
Cape Palmas	4 22	7 44	0 31	4 30	....	....	4	....	4·87
Sinu	5 00	9 08	0 37	5 00	....	....	4	....	5·45
Sangwin R	5 06	9 20	0 37	5 15	....	....	4	....	5·69
Sestos B	5 26	9 34	0 38	5 20	....	....	4	....	5·78
Edina	5 55	10 04	0 40	5 50	....	....	4	....	6·31
Junk R	6 10	10 23	0 42	5 45	....	....	5	....	6·26
Monrovia	6 19	10 49	0 43	6 00	....	....	6	....	6·52
Robert, port	6 42	11 24	0 46	....	....	....	3¼?	....	....
Gallinas R	7 00	11 38	0 47	6 45	....	....	4	....	7·30
Sherbro R., Buoy Pt	7 52	12 31	0 50	7 55	....	....	10¼	7¾	8·48
York I	7 32	12 28	0 50	8 40	....	....	6	4	9·20
Edmonstone I	7 41	12 33	0 50	....	....	....	8	....	....
Bagru R	7 40	12 34	0 50	....	....	....	11	....	....

Station.	Geographic position.			Estab-lish-ment. F. & C.	Semi-diurnal (HWI).	Range of tide.		Neap rise.	Cotidal hour.
	Latitude.	Longitude.				Mean (Mn).	Spring (Sg).		
		Arc.	Time.						
SOUTH ATLANTIC SYSTEM (AFRICO-BRAZILIAN LOOP)—c't'd.	° ′ *North.*	° ′ *West.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Banana Is	8 08	13 14	0 53	7 18	....	....	10	....	7·93
Sierra Leone	8 30	13 17	0 53	7 21?	....	....	12?	8	8·45
Yellaboi Sd	8 54	13 20	0 53	7 10	....	....	10	....	7·80
Mellakori R	9 07	13 20	0 53	7 40	....	....	11	....	8·29
Forikaria R	9 12	13 24	0 54	7 40	....	....	11	....	8·31
Manea R	9 30	13 32	0 54	7 40	....	....	11	....	8·31
Isles do Los (Tumbo)	9 28	13 48	0 55	6 38	....	....	14	7	7·33
River Pongo	10 09	14 00	0 56	7 30	....	....	12	9½	8·18
River Nunez, ent	10 30	14 42	0 59	9 45	....	....	17	11½	10·40
River Componi	10 54	14 48	0 59	10 00	....	....	15	11½	10·64
Bijouga Is. Orango Channel	10 56	15 48	1 03	10 00	....	....	11	....	10·71
Arkcas Chan	11 41	15 43	1 03	10 10	....	....	11–14	9	10·87
Bissao	11 39	16 01	1 04	11 00	....	....	8	....	11·70
River Cacheo	12 08	16 24	1 06	7 45	....	....	8	....	8 59
River Kasamanze, ent	12 36	16 46	1 07	9 55	....	....	5¾	....	10.70
River Gambia (Bathurst)	13 28	16 42	1 07	9 10	....	....	6½	5	9·98
Kansala	....	....	....	0 05	....	....	6	3	....
Salum R	13 48	16 44	1 07	8 10	....	....	5½	....	9·01
Goreé	14 40	17 25	1 10	8 08	....	....	5	....	9·03
Senegal R., bar	15 55	16 30	1 06	9 00	....	....	4	....	9·80
Guet N'dar	16 05	16 31	1 06	9 00	....	....	4	....	9·80
St. Louis	16 11	16 00	1 04	10 00	....	....	6½	....	10·73
Porto Grande, C. Verde Is	16 53	25 00	1 40	6 00	....	....	3½	....	7·47
Sal, Cape Verde Is	16 34	22 56	1 32	7 45	....	....	5	....	9·02
Mayo, Cape Verde Is	15 08	23 13	1 33	6 30	....	....	5	....	7·83
Porto Praya, Cape Verde Is	14 53	23 31	1 34	6 00?	....	....	5	....	7·37
Tarrafal B., S. Antonio	16 57	25 19	1 41	7 00	....	....	5?	....	8·44
S. Jago	15 18	23 47	1 35	7 28	....	....	5?	....	8·79
Fajao D'Agua, Brava	14 51	24 44	1 39	4 10	....	....	3½?	....	5·68
	South.								
Santa Catharina I	27 27	48 31	3 14	2 45	....	....	6	4½	5·89
Paranagua	25 31	48 30	3 14	3 00?	....	....	6½	....	6·13
San Sebastian	23 48	45 23	3 02	2 00	....	....	4	....	4·96
Ilha Grande B., Paratio	23 13	44 46	2 59	1 45	....	....	5½	....	4·67
Sapetiba B	23 00	43 50	2 55	2 00	....	....	5½	....	4.85
Rio Janeiro	22 55	43 09	2 53	3 00	....	....	4	3	5·78
Porto Frio	22 58	42 00	2 48	2 40	....	....	4½	....	5·38
Macahé	22 23	41 47	2 47	2 30	....	....	4½	....	5·20
Benevente	20 49	40 41	2 43	3 00	....	....	5	....	5·62
Espirito Santo B., and P. Victoria	20 19	40 20	2 41	3 00	....	....	4	....	5·58
Abrolhos	17 57	38 40	2 35	3 20	....	....	6–7	....	5·80
Martin Vas Rks	20 30	28 45	1 55	3 45	....	....	....	....	5·54
Os Ilheos	14 47	39 02	2 36	4 30	....	....	....	....	6·95
Camamu, P. of	13 52	38 56	2 36	4 00	....	....	6¼	....	6·46
Bahia	12 58	38 31	2 34	4 26	....	....	8	....	6·85
Maceio	9 35	35 41	2 23	4 30	....	....	8½	....	6·73
Pernambuco	8 04	34 54	2 20	4 40	....	....	8	6	6·84
Parahiba R. entr	6 57	34 50	2 19	5 00	....	....	8	5½	7·15
Cape St. Rogue	5 29	35 16	2 21	4 14	....	....	8–10	....	6·44
Rocas	3 51	33 49	2 15	5 15	....	....	10	....	7·32
Fernando Noronha	3 50	32 25	2 10	4 00	....	....	6?	....	6·03

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH ATLANTIC SYSTEM (AFRICO-BRAZILIAN LOOP)—c't'd.	° ′ South.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Aracati	4 28	37 45	2 31	6 00	......	......	8	6	8.32
Ceara	3 42	38 31	2 34	5 35	......	......	8¼	......	7.97
Jericoacoara	2 48	40 32	2 42	5 15	......	......	8	6	7.77
Tutoia Anch	2 46	42 21	2 49	5 13	......	......	12¾	......	7.86
Santa Anna Rfs	2 16	43 36	2 54	5 45	......	......	13	......	8.46
Maranham, San Luiz	2 30	44 19	2 57	7 00	......	......	16½	10¾	9.71
Manoel Luiz Rf	0 52	44 14	2 57	5 00	......	......	12	......	7.78
San Joao Is	1 17	44 55	3 00	6 24	......	......	14	......	9.18
SOUTH ATLANTIC SYSTEM (NORTH AMERICAN END).	North.							(Range)	
Halifax	44 40	63 35	4 14	......	7 34	4.3	5.2	3.2	11.54
Sandy Hook	40 27	74 00	4 56	......	7 30	4.6	5.6	3.6	12.18
Charleston, S. C	32 46	79 56	5 20	......	7 20	5.1	6.0	4.2	12.41
Savannah entr	32 02	80 51	5 23	......	7 10	6.8	7.9	5.5	12.30
Fernandina, Fla	30 41	81 28	5 26	......	7 39	5.9	6.9	4.8	12.82
								(Rise)	
Ireland Id. dockyard	32 20	64 50	4 19	7 14	......	......	3¾	2½	11.31
NORTH PACIFIC SYSTEM (PANAMA ANGLE).	South.								
Port Manta	0 56	80 30	5 22	3 04	......	......	6	......	8.33
Caracas R	0 35	80 25	5 22	3 30	......	......	10	......	8.75
Cape Pasado	0 22	80 30	5 22	3 30	......	......	10	......	8.75
	North.								
Atacames B	0 53	79 54	5 20	3 37	......	......	13	......	8.82
Santiago R	1 16	79 03	5 16	3 30	......	......	13	......	8.65
Tumaco Rd	1 51	78 40	5 15	2 33	......	......	12	......	7.71
Sanguianga, entr	2 38	78 25	5 14	4 10	......	......	9	......	9.26
	South.								
Charles I	1 13	90 30	6 02	2 10	......	......	6	......	8.12
Albemarle I	0 58	91 29	6 06	2 00	......	......	6	......	8.03
Chatham Id	0 47	89 27	5 58	2 23	......	......	6½	......	8.27
Indefatigable I	0 30	90 15	6 01	1 56	......	......	6	......	7.89
James I., west end	0 13	90 51	6 03	3 10	......	......	5	......	9.11
north side	0 13	90 44	6 03	2 34	......	......	5	......	8.53
	North.								
Wenman Is	1 23	91 49	6 07	2 10	......	......	......	......	8.21
Port Buenaventura, Negrilla Rf.	3 52	77 03	5 08	4 00	......	......	13	......	8.99
Off the town	3 52	77 24	5 10	6 00	......	......	13	......	9.03
San Juan R	4 17	77 29	5 10	6 00	......	......	12	......	10.97
Cabita B	5 28	77 28	5 10	3 40	......	......	12	......	8.71
Port Utria	5 58	77 20	5 09	4 00	......	......	12	......	9.01
Cupica B	6 35	77 23	5 10	3 30	......	......	13	......	8.55
Octavia B	6 53	77 42	5 11	3 30	......	......	13	......	8.56
Pinas B	7 34	78 11	5 13	3 15	......	......	14	......	8.36
Chepo R	8 59	79 07	5 16	3 40	......	......	16	......	8.81
Pedro Gonzales (Trapichi I.)	8 23	79 07	5 16	3 50	......	......	16	......	8.97

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH PACIFIC SYSTEM (PANAMA ANGLE)—continued.	° ′ North.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Chamé B	8 38	79 47	5 19	4 00	....	....	16	....	9·18
Taboga	8 48	79 33	5 18	4 00	....	....	14	....	9·16
Panama Rd	8 55	79 32	5 18	3 00	....	....	18¼	10½	8·20
Coiba I	7 27	81 45	5 27	3 10	....	....	12?	....	8·51
Bahia Honda	7 44	81 30	5 26	3 10	....	....	12?	....	8·49
Port Nuevo	8 06	81 42	5 27	3 10	....	....	12	....	8·51
Parida I	8 07	82 20	5 29	3 15	....	....	10	....	8·62
El Rincon Hr	8 42	83 29	5 34	2 51	....	....	6¼	....	8·32
Uvita B	9 07	83 47	5 35	2 19	....	....	4¾	....	7·82
Nicoya G. P. Herradura	9 39	84 39	5 39	3 09	....	....	10	....	8·69
Port Culebra	10 38	84 40	5 39	3 15	....	....	5¾	....	8·79
P. Elena	10 58	85 42	5 43	2 30	....	....	5	....	8·14
Port San Juan del Sur	11 15	85 53	5 44	3 08?	....	....	10?	....	8·76
Corinto Hr	12 28	87 12	5 49	3 06	....	....	11	....	8·82
San Lorenzo	13 19	87 29	5 50	2 50	....	....	12	8	8·57
Port la Union	13 20	87 51	5 51	3 15	....	....	10¼	8¼	8·99
Jiquilisco B. entr	13 16	88 33	5 54	2 38	....	....	7¼	4½	8·44
Libertad	13 29	89 19	5 57	2 50	....	....	10?	....	8·69
Acajutla B	13 34	89 50	5 59	2 35	....	....	10	8	8·48
San José Rd	13 56	90 49	6 03	2 55	....	....	9¼	6¾	8·87
Salina Cruz B	16 10	95 12	6 21	4 29	....	....	8½	6¼	10·68
Port Sacrificios	15 41	96 14	6 25	3 15	....	....	6	....	9·56
Maldonado	16 33	98 45	6 35	3 10?	....	....	8?	....	9·64
Acapulco	16 52	99 55	6 40	2 40	....	....	2¼	1	9·24
NORTH PACIFIC SYSTEM (ALASKAN ANGLE).								(Range)	
Haystack Id	54 43	130 37	8 42	....	0 10	12·9	16·5	8·6	8·86
Port Tongass, Tongass Id	54 46	130 44	8 43	....	0 08	13·1	16·8	8·8	8·85
Nakat Hr	54 48	130 42	8 43	....	0 12	13·0	16·6	8·7	8·91
Cape Fox	54 46	130 51	8 43	....	0 07	12·9	16·5	8·6	8·83
Cape Chacon, Prince of Wales I.	54 42	132 01	8 48	....	0 04	11·1	14·2	7·4	8·86
How-Kau, Kaigahnee Strait	54 49	132 49	8 51	....	0 25	12·0	15·4	8·0	9·25
Cape Muzon, Dall I	54 40	132 41	8 51	....	0 02	10·8	13·8	7·2	8·88
Port Bucareli, Suemez Island	55 19	133 26	8 54	....	0 04	12·5	16·0	8·5	9·09
Cape Ommaney, Baranof Island	56 10	134 32	8 58	....	0 05	7·6	9·7	5·2	8·96
Sitka, Baranof Island	57 03	135 20	9 01	....	0 06	7·7	9·9	5·2	9·12
George Id., Cross Sound	58 11	136 23	9 06	....	0 23	7·6	9·7	5·1	9·47
Port Mulgrave, Yakutat B	59 34	139 46	9 19	....	0 34	7·4	9·5	5·0	9·87
Icy Bay	59 55	141 18	9 25	....	0 30	7·4	9·5	5·0	9·90
Cape St. Elias	59 45	144 52	9 39	....	0 40	7·1	9·1	4·8	10·29
Copper R. Delta, Kokinhenic Id.	60 18	145 03	9 40	....	0 20	2·6	3·3	1·8	9·99
" " " Pete, Dahl Slough.	60 29	145 24	9 42	....	0 10	7·9	10·2	4·7	9·86
Eyak River entr	60 28	145 40	9 43	....	0 18	6·9	9·3	4·1	10·01
St. Paul, Harbor	57 48	152 21	10 09	....	0 16	7·0	9·0	4·5	10·41
NORTH PACIFIC SYSTEM (PHILIPPINE ANGLE).		East.							
Port Siassi, Siassi Id	5 32	120 51	8 03	....	5 54	6·8	9·0	4·1	9·65
Jolo Sulu Island	6 04	120 59	8 04	....	7 38	5·8	7·7	3·5	11·31

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH PACIFIC SYSTEM (PHILIPPINE ANGLE)—cont'd.	° ′	° ′	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
	North.	*East.*						(Range)	
Zamboanga, Mindanao I	6 54	122 03	8 08	....	6 54	2·7	3·6	1·6	10·54
Port Kacub, Siargas I	9 50	126 03	8 24	....	6 22	5·3	7·0	3·2	9·75
Davao, Mindanao I	7 02	125 35	8 22	....	6 05	5·2	6·9	3·1	9·51
Port San Pio V, Camigiun I	18 30	121 52	8 07	....	6 00	3·5	4·7	2·1	9·68
Alabat Island	14 08	121 52	8 07	....	9 50	6·1	8·1	3·7	1·38
Albay, Gulf of Albay, Luzon I	13 15	123 39	8 15	....	6 00	3·8	5·1	2·3	9·55
NORTH PACIFIC SYSTEM (CENTRAL LOOP).	*South.*	*West.*						(Rise)	
Penrhyn I	9 00	157 55	10 32	6 00?	....	....	1½	....	4·33
Caroline Is	10 00	150 15	10 01	4 00	....	....	1½	½	1·88
	North.								
Fanning I	3 50	159 20	10 37	6 15	....	....	2	....	4·66
Palmyra I	5 50	162 10	10 49	5 05	....	....	3	....	3·73
Christmas I	1 55	157 20	10 29	4 23	....	....	3¼	....	2·72
Midway Is	28 15	177 21	11 49	3 28	....	....	1½	1	3·17
		East.							
Ailuk, Kapenuer I	10 25	170 00	11 20	4 53	....	....	8	....	5·39
Wotje or Romanzoff Is	9 28	170 17	11 21	2 30	....	....	7	....	3·07
Arhno Is	7 00	171 40	11 27	4 45	....	....	6?	....	5·14
Port Rhin, Mulgrave Is	6 14	171 45	11 27	5 00	....	....	6½	....	5·38
Bonham Is., Anch	5 56	169 39	11 19	3 30	....	....	6	....	4·06
Ebon atoll	4 35	168 40	11 15	4 45	....	....	6	....	5·34
Menschikoff Is	9 00	167 20	11 09	4 00	....	....	5½	....	4·71
		West.							
Magdalena Hr	24 34	112 09	7 29	8 25	....	....	5½	3½	3·61
Ascuncion B	27 06	114 17	7 37	9 02	....	....	5¾	....	4·35
Port San Bartólomé	27 40	114 51	7 39	8 50?	....	....	7–9?	....	4·18
Cerros I	28 12	115 14	7 41	9 10	....	....	7–9	....	4·54
Playa Maria B	28 55	114 48	7 39	9 20?	....	....	7–9?	....	4·67
Rosario B	29 54	115 43	7 43	8 44	....	....	6½	....	4·16
Port San Quentin	30 25	115 54	7 44	9 19	....	....	4	....	4·73
Colnett B	30 57	116 15	7 45	8 45	....	....	6	....	4·20
Santo Tomas	31 33	116 39	7 46	9 00	....	....	4	....	4·47
Todos Santos B	31 51	116 36	7 46	9 28	....	....	5	....	4·92
								(Range)	
Kauai Island	21 57	159 40	10 39	....	4 00	1·6	2·0	1·1	2·51
Honolulu, Oahu Id	21 18	157 52	10 31	....	3 46	1·2	1·5	0·8	2·16
Molokai Id	21 05	157 02	10 28	....	2 38	1·6	2·1	1·1	1·01
Kahului, Maui Id	20 54	156 29	10 26	....	2 08	1·7	2·2	1·2	0·49
Kealakekua, Hawaii I	19 28	155 56	10 24	....	2 20	1·3	1·6	0·9	0·65
Hilo, Hawaii Id	19 46	155 06	10 20	....	3 09	1·8	2·3	1·3	1·37
NORTH PACIFIC SYSTEM (EASTER I., DUCIE I., ETC.).	*South.*							(Rise)	
Sala-y-Gomez I	26 19	105 26	7 02	4 00	....	....	4?	....	10·89
Easter I	27 10	109 21	7 17	0 39	....	....	irr.	....	7·91
Rapa I., Ahurei B	27 37	144 19	9 37	0 10	....	....	3	....	9·78
Gambier Is., Rikitea	23 05	135 00	9 00	2 30	....	....	4	....	11·42
Bow I	18 20	140 45	9 23	2 40	....	....	3	....	11·96

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH PACIFIC SYSTEM (CHILE, ETC.).	° ′ South.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Port Henry	50 03	75 18	5 01	0 00	....	....	5	....	5·02
Deutsche narrows	48 19	74 46	4 59	0 18	....	....	2½	....	5·27
Port Barbara	48 01	75 24	5 02	0 28	....	....	6	4	5·48
San Tadeo R	46 48	74 15	4 57	11 45	....	....	6	....	4·30
Port Otway	46 54	75 22	5 01	11 37	....	....	6	....	4·24
San Andres B	46 28	75 30	5 02	0 45	....	....	5	....	5·76
Port San Estevan	46 19	75 10	5 01	0 15	....	....	5	....	5·26
Anna Pink B	45 47	75 06	5 00	0 45	....	....	5	....	5·72
P. Yates	45 27	74 25	4 58	10 35	....	....	10	....	3·19
Vallenar Rd	45 16	74 35	4 58	0 18	....	....	5	....	5·26
Darwin channel	45 25	74 00	4 56	0 35	....	....	10	....	5·49
Port Low	43 50	73 57	4 56	0 40	....	....	7	....	5·57
Harchy B	45 43	73 53	4 56	1 30	....	....	10	....	6·38
Port Lagunas	45 17	73 45	4 55	1 10	....	....	7	....	6·05
Port Chacabuco	45 26	72 59	4 52	1 15	....	....	7	....	6·08
Port Perez	45 15	73 21	4 53	1 12	....	....	7½	....	6·04
Port Tangbac	45 02	73 44	4 55	11 40	....	....	10	....	4·19
Port San Domingo	43 57	73 08	4 53	0 00	....	....	7	....	4·88
Piti-Palena	43 47	72 59	4 52	0 23	....	....	10	....	5·24
Tictoc B	43 40	72 55	4 52	1 45	....	....	11	....	6·56
Huafo I	43 36	74 43	4 59	0 00	....	....	7	....	4·98
Cucao B	42 40	74 06	4 56	0 00	....	....	6	....	4·93
Port San Carlos	41 52	73 51	4 55	0 14	....	....	6	....	5·14
Carelmapu	41 43	73 43	4 55	0 50	....	....	10	....	5·72
Petucura Rk	41 48	73 31	4 54	0 50	....	....	16	....	5·70
Chacao B	41 49	73 32	4 54	0 40	....	....	14	....	5·54
Chacao narrows	41 49	73 32	4 54	0 50	....	....	16	....	5·70
San Pedro passage	43 20	73 42	4 55	0 30	....	....	9	....	5·40
P. Quellon	42 55	73 38	4 55	0 40	....	....	14¾	....	5·56
Huildad inlet	43 03	73 36	4 54	0 48	....	....	16–20	....	5·67
Talcan I	42 45	73 00	1 52	1 03	....	....	15½	....	2·88
Poqueldon Hr	42 35	73 41	4 55	0 54	....	....	18	....	5·79
Castro	42 28	73 46	4 55	0 11	....	....	18	....	5·10
Dalcahue	42 26	73 41	4 55	0 26	....	....	....	....	5·34
Chauquis Is	42 17	73 14	4 53	0 35	....	....	....	....	5·44
Quicavi bluff	42 14	73 21	4 53	0 57	....	....	20	....	5·80
P. Linao	41 58	73 32	4 54	0 24	....	....	8	....	5·29
Manao B	41 55	73 32	4 54	0 07	....	....	7	....	5·01
Oscuro cove, Huité	31 28	71 37	4 46	0 54	....	....	10	....	5·64
Lobos Hd	31 57	71 33	4 46	0 29	....	....	....	....	5·24
Huapilinao Hd	....	....	....	1 25	....	....	15½	....	....
Tres Cruces Pt	33 30	71 40	4 47	1 15	....	....	16	....	5·99
Coman inlet	42 05	72 42	4 51	1 10	....	....	17	13¾	5·98
Cullen I	41 52	72 57	4 52	....	....	....	20	....	....
Reloncavi inlet, Sotomo B	41 43	72 40	4 51	0 55	....	....	18	....	5·74
Port Montt	41 30	72 56	4 52	0 48	....	....	18–20	14–15	5·64
Puluqui I	41 48	73 04	4 52	1 05	....	....	....	....	5·92
Calbuco	41 46	73 07	4 52	1 22	....	....	15–20	....	6·19
Port Abtao	41 48	73 23	4 54	1 18	....	....	16–18	....	6·16
Maullin R	41 36	73 36	4 54	0 30	....	....	8	....	5·38
Port Corral	39 53	73 27	4 54	10 35	....	....	5½	....	3·12
Port Valdivia	39 50	73 18	4 53	11 35	....	....	4	....	4·07

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH PACIFIC SYSTEM (CHILE, ETC.)—continued.	° ′ South.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Tolten R	39 15	73 15	4 53	10 28			5		2·99
Mocha I	38 20	73 57	4 56	10 30			3		3·07
Lebu R	37 37	73 42	4 55	10 30			5		3·06
Santa Maria I	37 03	73 32	4 54	10 20			6		2·88
Arauco B	37 06	73 11	4 53	10 00			5		2·54
Talcahuano	36 43	73 08	4 53	10 15			5¼	3¼	2·78
Buchupureo Rd	36 04	72 47	4 51	10 14			2?		2·74
Curanipe Rd	35 48	72 38	4 51	10 35			4		3·07
Maule R	35 19	72 25	4 50	10 00			5		2·49
Llico	34 45	72 07	4 48	10 00			4-5½		2·46
Tuman B	34 08	71 58	4 48	9 55			6	4	2·38
Topocalma Rd	34 05	71 58	4 48	9 55			6	4	2·38
Matanza	33 58	71 54	4 48	9 50			5		2·30
Toro Pt	33 45	71 48	4 47	9 45					2·20
Port San Antonio	33 34	71 39	4 47	9 43			5		2·17
Quintai Rd	33 11	71 42	4 47	9 35			5		2·04
Valparaiso	33 02	71 39	4 47	9 32			5		1·99
Juan Fernandez I	33 38	78 53	5 16	9 55			5½		2·85
P. Papudo	32 30	71 28	4 46	9 25?			5		1·87
Pichidanque B	32 06	71 33	4 46	9 20			4		1·79
Oscuro cove	31 28	71 37	4 46	9 00			6½	4¼	1·47
Port Tongoy	30 15	71 31	4 46	9 10			5		1·63
Port Herradura	29 58	71 23	4 46	9 08			5		1·59
Coquimbo B	29 57	71 22	4 45	9 08			5		1·57
Port Huasco	28 27	71 15	4 45	9 30			6	4	1·93
Tortoralillo B	29 29	71 21	4 45	9 00			5		1·45
Carrisal Bajo B	28 04	71 12	4 45	8 30			5		0·96
Copiapo	27 20	70 59	4 44	8 30			5		0·94
Esmeralda cone	25 54	70 45	4 43	9 20			5¼		1·74
Port Flamenco	26 34	70 44	4 43	9 10			5		1·58
Chañaral, las Animas B	26 20	70 41	4 43	8 55?			5		1·34
Lavata B	25 39	70 44	4 43	9 20			5		1·74
Paposo	25 03	70 30	4 42	9 40			5		2·04
Grande Pt	25 07	70 30	4 42	9 45			5		2·12
Blanco Encalada Rd	24 22	70 34	4 42	10 00			3¼		2·36
Constitucion cove, Moreno	23 27	70 38	4 43	10 00			4		2·38
Mejillones del Sur B	23 06	70 28	4 42	9 45			4		2·12
Cobija B	22 34	70 18	4 41	9 54			4		2·24
Paquica or C. San Francisco	21 55	70 11	4 41	9 45					2·10
Chipana B	21 21	70 09	4 40	9 19			5?		1·67
Iquique	20 12	70 10	4 41	8 55			5-4?		1·30
SOUTH PACIFIC SYSTEM (SOUTH SHETLAND LOOP).									
Stewart Hr	54 55	71 30	0 46	2 50			4		7·51
Townshend Hr	54 43	71 55	0 48	2 30			5		7·22
Fury Hr	54 28	72 17	4 49	2 30			4		7·24
North cove Fury I	54 25	72 17	4 49	2 30			4		7·24
Hewett B	54 16	72 21	4 49	0 30			6½		5·30
Bedford B	54 01	72 22	4 49	0 30			7½		5·30
Smyth Hr	53 49	72 19	4 49	0 00			6½		4·82
Noir I	54 26	73 03	4 52	2 30			5		7·29

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH PACIFIC SYSTEM (SOUTH SHETLAND LOOP)—continued.	° ′ South.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Laura Hr	54 08	73 19	4 53	1 00	...	...	6	...	5·85
Cape Gloucester	54 05	73 30	4 54	1 30	...	...	5	...	6·35
Latitude B	53 18	74 15	4 57	2 05	...	...	4	...	6·96
Week Is	53 12	74 21	4 57	2 00	...	...	5	...	6·88
Dislocation Hr	52 54	74 37	4 58	1 40	...	...	4	...	6·58
Evangelists	52 21	75 08	5 01	1 00	...	...	5	...	5·99
Port Henry	50 03	75 18	5 01	0 00	...	...	5	...	5·02
Deutsche narrows	48 19	74 46	4 59	0 18	...	...	2½	...	5·27
Port Barbara	48 01	75 24	5 02	0 28	...	...	6	4	5·48
San Tadeo R	46 48	74 15	4 57	11 45	...	...	6	...	4·30
Port Otway	46 54	75 22	5 01	11 37	...	...	6	...	4·24
San Andres B	46 28	75 30	5 02	0 45	...	...	5	...	5·75
Port San Estevan	46 19	75 10	5 01	0 15	...	...	5	...	5·26
Anna Pink B	45 47	75 06	5 00	0 45	...	...	5	...	5·72
SOUTH PACIFIC SYSTEM (NEW ZEALAND LOOP).		East.							
Cape Palliser	41 37	175 16	11 41	6 00	...	...	6	...	6·12
Napier (Ahuriri Hr.)	39 29	176 55	11 48	6 15	...	...	3–4	...	6·24
Mohaka R	39 07	177 12	11 49	6 40	...	...	...	...	6.62
Wairoa R	39 04	177 25	11 50	6 45	...	...	7	4	6·69
Waikokopu	39 04	177 51	11 51	6 30	...	...	...	...	6·43
Long Pt	39 10	177 50	11 51	6 00	...	...	5	4	5·95
Poverty B	38 43	178 00	11 52	6 30	...	...	5½	...	6·41
East C	37 40	178 32	11 54	8 55	...	...	7	...	8·72
Hicks B	37 35	178 22	11 53	9 00	...	...	7	...	8·82
Cape Runaway	37 32	178 00	11 52	9 16	...	...	7	...	9·08
Te Kaha Pt	37 44	177 41	11 51	6 30	...	...	9	...	6·43
Opotiki R	38 00	177 18	11 49	7 00	...	...	7	...	6·94
Tauranga Hr	37 40	176 10	11 45	7 10	...	...	6	4½	7·17
Mercury B	36 48	175 50	11 43	7 21	...	...	7	5	7·38
Mangrove R	36 48	175 45	11 43	7 21	...	...	7	5	7·38
Gt. Barrier I., Nagle cove	36 09	175 21	11 41	6 25	...	...	10	7	6·52
Coromandel Hr	36 47	175 30	11 42	7 00	...	...	11	8	7·06
R. Thames, entr	37 10	175 34	11 42	7 45	...	...	11	8½	7·79
Auckland Hr	36 53	174 48	11 39	7 32	...	...	11	9	7·63
Kawau I	36 25	174 50	11 39	6 30	...	...	10	7	6·63
Mahurangi Hr	36 31	174 46	11 39	7 00	...	...	10	...	7·11
Whangarei Hr	35 51	174 31	11 38	7 00	...	...	9	7	7·13
Tutukaka Hr	35 38	174 33	11 38	7 00	...	...	9	7	7·13
Whangaruru	35 23	174 21	11 37	7 10	...	...	9	7	7·30
Bay of Islands, P. Russell	35 16	174 08	11 37	7 15	...	...	9	6	7·38
Whangaroa Hr	35 04	173 48	11 35	8 15	...	...	7	...	8·39
Cavalli Is	35 00	174 00	11 36	8 00	...	...	7	...	8·13
Mangonui P	35 00	173 34	11 34	8 00	...	...	7	...	8·16
Awanui R. Rangaunu	34 54	173 20	11 33	7 44	...	...	7	...	7·92
Paranga renga Hr	34 32	173 00	11 32	7 54	...	...	7	...	8·10
		West.							
Suvarov (Suvarrow) I	13 13	163 12	10 53	7 48?	...	...	2¼	...	6·42
Pango Pango	14 17	170 42	11 23	7 11	...	...	3½	...	6·32
Upolu I. (Apia)	13 46	171 44	11 27	6 28	...	...	4	...	5·69
Manua	14 15	169 30	11 18	...	...	...	6	...	...

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH PACIFIC SYSTEM (NEW ZEALAND LOOP)—continued.	° ′ *South.*	° ′ *West.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Uea or Wallis I	13 24	176 08	11 45	6 40	....	....	6?	....	6·19
Rotumah I	12 30	182 58	12 12	4 40	....	....	7	4¾	4·71
Phoenix Is., Canton I	2 49	171 43	11 27	5 00	....	....	4?	....	4·28
Funafuti, Ellice Is	8 30	180 50	12 03	5 20	....	....	6¼	4¾	5·20
Nukualofa, Tongátabu	21 10	175 12	11 41	7 00	....	....	4¾-5¾	3-4¾	6·44
Nomuka	20 15	174 46	11 39	7 15	....	....	3½-4¾	....	6·65
Lifuka	19 48	174 22	11 37	7 15	....	....	5	3½	6·62
Neiafu Vavau	18 34	173 58	11 36	7 05	....	....	5	3¼	6·44
North Minerva	23 36	179 06	11 56	8 00	....	....	6	....	7·66
South Minerva	24 00	178 54	11 56	8 00	....	....	6	....	7·66
Vatoa or Turtle I	19 49	178 14	11 53	6 11	....	....	4	....	5·85
Tova or Na Vatu Rf	18 40	179 34	11 58	6 08	....	....	4	....	5·90
Mango I	17 25	179 10	11 57	6 10	....	....	4¾	....	5·91
Matuku	19 10	180 15	12 01	6 18	....	....	5	3	6·11
Totoya	18 56	179 50	11 59	6 37	....	....	4½	....	6·37
		East.							
Moala	18 35	179 50	11 59	5 50	....	....	5	....	5·66
Ngau I	18 00	179 15	11 57	6 07	....	....	5	3¾	5·96
Nairai I	17 50	179 22	11 57	5 53	....	....	4½	3¼	5·73
Ovalau	17 40	178 40	11 55	6 00	....	....	5	3	5·88
Makongai and Wakaya Is	17 25	178 55	11 56	6 00	....	....	4	3	5·87
	17 35	178 55	11 56	....	....	....	....	....	....
Nandi passage and B	17 00	178 48	11 55	6 35	....	....	4½	....	6·44
Sandalwood B	16 50	178 30	11 54	6 00	....	....	6?	....	5·90
Viti Levu, Mbau roads	17 57	178 35	11 54	5 45	....	....	6	....	5·66
P. Nukulau	18 10	178 28	11 54	6 47	....	....	3½-5¾	....	6·54
Suva Hr	18 08	178 26	11 54	6 55	....	....	4½-5¾	3¼-4	6·78
Nadronga	18 07	177 19	11 49	6 00	....	....	5-6	....	5·98
Likuri I	....	....	....	6 30	....	....	4¼	3¾	....
Manava sand cay	....	....	....	6 02	....	....	6¼	3-4	....
Vanua Levu, Savu, Savu B	16 43	179 15	11 57	6 00	....	....	4½	3¼	5·85
Valanga B	....	....	....	5 55	....	....	5¾	4	....
Ngaloa B., Kandavu I	19 02	178 15	11 53	6 38	....	....	5¼	4½	6·53
Ono I	18 51	178 30	11 55	6 00	....	....	6	4½	5·90
SOUTH PACIFIC SYSTEM (CALIFORNIAN LOOP).	*North.*	*West.*							
Magdalena Hr	24 34	112 09	7 29	8 25	....	....	5½	3½	3·61
Ascuncion	27 06	114 17	7 37	9 02	....	....	5¾	....	4·35
Port San Bartolomé	27 40	114 51	7 39	8 50?	....	....	7-9?	....	4·18
Cerros I	28 12	115 14	7 41	9 10	....	....	7-9	....	4·54
Playa Maria B	28 55	114 48	7 39	9 20?	....	....	7-9?	....	4·67
Rosario B	29 54	115 43	7 43	8 44	....	....	6½	....	4·16
Port San Quentin	30 25	115 54	7 44	9 19	....	....	4	....	4·73
Colnett B	30 57	116 15	7 45	8 45	....	....	6	....	4·20
Santo Tomas	31 33	116 39	7 47	9 00	....	....	4	....	4·48
Todos Santos B	31 51	116 36	7 46	9 28	....	....	5	....	4·92
								(Range)	
San Diego Bar	32 40	117 14	7 49	....	9 29	3·9	5·2	2·3	4·98
San Diego, La Playa	32 42	117 14	7 49	....	9 32	3·8	5·1	2·3	5·03
San Juan Capistrano	33 27	117 43	7 51	....	9 42	3·7	4·9	2·2	5·22

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH PACIFIC SYSTEM (CALIFORNIAN LOOP)—continued.	° ′ North.	° ′ West.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet. (Range)	h.
Santa Catalina Har., Catalina Island	33 26	118 29	8 54	....	9 28	3·8	5·1	2·3	6·05
Corral Hr., San Nicolas I	33 17	119 31	7 58	....	9 20	3·7	4·9	2·2	4·99
Prisoner Hr., Santa Cruz I	34 01	119 41	7 59	....	9 29	3·7	4·9	2·2	5·14
Cuyler Hr., San Miguel I	34 03	120 21	8 01	....	9 23	3·7	4·9	2·2	5·08
Lompoc Landing	34 44	120 37	8 02	....	9 55	3·6	4·8	2·2	5·61
Point Sal	34 54	120 40	8 03	....	10 02	3·6	4·8	2·2	5·74
San Luis Obispo	35 11	120 44	8 03	....	10 17	3·7	4·9	2·2	5·99
Morro, Morro B	35 21	120 50	8 03	....	10 31	3·7	4·9	2·2	6·21
Cayucos, Estero B	35 27	120 55	8 04	....	10 33	3·8	5·1	2·3	6·26
San Simeon	35 39	121 11	8 05	....	10 38	4·0	5·3	2·4	6·35
Monterey Hr., Light	36 37	121 52	8 07	....	10 43	4·0	4·8	3·1	6·47
Santa Cruz Hr., Light	36 57	122 02	8 08	....	10 54	4·3	5·2	3·3	6·66
Half Moon Bay	37 30	122 27	8 10	....	10 48	3·9	4·7	3·0	6·60
Southeast Farallon Light	37 42	123 00	8 12	....	10 40	3·7	4·5	2·9	6·50
San Francisco Bar	37 46	122 38	8 11	....	11 37	3·5	4·2	2·7	7·40
NORTH INDIAN SYSTEM (EAST END).	South. ° ′	East. ° ′	h m					(Rise)	
Baudin I	14 08	125 36	8 22	11 31	....	....	19–22	12–15	2·76
Swift B	14 34	125 40	8 23	0 00	....	....	18	....	3·62
Prince Frederick Hr	15 00	125 00	8 20	0 00	....	....	28	....	3·68
Port Nelson	15 06	125 03	8 20	0 00	....	....	27	....	3·67
Careening B	15 08	125 00	8 20	11 45	....	....	30	....	3·02
Prince Regent R., St. George basin	15 20	125 05	8 20	0 20	....	....	24–37	....	3·99
Hanover B	15 15	124 45	8 19	11 30	....	....	24–38	....	2·79
Camden Sd	15 25	124 30	8 18	11 30	....	....	30	....	2·81
Beagle Bk	15 20	123 30	8 14	10 00	....	....	12	....	1·43
Montgomery Isles	15 55	124 10	8 17	0 00	....	....	36	....	3·72
Collier B	16 23	124 25	8 18	11 45	....	....	36	....	3·05
P. Usborne, King Sd	16 38	123 36	8 14	1 45	....	....	34	....	5·46
Fitzroy R. entr	17 35	123 33	8 14	2 30	....	....	36	20	6·19
Swan Pt	16 22	123 01	8 12	0 10	....	....	26	....	3·96
Beagle B	16 53	122 35	8 10	0 00	....	....	17½	12¾	3·82
Lacepede Is	16 53	122 10	8 09	0 00	....	....	20	....	3·85
Carnot B	17 12	122 20	8 09	11 00	....	....	18	....	2·48
Roebuck B	18 05	122 22	8 09	11 00	....	....	28	....	2·48
Turtle Isle (North)	19 53	118 50	7 55	11 00	....	....	18	12	2·71
Oyster Inlet	20 20	118 30	7 54	10 35	....	....	18	....	2·32
Depuch Isle	20 38	117 40	7 51	10 40	....	....	14	10	2·45
P. Walcott	20 39	117 13	7 49	11 43	....	....	18	....	3·50
P. Robinson	20 40	116 58	7 48	11 15	....	....	19	....	3·07
Dampier Arch	20 30	116 50	7 47	11 30?	....	....	16–17	....	3·33
Hermite Isle	20 29	115 28	7 42	10 00	....	....	14	....	1·96
Hampton Hr	20 40	116 42	7 47	10 30	....	....	14½	9¾	2·36
Fortescue Rd	21 00	116 06	7 44	10 25	....	....	13½	8½	2·33
P. Weld	21 23	115 40	7 43	0 00?	....	....	10–12	....	4·28
Ashburton Rd	21 39	114 57	7 40	11 30?	....	....	6–8	4–5½	3·44
Cloates Pt	22 35	113 40	7 35	10 41	....	....	5¾	3½	2·74

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Estab-lish-ment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
NORTH INDIAN SYSTEM (CENTRAL LOOP).	° ′ South.	° ′ East.	h. m.	h. m.	h. m.	Feet.	Feet.	Feet.	h.
Diego Garcia	7 20	72 30	4 50	1 38	....	....	5¾	3¾	8·75
Peros Banhos	5 20	71 50	4 47	1 30	....	....	5	....	8·67
Salomon Is.	5 21	72 11	4 49	1 30	....	....	5	....	8·63
NORTH INDIAN SYSTEM (WEST END).	North.								
Juba R	0 14	42 38	2 51	4 30	....	....	9–10	....	1·50
Brawa	1 08	44 04	2 56	4 10	....	....	8	....	1·10
Marka or Muerka	1 42	44 54	3 00	4 30	....	....	8	....	1·35
Mogdishu	2 02	45 25	3 02	4 30	....	....	8	....	1·32
Warsheik Rd	2 36	46 11	3 05	4 30	....	....	8	....	1·27
Athelet	2 46	46 22	3 05	3 00?	....	....	6?	....	11·82
Ras Hafún	10 20	51 22	3 25	6 15	....	....	4	....	2·62
Ras Asir (Guardafui)	11 53	51 15	3 25	6 15	....	....	6	4½	2·62
Sokotra	12 40	53 55	3 36	7 20?	....	....	8	....	3·48
Abd al Kuri	12 11	52 13	3 29	8 30	....	....	6	....	4·73
Kal Farun	12 26	52 09	3 29	8 20	....	....	6	....	4·57
Bandar Alúleh	12 00	50 45	3 23	6 45	....	....	6	....	3·14
Berbereh	10 26	45 00	3 00	9 30	....	....	8½	6	6·18
Zeila	11 24	43 28	2 54	7 45	....	....	8–9¼	5¾–8¼	4·59
Obokh	11 59	43 17	2 53	8 15?	....	....	8¼	....	5·09
Bandar Fukom	12 44	44 48	2 59	10 00	....	....	8½	....	6·68
Aden	12 47	44 59	3 00	7 54	....	....	7	4½	4·63
Shukra	13 22	45 40	3 03	8 00	....	....	6	....	4·68
Makatein	13 25	46 26	3 06	9 00	....	....	6	....	5·60
Ras-al-Aseida	13 57	48 10	3 13	8 30	....	....	5½	....	4·99
Makalla	14 32	49 06	3 16	8 30	....	....	7	....	4·94
Ras Sharma	14 49	49 57	3 20	9 00	....	....	8	....	5·37
Merbat	17 00	54 41	3 39	9 00	....	....	7	....	5·05
Khorya Morya B. and Is.	17 30	56 00	3 44	8 20	....	....	6½	....	4·32
Ras Madraka	19 00	57 51	3 51	9 00	....	....	10	....	4·85
Shab Kadun	19 30	58 00	3 52	9 20	....	....	10	....	5·15
Jezirat Hamar-alnafur	19 48	57 49	3 51	9 30	....	....	10	....	5·33
Shab Bu Saifa	19 56	59 24	3 58	9 45	....	....	10	....	5·55
Ghubbet Hashish	20 30	58 10	3 53	10 00	....	....	10	....	5·78
'Om-Rasas, Masira	20 30	58 48	3 55	10 00	....	....	10	....	5·74
Ras Sheiballa	20 58	58 49	3 55	10 00	....	....	10	....	5·74
Ras al Hadd	22 34	59 50	3 59	9 30	....	....	9	....	5·20
Khor al Hajar	22 32	59 46	3 59	9 30	....	....	10?	....	5·20
Khor Jarama	22 30	59 44	3 59	9 30	....	....	10	....	5·20
Bandar Khairan	23 30	58 43	3 55	9 00	....	....	5	....	4·82
Bandar Jissa	23 33	58 38	3 55	9 00	....	....	5	....	4·78
Maskat	23 37	58 35	3 54	9 15	....	....	6–9	....	5·04
Jezírat Jún	23 50	57 58	3 52	9 30	....	....	10?	....	5·31
Suádi Is	23 46	57 47	3 51	9 30	....	....	10?	....	5·33
Kubbat Ghazira	26 06	56 30	3 46	9 30	....	....	10	....	5·41
SOUTH INDIAN SYSTEM (EAST END).	South.								
Lady B	38 23	142 26	9 30	0 37	....	....	3	....	3·10
Port Fairy	38 24	142 15	9 29	0 31	....	....	3	....	3·02

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. & C.	Semi-diurnal (HWI).	Range of tide. Mean (Mn).	Range of tide. Spring (Sg).	Neap rise.	Cotidal hour.
SOUTH INDIAN SYSTEM (EAST END)—continued.	° ′ *South.*	° ′ *East.*	*h. m.*	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*Feet.*	*h.*
Portland B	38 20	141 37	9 26	0 30	....	....	3?	....	3·05
Port Macdonnel	38 04	140 40	9 23	0 02	....	....	4	....	2·65
Rivoli B	37 45	140 15	9 21	0 33	....	....	4	....	3·18
Guichen B	37 10	139 30	9 18	0 37	....	....	4	....	3·30
Kingston	36 50	139 51	9 19	0 06	....	....	5	....	2·78
Murray R., bar	35 31	138 47	9 15	0 50	....	....	3–4	2–3	3·55
Victor Hr	35 34	138 39	9 15	1 09	....	....	4¾	....	3·86
Coffin B	34 26	135 22	9 01	0 45	....	....	6	....	3·70
Venus Hr	33 10	134 42	8 59	1 30	....	....	4–5	....	4·47
Blanche P., Streaky B	32 48	134 15	8 57	0 05	....	....	6	....	3·13
Denial B	32 11	133 28	8 54	0 50	....	....	7	....	3·90
St. Francis Isle, Petrel Bay	32 30	133 15	8 53	0 00	....	....	6	....	3·12
Port Eyre	31 57	132 30	8 50	0 00	....	....	5½	....	3·17
Eucla Rd	31 45	129 00	8 36	11 05	....	....	5	....	2·11
Esperance B	33 53	122 00	8 08	0 10	....	....	3–4	2–3	4·03
King George Sd.; Princess Royal Hr	35 01	117 54	7 52	11 03	....	....	2½	....	2·81
West Cape Howe	35 08	117 38	7 51	9 00	....	....	2	....	0·85
SOUTH INDIAN SYSTEM (WEST END).									
See stations under S. Atlantic system lying between lats. 20° and 34° S., and longs. 20° and 47° E.									

80. *Tides in the Red Sea.*

Most of the information now available concerning the tides in the Red Sea is found in the Tide Tables for the British and Irish Ports and in The Red Sea and Gulf of Aden Pilot, both published by the Admiralty. In studying the causes of the tides Admiralty Chart 2523, or a less detailed form of it shown in Fig. 36, will be found serviceable.

From the Tide Tables and this chart the following table is constructed. No great reliance should be placed upon the ranges or heights. It is probable that the values are excessive because of the considerable diurnal inequality which may have had its effect upon the estimation of the range of the tide.

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. and C.	Spring range.	Neap rise.	Cotidal hour.
RED SEA.	*North.* ° ′	*East.* ° ′	*h. m.*	*h. m.*	*Feet.*	*Feet.*	*h.*
Bab-el-Mandeb, Perim I	12 38	43 24	2 54	8 00	6½–7¾	5½–6¼	4·83
Mokha Rd	13 19	43 12	2 53	0 00	4½	....	9·12
Hanish Is	13 44	42 42	2 51	1 00	2½	1	10·12
Hanfela B	14 46	40 42	2 43	....	3–4	....	....
Dahalak Bk	16 15	40 30	2 42	1 10?	3–4	....	10·43

Station.	Geographic position.			Establishment. F. and C.	Spring range.	Neap rise.	Cotidal hour.
	Latitude.	Longitude.					
		Arc.	Time.				
	° ′	° ′	h. m.	h. m.	Feet.	Feet.	h.
RED SEA—continued.	North.	East.					
Annesley B.	15 06	39 46	2 39	1 00	3-5	....	10·32
Massawa	15 37	39 35	2 38	1 00	4	3	10·34
Kamaran B	15 20	42 45	2 51	1 04	3¼	....	10·18
Loheiya	15 42	42 39	2 51	1 30	3	....	10·60
* Sawâkin	19 06	37 21	2 29	1 00?	1½	....	10·49
Trinkitat	18 41	37 45	2 31	0 00 (Feb.)	1?	....	9·48?
Makawar I.	16 57	41 20	2 45	0 30	2	....	9·73
Lith	20 08	40 14	2 41	....	2	....	....
Jidda	21 27	39 10	2 37	....	2?	....	....
Mersa Shab	22 52	35 48	2 23	6 00	....	....	3·42
Hassani I	24 58	37 04	2 28	6 00	....	....	3·33
Mardunah I.	26 04	36 28	2 26	6 00	3	....	3·37
Sherm Noman	27 05	35 45	2 23	6 40	....	....	4·06
Brothers Is.	26 19	34 51	2 19	6 00	2	....	3·48
Koseir	26 08	34 16	2 17	6 00	3	....	3·52
Omeider I.	29 10	34 56	2 20	6 00	4	....	3·47
Akabah	29 28	35 01	2 20	6 50	4	....	4·27
Dahab	28 30	34 32	2 18	7 00	....	....	4·46
Shermsheik	27 51	34 18	2 17	6 30	....	....	4·00
Jifatin	27 14	33 55	2 16	6 00	2	....	3·53
Ashrafi Is	27 47	33 43	2 15	6 00	1¾	....	3·55
Ras Iknaisi	....	....	....	5 30	1¾	....	....
Tor	28 14	33 37	2 14	6 00	1¼	....	3·57
Ras Gharib	28 21	33 06	2 12	11 30	1½	....	8·91
Sheratib Rf	28 36	33 13	2 13	11 00	3	....	8·41
Zafarana Lt. Ho	29 06	32 40	2 11	11 00	5½	....	8·45
Suez B., Hd. of Gulf	29 58	32 32	2 10	11 59	7	4	9·41

*One high and one low water in the 24 hours.

More accurate information is available for Aden (No. 840, § 97 and Fig. 21) and for Djibouti, Gulf of Aden (No. 857, § 97 and Fig. 21). The M_2 cotidal hour at the former place is IV·55 and at the latter IV·45. The amplitudes of M_2 are 1·57 and 1·74 feet, respectively. At these two places there are good phase and diurnal inequalities.

The above data show that for the southeastern half of the sea, the Greenwich cotidal hour is about X·4, while for the northwestern half it is about III·7. They show that high water in the Gulf of Akabah and lower portion of the Gulf of Suez occurs at about the same time as in the northwestern half of the Red Sea; also that in the portion of the Gulf of Suez lying above Tor Bank the cotidal hour is about VIII·8, showing that high water in the upper portion of the gulf is about simultaneous with low water at the mouth. The following quotations give further information respecting the tides in question. Since they assert that high water at one end of the gulf is simultaneous with low water at the other end, it is probable that VIII·8 should be replaced by a value more nearly equal to 3·7 + 6 or IX·7 for the cotidal hour at full and change.

When the water is rising at Suez, the stream, throughout the whole length of the gulf, runs to the northward, and, when falling, to the southward.

In the strait of Jubal, at the southern end of the Gulf of Suez, the tidal streams run at from $1\frac{1}{2}$ to 2 knots an hour in mid-channel . . .

In the portion of the gulf northward of Tor high water occurs nearly at the same time as at Suez, the rise of tide increasing from $1\frac{1}{2}$ feet at the Ras Gharib to 7 feet at Suez. It is high water in the southern portion of the gulf when it is about low water at Suez, and vice versâ.*

There is a tidal rise and fall of one foot nine inches at Ashrafi, and of 2 feet at the Brothers, more than 100 miles farther south-eastward; but there is a rise of only one foot three inches at Tor and there appears to be none at Cape Zeiti . . .

Along the shores of the Red sea a rise and fall of tide has been observed in some places, and in some of the narrowest channels a tidal stream seems to flow; but at other parts, until the strait of Bab-el-Mandeb is neared, it is imperceptible. Here, however, the tides of the gulf of Aden begin to make themselves felt, so that at Jebel Zukur there is a rise of $2\frac{1}{2}$ feet at springs and of 7 feet at Perim.†

Strait of Bab-el-Mandeb.—

It is high water, full and change, at Perim and in the straits generally at 8^h.; springs. rise $6\frac{1}{2}$ to $7\frac{3}{4}$ feet, neaps $5\frac{1}{2}$ to $6\frac{1}{4}$ feet. The flood sets N. W., the ebb S. E. The streams are very irregular both in period and in velocity; sometimes in the center of the strait there is very little ebb, while at other times, particularly at night, at full and change, it runs at the rate of 4 miles an hour, creating a strong ripple when opposed to the wind.‡

On a small Admiralty chart of the strait (No. 8e) it is stated that the tidal streams are "very strong and irregular" between Perim Island and Cape Bab-el-Mandeb (See Pilot, pp. 235, 236).

Suez and Suez Canal.—

The tidal observations which we were able to make were necessarily somewhat imperfect from want of time, but they were made at that period of the moon's age when their effect would be greatest; the results show that in the southern portion of the canal, between Suez and Great Bitter Lake, the tidal influence from the Red Sea is felt, there being a regular flow and ebb, — the flood running in for about seven hours, and the ebb running out for five hours; at the Suez entrance the rise at springs, unless affected by strong winds, is between 5 and 6 feet; about half way from Suez to the Small Bitter Lake, a distance of 6 miles, it is under 2 feet; at the south end of Small Bitter Lake, a few inches only; while at the south end of the Great Lake there is scarcely any perceptible tidal influence.§

The tides at the head of the Gulf of Suez have some historic interest, as has been noted in Part I, § 63, and footnote.

81. *Explanation of the tides in the Gulf of Suez.*

The average depth of the gulf for various cross sections is tolerably constant. Above Tor Bank it is about 20 fathoms. Regarding the gulf as a canal, this depth would give (Tables 50, 51) 114 sea miles for the value of $\frac{1}{4}\lambda$, which is the distance between Suez and Tor Bank. Although the narrowing toward the end decreases the virtual length of a body, it is probable that this effect is offset by the shoaling. See lemma 6.

Hence the virtual length of the gulf above a line crossing Tor Bank is probably almost exactly $\frac{1}{4}\lambda$, or say 90°. From Suez, Zafarana Light is $\frac{50}{114}\cdot\frac{1}{4}\lambda$, or 39°; Ras Sherateeb is $\frac{86}{114}\cdot\frac{1}{4}\lambda$, or 68°; Ras Gharib is $\frac{100}{114}\cdot\frac{1}{4}\lambda$, or 79°; the cosines of these angles are 0·777, 0·375, 0·191, respectively. These multiplied by 7 feet give as the spring ranges, computed from that at Suez, 5·4, 2·6, and 1·3 feet. The Admiralty Tide Tables give, as shown in the above table, 5·5, 3, and 1·5 feet. From the nodal line across Tor Bank to deep water in the Strait of Jubal is 43 sea miles, the average depth being about 25

*The Red Sea and Gulf of Aden Pilot, fifth edition, London, 1900, p. 17.

† Ibid., p. 18.

‡ Ibid., p. 235.

§ Report on the Maritime Canal connecting the Mediterranean at Port Saïd with the Red Sea at Suez, by Lieutenant-Colonel Clarke, R. E., for British Admiralty, Feb., 1870.

fathoms, and so the mouth of the gulf is $\frac{43}{128} \cdot \frac{1}{4}\lambda$, or 30° from the nodal line. Tor is $\frac{8}{128} \cdot \frac{1}{4}\lambda$, or 6°; Ashrafi I. is $\frac{30}{128} \cdot \frac{1}{4}\lambda$, or 22°; and so their spring ranges derived from the value at Suez are 0·7 and 2·6 feet. At the strait the spring range should be 3·5 feet. The above table gives 1·25, 1·75 and, perhaps, 3 feet. The last quotation given above indicates that 5 or 6 feet is a better value than 7 feet for the spring range at Suez.

Explanation of the tides in the Gulf of Akabah.—This gulf is approximately canal-like in form; the great depths show that its length is but a small fraction of λ. Consesequently (lemma 12) the tide should be simultaneous with the tide outside, and the rise and fall everywhere should be about equal to that at the mouth. This inference is reasonably well borne out in the values given above for Dahab, Akabak, and Omeider I.

82. *Explanation of the tides in the main body of the Red Sea.*

The Gulfs of Suez and Akabah constitute fractional areas whose tides depend directly upon those of the Red Sea proper. It remains to try to account for the latter tides in a rational manner.

Consider the body of water extending from the Straits of Jubal and Tirán southeasterly 972 sea miles to Great Hanish Island. The latitude and longitude of the middle point of the line thus defined are 20° 47′ N. and 38° 35′ E. $= 2^{h}\cdot 56$. The direction of this line is about N. 29°·5 W. The average depth of the body of water is about 350 fathoms, perhaps a little more. Table 50 shows that a half (lunar) wave length corresponding to this depth is 954 sea miles. But for a body of water as broad as is the Red Sea, it is probable that the free wave travels faster than the rate implied in this depth, because the depth along the axis is far in excess of 350 fathoms (Cf. §§ 36, 37). Hence the free period of this body is probably sensibly less than 12 lunar hours. The force diagrams, applied as in the case of oscillating areas, give IV. 5 as the cotidal hour of the north end and X. 5 as that of the south end. (Were the body less than $\frac{1}{2}\lambda$ long and could friction be ignored, then the canal theory of § 68 would apply, giving as the cotidal hours I. 5 and VII. 5, respectively). The tides in the extreme southeastern portion of the sea should be governed by those of the Gulf of Aden. Assuming the cotidal hour of the northwestern corner of this gulf to be V, the derived wave should occur at the time indicated by the depth plus about two hours, due to delay in passing the strait. (See § 113.) It is probable that this derived wave constitutes the greater part of whatever semidiurnal tide may exist at the nodal line of the main area; and that, because less than six hours are required to pass from the southern portion of the sea to the north end, this derived wave causes the observed cotidal hour to be less than IV. 5 at the mouth of the Gulf of Suez.

83. *Tides in lakes and inland seas whose periods of free oscillation are considerably less than twelve hours.*

Whenever the free period is several times less than twelve hours the corrected equilibrium theory can generally be applied with advantage unless the body is very narrow in comparison with its length. In this latter case the canal theory with the disturbing force uniform over the whole extent of the body (§ 68) is more appropriate. Friction may be ignored in the first approximation. Either theory gives the same cotidal hours at the ends of the canal. On the chart, Fig. 23, are shown the theoretical cotidal lines for small seas. The lines of each set radiate from a no-tide point whose longitude in time is written underneath, and this must be added to the numberings of the cotidal lines to reduce them to their Greenwich values. The bounding curve, drawn in a broken line, indicates a line of equal range; it shows how far one would have to go from the no-tide point to obtain a range of 0·1 UC_2; in particular, of 0·08 foot, or about 1 inch, for the M_2 tide. Along the equator this distance (east and west) would be 86 sea miles. (See § 3 and Fig. 2.) By aid of such diagrams, contructed for various latitudes, the theoretical time and range of the corrected equilibrium tide for any body to which the theory is applicable can be seen at a glance. In this way the tides of the Great Lakes, notably of Lake Superior, can be approximately inferred. (In this connection see §§ 40, 42, Part I; § 49, Part II; § 3, Part IV A; also, Comstock, Annual Report of the Survey of the Northern and Northwestern Lakes, 1872, 1873; Ferrel, Tidal Researches, pp. 250–255.) Observations go to show that the times of the tides in Lake Michigan are better explained by the canal theory just referred to than by the equilibrium theory. This would probably be the case with Lakes Erie and Ontario. Where the equilibrium theory best applies, provided, of course, the body is not too small, there should careful observations be made for the purpose of determining from the tides the relative masses of sun and moon, as well as the eccentricity of the moon's orbit and perhaps other astronomical quantities. The Black Sea is probably the most suitable body for this purpose, and next in order would be Lake Superior. Much interesting and important work can probably be done along this line when good observations, made in suitable places, become available. For this reason the subject of tides in lakes and inland seas will be postponed to some future time. We shall, however, consider here in some detail the tides in the Mediterranean Sea and also those in the Gulf of Mexico.

84. *Tides in the Mediterranean Sea.*

The chief sources of information respecting the tides in the Mediterranean Sea are the Tide Tables for the British and Irish Ports, the Mediterranean Pilots, both published by the Admiralty, and a number of harmonic analyses at places shown on the chart of tide stations (Fig. 21). Reference may here be made to the accompanying charts of the Mediterranean Sea, Gibraltar, and Messina straits (Figs. 37, 38, 39). The establishments and ranges or heights in the following table are those given by the Tide Tables of the Admiralty. The establishment for Tripoli appears to be several hours in excess of what it should be, judging from near-by places. Other than tidal effects have probably been included in the ranges and heights, making them, in some instances, several times their true values.

Station.	Geographic position.			Establishment. F. and C.	Spring range.	Neap rise.	Cotidal hour.
	Latitude.	Longitude.					
		Arc.	Time.				
	° ′	° ′	h. m.	h. m.	Feet.	Feet.	h.
MEDITERRANEAN SEA.	North.	West.					
Ceuta	35 53	5 17	0 21	2 06	3¾	2½	2·38
Tetuan	35 37	5 11	0 21	2 23	2½	1½	2·65
Malaga	36 44	4 25	0 18	2 30	3	....	2·72
		East.					
Tunis (Goletta)	36 48	10 18	0 41	....	3	....	....
Shebba	35 14	11 10	0 45	....	1	....	....
Kerkenah Bks	34 40	11 15	0 45	4 32	2	1½	3·63
Sfax Rd	34 44	10 46	0 43	3 47	4¼	2½	2·94
Surkenis B.	34 18	10 10	0 41	4 03	5½	3½	3·23
Jerba I	33 55	10 55	0 44	4 23	5¼	3¼	3·51

Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	Establishment. F. and C.	Spring range.	Neap rise.	Cotidal hour.
	° ′	° ′	h. m.	h. m.	Feet.	Feet.	h.
MEDITERRANEAN SEA—continued.	North.	East.					
Zarzis	33 30	11 07	0 44	3 13	2¼	1½	2.38
Ras et Ketef	...	...	...	2 33	2¼	...	...
Tripoli	32 54	13 11	0 53	10 20	2	...	9.10
Malta (Valetta Har.)	35 54	14 31	0 58	3 30	1?	...	2.41
P. Augusta, Sicily	37 13	15 14	1 01	3 20?	¼–1¼	...	2.20
Port Said	31 15	32 18	2 09	10 00?	½–1½	...	7.51
Alexandria	31 12	29 53	2 00	10 05	1?	¼	7.74
Yafa (Syria)	32 03	34 45	2 19	10 00	1½	...	7.51
Famagousta, Cyprus	35 07	33 57	2 16	10 00	1½	...	7.39
Vromo passage, G. of Volo	39 05	23 00	1 32	9 30	2½	1¾	7.65
Euripo	38 28	23 35	1 34	5 15	2	...	3.50
Patras	38 15	21 44	1 27	4 54	2⅓	1½	3.29
P. Galaxidi (Gulf of Corinth)	38 23	22 23	1 30	5 00?	2⅓	1⅓	3.33
Aspra Spitia B	38 22	22 39	1 31	...	2⅓	1⅓	...
Corinth canal, each end	38 00	22 55	1 32	5 00	¾	...	3.30
P. Pandelemona	...	...	...	3 10	¾?	...	...
Dragamesti B	38 31	21 05	1 24	3 10	¾	...	1.66
Lissa (Adriatic)	43 05	16 10	1 05	4 10	2½	...	2.95
Port Sebenico (Adriatic)	43 43	15 51	1 03	6 26	1	...	5.07
Port Lussin Piccolo (Adriatic)	44 33	14 26	0 58	8 26	1	...	7.18
Port Fiume (Adriatic)	45 19	14 27	0 58	8 36	1¼	...	7.34
Port Pola (Adriatic)	44 53	13 48	0 55	9 16	3½	...	8.03
Trieste (Adriatic)	45 38	13 45	0 55	9 35	2	...	8.34
Port Malamocco (Adriatic)	45 20	12 19	0 49	10 30	2¼–4	...	9.32

The following quotations are taken from the sources indicated in the footnotes.

The movement of the whole body of water in the strait of Gibraltar is, however, tidal, affected by the . . . surface current running into the Mediterranean from the Atlantic.

According to a table, which is here omitted, the east-going stream begins in the main body of the strait at one and one-half hours on the days of full and change, the west going at seven and one-half hours; between the 100-fathom line and the shore the east-going stream begins at ten and one-half hours, the west going at four and one-half hours.

Within a cable of Tarifa the west-going stream at spring tides has a rate of 2 to 3 miles an hour; but at neaps it is reduced to little more than one mile an hour. At springs the stream of the tide near the coast and in the bays runs at the rate of 1½ to 2 miles an hour, but at neaps there are places where it nearly ceases. These inshore streams run faster or slower according as they continue with or set against the prevailing easterly current.

When the tidal stream is setting to the eastward, the current at a cable distant from Tarifa attains a velocity of from 4 to 5 knots an hour, and from 5 to 6 knots an hour at 4 miles north of Alcazar point.

When the tidal stream inshore is setting to the westward the rate of the general east-going set through the strait is considerably checked, its rate on the meridian of Tarifa being only from 2 to 3 miles an hour in the middle of the strait, 2 miles on the coast of Africa, and rather more than one mile in the vecinity of Tarifa. Along the shores (at a greater or less distance, according to the time of the tide), the west-going stream is experienced, but always at a greater distance from the Spanish than the African coast.

The bay of Cala Grande, on the African coast, between Al Boassa and Cires, has this great advantage, that near the shore the stream runs continually to the westward. This fact is of great importance to sailing vessels passing through the strait from east to west with foul winds.

It is only during easterly winds and calms that a decided set to the westward (maximum rate one knot an hour) is experienced in the middle of the strait. The nearer a ship is to the edge of the inshore zones, as indicated by pecked lines upon the chart . . . [Fig. 38], the greater will be the chance of finding slack water or a westerly set at the proper time outside those zones.

The preceding remarks refer only to the surface water; the bottom stratum is unaffected by the inrunning current of the Atlantic, and sets east or west for equal periods according to the tide, the change in the tidal streams corresponding with the time of high and low water at Gibraltar.

On the shallow ridge at the western entrance to the strait, the surface and bottom streams are tidal, the inrunning current from the Atlantic not being sufficiently strong to overrun the west-going stream.

The tidal wave arrives simultaneously at Mogador in Africa, and Conil in Spain, and entering the strait, causes high water at the same time on all the coast between cape Plata and Europa point. It is not, however, until about 20 minutes after it has attained its highest level on the coast of Spain, that the water reaches its highest level on the African shore opposite.

It is high water, full and change, with the rise of tide at the several places, as mentioned in the following table:

Places.	High water, full and change.	Springs rise.	Neaps rise.	Neaps range.
	h. m.	*Feet.*	*Feet.*	*Feet.*
Chipiona	1 30	12·5	8·0	3·6
Rota	1 24	12·6	8·0	3·6
Cadiz	1 23	12·9	8·2	....
Conil	1 18	12·0	7·5	3·3
Cape Plata	1 45	8·0	5·3	2·6
Tarifa	1 46	6·0	3·6	1·3
Algeciras	1 49	3·9	2·6	1·3
Gibraltar	1 47	3·2	2·5	1·4
Ceuta	2 06	3·7	2·5	1·3
Tetuan	2 23	2·6	1·6	0·6
Tangier	1 42	8·3	5·1	2·0
Rabat	1 46	11·0	7·1	3·3
Mogador	1 18	12·4	8·0	3·6

. . . .

There are probably few places in which tide races are more numerous than in the strait of Gibraltar. They are generally found off all the salient points of the strait where the direction of the coast changes, and near the banks in their neighborhood. They form without warning of any kind; the sea gets up like water boiling over a fire; short, irregular, and deep. These races are dangerous, not only for boats, but even for small vessels; the wind, of course, contributes to form them, and always augments their violent character. The most turbulent races in the strait are generally where the angle of the point is most acute, and off which the water is not so deep; they are generally formed when the current is strongest.

In some parts both streams produce these races; in others, the race is only produced by the east-going stream. The points on the coast of Spain where races are found are, cape Trafalgar, the Cabezos shoals, the south point of Tarifa, Frayle point, the Pearl rock, and Europa point. On the coast of Africa, cape Spartel, points Malabata, Altares, Al Boassa, Cires, Leona, and the northeast point of Ceuta have also races off them.

Off cape Trafalgar a race forms at the strength of both streams. It extends to a considerable distance off the cape in a W. S. W. direction, crossing the bank of Aceytera, and over all the small banks of the Phare. This race, which is more formidable both in extent and violence than any other in the strait, most probably arises from two causes; the sudden change of direction in the coast and the number of banks off it.

A race is also formed on both streams on Cabezos shoals, or near them, varying both in its extent and direction; and sometimes by following the small shoals it becomes considerably extended, although not so violent as the races generaly are off the points; it gets up with a troubled sea even in calm weather; and in bad weather, with much sea on, extends over the whole breadth of the strait, from the Cabezos to the flats between Malabata and Al Boassa points, on the African coast.

The race off Tarifa point is comparatively of limited extent; with the east-going stream it extends to the S. E., but with the west-going S. W. It appears at the strength of each tide, that on the east-going stream being generally more considerable than that on the west-going. The races off Frayle and Europa points are much the same as those just mentioned, the first resembling that of the Cabezos, and the last that of Tarifa; their only difference is, in being less extensive and less violent.

On the African coast, off cape Spartel, Judios point, and Tangier point, the races are generally of small extent and of little importance, although they are found with both streams. The worst races are between the Malabata and Al Boassa points, over the Almirante, Phoenix, and Jaseur banks, and, as above mentioned, reach across the strait to the Cabezos. The races off Cires, Leona points, &c., as far as Ceuta, are of small extent; they are sometimes rather violent, like the tide which produces them: but this is only during the east-going stream. In fact, in the strait, and principally to the northward of Tangier, there are occasional eddies as well as counter streams at springs, but they are of small extent and short duration.*

85. The Strait or Faro of Messina (the *Fretum Siculum* of the ancients), trends in from the gulf of Giorga, between the overlapping points of Calabria and Sicily, in a westerly direction for about 4 miles, then turns to the S. S. W. for 14 miles; in breadth it varies from 13¾ miles between the Faro and the opposite coast west of Scilla to 2¾ miles abreast of Messina, and nearly 12 miles between cape Grosso and cape dell Armi, its southern boundary. This strait, dreaded by the ancients, and invested by them with many imaginary terrors, requires some caution in its navigation, on account of the rapidity and irregularity of the currents, known to them as the Charybdis, but now locally termed Garofalo. The winds are also baffling when off the high land, and heavy gusts blow down the valleys and gorges; without a steady and commanding breeze a vessel may become quite unmanageable, and be turned round even when under steam. The strait is everywhere clear of danger and the water deep.

. . . .

The currents in the strait of Messina are variable, and at times attain a velocity of 5 knots. They are, however, to a great extent tidal, their greatest strength being on the day following the full and change of the moon. Occasionally the tidal currents are overpowered by other general movements of the water in the neighborhood, from winds or other causes, and the stream may then run in one direction for many hours.

The flood stream runs to the northward, the ebb to the southward, but near the coasts there are counter currents of which the mariner may take advantage. These counter streams, which are felt between one and two hours after the commencement of the main stream, are termed Refoli when produced by the ebb, and Bastardi when caused by the flood.

On the Sicilian side the principal counter streams of the ebb occur between Palazzo tower and cape Peloro; Pace and river Guardia; S. Salvatore dei Greci and S. Francesco di Paola. The breadth of these counter currents increases in proportion as the general stream has more duration, and is important during springs, when they extend a mile from the shore. On the Calabrian side the counter stream on the ebb does not occur north of Pezzo point, but thence south to Cantone (opposite Messina), is about a mile in breadth. With the flood or northerly stream, the only important counter current or Bastardi on the Sicilian side occurs in Messina Strait, between the light-house and Palazzo point; the others are insignificant. On the Calabrian side, however, after 2 hours flood, between Alta Fiumara and Pezzo point, there is an eddy setting to the south, having its greatest breadth off Canitello, where it extends about half a mile from the shore.

At full and change the ebb stream begins at 9 h. a. m., at cape Peloro, Messina strait, and sets toward Alta Fiumara in Calabria, thence to Pezzo Point, and toward Pace in Sicily; afterwards to Salvatore dei Greci, arriving off the northeast light-house of Messina about 11 h., setting thence toward Reggio in Calabria.

At full and change the flood stream commences about 3 h. at Pezzo point, gradually enlarges,

* Mediterranean Pilot, Vol. I, third edition, 1894, pp. 19–24.

and uniting with the counter current between Palazzo tower and Sottile point, the whole stream runs to the northeast in the direction of the channel. After 2 hours its direction changes toward Scilla, but at the same time a stream from the north unites with the former near Scilla, and causes a current toward the offing. At Messina the northerly current does not commence till about 5 h.

At neaps the southerly currents follow the same direction as those of full and change, and produce the same counter current but with less velocity. It begins at capo di Faro at 0 h. 45 m., and off Messina at 3 h. 45 m. At capo di Faro the rise of water is scarcely perceptible; at Messina the maximum rise is from 10 to 13 inches, but it is greatly influenced by the winds. The meeting of the two opposing currents produces in several parts of the strait, whirls and great ripplings, locally termed Garofalo; they are represented on the chart by a scroll. The principal are, on the coast of Sicily between the Faro point and Sottile point with the ebb; and off Palazzo tower with the flood; the latter are very strong.

Off Secca point, the northeast extreme of the Braccio di San Ranieri, it is also very strong, and dangerons with a southeast wind. At Pezzo point on the Calabrian coast, there is a very strong Garofalo, which is also dangerous with a southeast wind. The other great ripplings without whirls, caused by the current over the uneven bottom, are termed Scala di Mare. The celebrated vortex of Charybdis, so much dreaded by the ancients, is described by Admiral Smyth as that outside the Braccio di San Ranieri, but in the French survey of the strait in 1858 the position of Charybdis is assigned to the Garofalo immediately southward of the Faro, and this being so much nearer Scilla, would be more in accordance with the famous proverbial expression, "*Incidit in Scyllam cupiens vitare Charybdim*," applicable to those who, to avoid a less, run into a greater danger.

To the southward of cape Pellaro, in Calabria the tidal streams are not felt, and the current generally is determined by the wind.*

86. The level of the water in the Ægean sea is, as in most parts of the Mediterranean, more influenced by wind than by the tide; but in such places as the rise and fall of the latter is appreciable it is regular, especially at springs.

The effect of the tide at the Euripus bridge, at which place the spring tide rises about 2 feet, is very pronounced. Here the stream runs to the northward at half ebb, and to the southward at half flood, attaining a velocity of 6 or 7 knots an hour. At neaps the stream is irregular and its strength only from ½ to 1 knot an hour, and at times but little movement is experienced.

At the entrance of Talanta channel, in the vicinity of the Lithada islets, the tides correspond with those at Euripus, but less in strength, the flood running in at from 1¼ to 2 knots an hour, and ebb setting out and to the northward at the same rate; there is a sensible rise and fall affected at times by the wind. At Volo, the rise and fall at full and change of the moon is about 8 inches.

At Smyrna the water level rises with a southerly wind and falls with a northerly. The variation in the level is from 3 to 3½ feet, but at Khios and places adjacent it is only about 2 feet.

On the coast of Candia or Crete, in fine weather at about the full and change of the moon, the rise and fall is from 6 to 8 inches.†

87. *Explanation of the tides in the eastern part of the Mediterranean.*

To apply the equilibrium theory to that part of the Mediterranean lying east of Sicily we draw upon the chart of the world (Fig. 23) a set of cotidal lines radiating from a no-tide point whose position is the center of gravity of the surface, the elliptical outline showing how far we must go from this point to obtain an M_2 range of 0·08 foot, or about 1 inch. To reduce the cotidal hours of the diagram to the meridian of Greenwich, subtract the 1·56 hours. The cotidal hour for the coast of Syria should be about 9—1·56 or VII·5 say, and for eastern Sicily about 3·5—1·56 or II. The range of the lunar tide for the first locality should be 0·45 foot and for the latter 0·32 foot. Observations at Malta make the cotidal hour II·1 and $M_2 = 0·20$ foot or $2\ M_2 = 0·4$ foot. (See No. 935 of table given under § 97.) It is also to be noted that the age of the phase inequality is not great at Malta; this is in accordance with the equilibrium theory. In

* Mediterranean Pilot, Vol. I, third edition, 1894, pp. 406–408.

† Mediterranean Pilot, Vol. IV, second edition, 1892, p. 11. See § 64, Part 1, this manual.

attempting to explain the tides of a body whose length is several times its width, it should be borne in mind that the times are largely governed by their end values, as in the canal theory. Agreeably to theory, the above quotations show that the tides in the vicinity of Candia, or Crete, are relatively small.

The varying depths of the Adriatic Sea and the large cross section of the Strait of Otranto would indicate that a wave progresses upward at a rate due to depth. Moreover, the shoaling and contracting toward the head of this sea would account for a considerable increase in the range of tide. These statements agree well with the results of observation.

88. *Explanation of the tides in the western part of the Mediterranean.*

A set of cotidal lines for the part of the Mediterranean Sea west of Sardinia is also drawn on the chart of the world. (Fig. 23.) The tides of this region are necessarily influenced by those of the remainder of the sea and of the Atlantic Ocean. In the vicinity of Marseilles and Toulon the equilibrium tide ought to be more conspicuous than in localities nearer to the no-tide point or nearer to the openings. The equilibrium cotidal hour should be a little more than VI for Marseilles and a little less than VII for Toulon. The range of the lunar tide should be about 1·6 inches. From harmonic analysis of observations the cotidal hours are found to be VII·2 and VIII·0; the ranges are 0·44 and 0·38 foot, respectively. Although these cotidal hours are not very different from those given by theory, the discrepancy in range is too great to be accounted for by the small shoal along the southern coast of France. If there were a solid wall along the meridian of Sardinia, the tide in the portion of the sea west of it would, so far as the effect of the Atlantic is concerned, be six hours behind the tide outside the Strait of Gibraltar. This would make the cotidal hour VIII, or a little less. (See § 103; also the preceding quotations concerning the strait.) By § 103 it is possible to ascertain roughly the velocity in the strait; with the assumed wall, the resulting rise and fall of the portion of the sea west of it, due to the influx through the strait, will be found to be nearly equal to the observed ranges at Marseilles and Toulon. Hence we conclude that the tides at these two places are chiefly derived from the tides of the Atlantic, but that they are augmented by the equilibrium tide.

From the quotations given above it is to be noted that the eastward current in the Strait of Gibraltar and the northward current in the Strait of Messina begin at about the times of high water at their outer ends, that is, ends where the tides are greatest. In the one case, the Atlantic Ocean is the tided body, in the other the Ionian Sea. By referring to § 103 it is easily seen that these statements accord well with the theory for a strait leading from a tided to a tideless body of water. The observed dimunition of range is also in accordance with theory.

89. *Tides in the Gulf of Mexico.*

The semidiurnal tides in many parts of the Gulf are so small in comparison with the diurnal that they can not be observed directly. For this reason we should depend chiefly upon the results of harmonic analyses whenever we attempt to compare theory with observation. The consideration of the diurnal portion of the tide will be deferred to a later section (§ 92). The following is a list of stations, together with their cotidal hour and range of lunar tide (2 M_2) in feet: Key West, II·1, 1·12; Tortugas Harbor Light, II·8, 0·96; Cedar Keys VI·3, 2·12; St. Marks Light, VII·1, 2·24; Warrington Navy-Yard, Pensacola Bay, IV·4, 0·12; Mobile Point Light, Mobile Bay, III·9, 0·14; Biloxi Light, VI·3, 0·22; Cat Island Light, VI·3, 0·24; Port Eads, IV·5, 0·12; Galveston, X·5, 0·44; Tampico, VIII·6, 0·16; Vera Cruz, VIII·9, 0·40; and Campeche, IX·0, 1·6. No great reliance can be placed on the Tampico values because they were obtained from a record in which twenty-four hours were represented by 0·4 of an inch.

90. *Explanation of the semidiurnal tides in the Gulf of Mexico.*

By inspecting the cotidal diagram for the Gulf, shown upon the chart of the world (Fig. 23), we obtain the following cotidal hours and ranges (at the shore) for the equilibrium tide: Cedar Keys, II·5, 0·37; Port Eads, I·2, 0·11; Galveston, X·0, 0·21; Vera Cruz, VIII·2, 0·26; and Campeche, VI·0, 0·10. On account of extensive shoaling, the range of tide at Cedar Keys, Galveston, and Campeche, especially, should be greatly increased. All intervals should have their (off-shore) equilibrium values increased by the time required for a free wave to pass from deep water to the shore. Thus modified, the cotidal hours become for Cedar Keys, V·8; for Port Eads, I·6; for Galveston, XII·4; for Vera Cruz, VIII·6; and for Campeche, IX·0.

Consider now the derived wave coming from the Atlantic through Florida Strait. The cotidal hour for the outer coast of northern and eastern Florida is XII. Although this would to a certain extent come under §§ 103, 113, the result is probably about the same as would be obtained from the consideration of a free progressive wave moving at rates due to depths. Upon referring to the charts of depths we see that the cotidal hour for a point at the extreme west end of the keys might reasonably be III, or a line less, which is in agreement with observation. Starting with this value, we have as the cotidal hours of the progressive wave, Cedar Keys, VII; Port Eads, V; Galveston, VIII; Vera Cruz, VI; and Campeche, VIII. The means between these times and the modified equilibrium values agree tolerably well with the results of observation given above. It is reasonable to suppose that the derived wave in the deep water of the Gulf should be very small in comparison with its value at Key West. This surmise is further confirmed by the fact that at Port Eads the equilibrium tide is small; yet when combined with the derived wave, in phases specified by I·6 and V, the resultant tide is about the size of the equilibrium tide. Hence the derived wave here has considerably less than twice the range of that of the equilibrium theory. For Cedar Keys, Vera Cruz, and Campeche, the two theoretical waves are in approximately like phases; hence their effects are added together. At Galveston the waves meet in nearly opposite phases. Both waves are greatly increased by the effect of shoaling for Cedar Keys, Galveston, and Campeche.

91. *Fractional oscillating areas.*

Two areas of this kind have already been described—the Bay of Bengal and the Gulf of Suez. In these the cotidal hours are the same as those of the system upon which they depend. It often happens that the wave has proceeded for some considerable distance from its source before reaching the dependent fractional areas. For instance, the cotidal hour for the mouth of the English Channel is V, while that of the source of the West-European tide is II, so that three lunar hours must be allowed for wave propagation across the Bay of Biscay to the mouth of the Channel. Again, four or more hours are required for a wave to pass from the region marked VI through Cape Horn Strait to west of the Falkland Islands. This consideration should be borne in mind in attempting to connect the fractional dependent areas with the areas where the tides originate. As already stated, areas $\frac{1}{4}\lambda$ long are of a critical length and generally have their tide about three hours later than the tide outside. In the following list "observed" means values obtained or inferred from such observations at or near the given localities as are available.

Name of area.	Port.	Position.	Distance.	Observed H W I.	Observed range 2 M_2.	Approximate cotidal hour.
				h. m.	*Feet.*	
English Channel	Head	Pas-de-Calais	0	11 10	18	XI
	Node	Christchurch	$\frac{1}{4}\lambda$	10 00	2·5	....
	Mouth	Lizard Head	$\frac{1}{2}\lambda$	4 45	10	V
Irish Sea	Head	English shore	0	11 00	18	XI
	Node	Courtown	$\frac{1}{4}\lambda$	7 30	1	....
	Mouth	Roches Point	$\frac{5}{12}\lambda$	4 30	8·4	V
Gulf of St. Lawrence	Head	Point de Monts	0	1 48	8	VI
	Node	North of Magdalen Islands	$\frac{1}{4}\lambda$	9 30	1·5	....
	Mouth	South of Cape Ray	$\frac{1}{3}\lambda$	8 15	3·5	XII
Gulf of Maine	Head	St. John	0	11 07	20	III
	Node	Georges Bank	$\frac{1}{4}\lambda$	8 00	2	0
	Mouth	....do	$\frac{1}{4}\lambda$	8 00	2	0
Long Island Sound	Head	Execution Rocks	0	11 05	6·5	III·6
	Node	71° 45′ W	$\frac{1}{4}\lambda$	8 05	2	....
	Mouth	....do	$\frac{1}{4}\lambda$	8 05	2	0·6
Southeast of Patagonia	Head	Bahia Grande	0	9 00	30	I·3
	Node	52½° S., 62½° W	$\frac{1}{4}\lambda$	6 30	3	X·3
	Mouth	....do	$\frac{1}{4}\lambda$	6 30	3	X·3
Corcovado Gulf	Head	41° 50′ S	0	0 40	13	V
	Mouth	East of Huafo Island	$\frac{1}{8}\lambda$	0 00	5	V
Gulf of Georgia	Head	Cortes Island	0	6 00	8	II
	Node	Discovery Island Light	$\frac{1}{4}\lambda$	2 27	2	....
	Mouth	Cape Flattery	$\frac{3}{8}\lambda$	0 08	5	VIII
Dixon Entrance*	Head	Mary Island	0	0 22	12	IX
	Mouth	133° W	$\frac{1}{12}\lambda$	0 00	10	IX
(?) Cook Inlet	Head	Redoubt Bay	0	3 00	16	I
	Node	West end of Portloch Bank	$\frac{1}{4}\lambda$	0 00	7	....
	Mouth	....do	$\frac{1}{4}\lambda$	0 00	7	X

*Branching off from the Dixon-Entrance area are several dependent areas, viz., Portland Canal, Behm Canal, Clarence Strait with Western Behm Canal and Ernest Sound (Fig. 32). In all the wave is nearly stationary so that the cotidal hours are but little more than IX, and the range at the heads is about 13 or 14 feet. Throughout Chatham Strait and its branches the cotidal hour is but little more than IX. The range of tide (2 M_2) near the head of Lynn Canal is about 12 feet.

DIURNAL TIDES.

92. The principal systems for the diurnal tide may be designated thus: 1. West Atlantic diurnal; 2. North Pacific diurnal; 3. Indian diurnal.

The West Atlantic system (if we may so use the word "system") consists of a partially inclosed body of water whose tides are assumed to be roughly in accord with the corrected equilibrium theory. For the sake of definiteness, consider a circular area 40° in diameter with its center situated at 30° N. and 50° W. The equilibrium times (50th meridian) are as shown on the chart for the diurnal systems (Fig. 24). At the north the cotidal hour is numbered 0; at the west, 6; at the south, 12; and at the east, 18. The Greenwich values are obtained by adding three and one-third hours to the diagram values. The theoretical amplitude for this area is shown (in stereographic projection) in Fig. 6. The unit used is $U\,C_1$, which is (§ 3) about 0·8 foot for K_1+O_1. There are several reasons why this hypothesis does not apply very accurately to the case in hand: (1) There are two broad openings, one between Brazil and western Africa, the other between Europe and Greenland; (2) the dimensions and depths are such that a free wave can not cross and recross a sufficient number of times in twenty-four hours to permit the formation of a very good level surface; (3) shallow regions near the shores, as usual for this theory, do not form a part of the equilibrating body of water; as a consequence wave motion should be set up which might greatly increase the range of the tide, and, in the common case of a progressive wave, cause an increase in the cotidal hours.

This theory should best apply to the eastern coast of the United States, the Bermuda Islands, and the outer coast of the West Indies. There the age of the diurnal inequality (or $K_1° - O_1°$) should be small, and the amplitudes K_1, O_1, P_1 should have their theoretical ratios to one another.

An inspection of the diurnal chart shows that the diurnal cotidal hour for the Windward Islands should be about $10\frac{2}{3} + 3\frac{1}{3}$ or XIV. The chart of depths shows that a fractional dependent area extends from these islands to the Gulf coast of the United States. Suppose a nodal line to be drawn from western Haiti to Nicaragua. Now imagine the portion of the area northwest of this line to be duplicated by a like area lying south of this line as a line of symmetry. Then applying lemma 7 we can see how the virtual length of the region northwest of the nodal line is increased. The distance between the nodal line and the Windward Islands is about three lunar hours, or $\frac{1}{8}\lambda$. Hence the cotidal hour for the diurnal tide in the Gulf should be XIV + 12, or II; and the range of that wave should there be somewhat greater than at the Windward Islands.

The stations for which harmonic analyses have been made are shown upon the chart of tide stations (Fig. 21). The value of $K_1 + O_1$ and the cotidal hour are given under § 97. Along the eastern coast of the United States the theoretical cotidal hour should be increased by about 3 on account of the extensive shoaling, which gives rise to a progressive wave. Of course the theoretical amplitudes should be greatly increased. For Porto Rico, St. Thomas Islands, and even Lisbon, the theoretical times should be increased by but a fraction of an hour, and the theoretical amplitudes should not be greatly increased. Since the Gulf of Mexico forms part of oscillating area, the tides should be nearly simultaneous along the open coast from northern Florida to Yucatan (lemma 9); the cotidal hour should be II.

93. The North Pacific diurnal system consists at first of an east-and-west strip of water whose southern boundary approximately coincides with the parallel 20° N. The eastern boundary consists of Lower California, California, Oregon, Washington; the western, of the Bonin Islands and shoals, eastern Japan, the Kuril Islands and shoals. The center of this area being 11·5 hours west of Greenwich, we should have, by § 67, XI·5 as the cotidal line for the east end, and XXIII·5 for the west end. But the principal area responsible for the diurnal tides consists of the whole of that portion of the Pacific Ocean which lies northwest of a line drawn, say, from Point Arguella, southern California, to the eastern extremity of San Christoval Island. The force diagrams applied to this somewhat triangular area give XV for the cotidal hour of the American end and III for that of end extending from the Philippine to the Solomon Islands. As a matter of fact, the observed value for Alaska is about XVIII, and for the Pacific Coast of Gilolo, and perhaps New Guinea, VI. This discrepancy may possibly be explained by considering a progressive wave due to the superposition of the two oscillations just described, which differ in phase, taken in connection with the virtual length of the principal area, which probably is in excess of λ. See §§ 26, 32, and 31 (end), 61.

The greatest rise and fall should occur along the coast extending from Oregon to the Gulf of Alaska. Because of the two overlapping areas the cotidal hour should be XI·5 for Lower California and increase quite rapidly to Oregon; thence northwesterly the increase should be slow, the prevailing cotidal hour being, it appears from observation, XVIII. The cotidal hour for the Kuril Islands should be XXIII·5 or —0·5, and this probably increases to about VI on the Philippine coast, and so VI is probably the hour for Molucca Passage, New Guinea, and the Solomon Islands. The two overlapping areas prevent there being any nodal line in the North Pacific. The tides at Honolulu should be small in comparison with those on the coast of southeastern Alaska, and the cotidal hour should lie between XI·5 and XVIII. The tide at St. Michael should be somewhat later than that at the Kuril Islands and Kamchatka, to allow for the transmission of a free wave across the shoal portion of Bering Sea. It is, however, probable that the deeper portion of Bering Sea forms a dependent fractional area. If so, the simultaneous motion would, by lemma 9, extend well up toward St. Matthew Island before a progressive wave comes into being; cf., the Gulf of Maine and the Bay of Fundy. Possibly only a few hours would have to be added to the Kuril and Kamchatka values. By referring to the chart of semidiurnal tides, we infer, because of the proximity of a nodal line, that the tides along the northern shores of New Guinea should be largely diurnal.

It is difficult to see how any considerable derived tide could set out from the Northern Pacific Ocean into the Southern.

To compare with observations, see the table in § 97, where are given the cotidal hours derived from harmonic constants. See also Van der Stok's map of the East Indies for K_1. His values can be converted into hours by dividing by 15, and reduced to the meridian of Greenwich by subtracting 7·1 from the quotient. Of course K_1 hours are not quite equal to $K_1 + O_1$ hours, which are practically lunar hours. Observations are much wanted on the eastern coast of the Philippines and the northern coast of New Guinea.

94. The Indian diurnal system consists of a half-wave area extending from northwestern and western Australia to Somali and Arabia. As shown on the chart, the nodal line lies south of Ceylon and not very far away. Hence the diurnal tide should there be small. A reference to the chart of the semidiurnal system (Fig. 23) will show that the semidiurnal tide also is there small. Hence the tide at eastern Ceylon, both diurnal and semidiurnal, is small. By applying the force diagrams, we see that the cotidal hour for the east end of the area should be XII and for the west end XXIV.

As already stated, the time required for a free wave to pass from Timor Island to Molocca and Gilolo passages is perhaps six hours. Now, the cotidal hour for the former locality is XII and for the latter, VI. The openings from the north are greater than those from the south. Hence the wave from the Pacific should progress through the passages almost to Timor Island before being met by the wave from the south.

According to lemma 19, it might be inferred that a derived wave should be formed on the western coast of Australia, which might be sensible along the southern and even the eastern coasts and possibly to New Zealand if not obscured by a greater wave derived from other sources. Since there appear to be no such sources which might cause the diurnal tides in these localities, this explanation seems to be plausible.

To compare theory with observation, consult the sources of information referred to in the last section, especially Van der Stok's map of the K_1 tide (Fig. 30). Besides consulting the charts of depths covering the world (Figs. 19, 20), one should also consult Fig. 34, which shows the depths around southeastern Australia.

95. *The diurnal tides of the Mediterranean Sea.*

In attempting to explain these tides, the first question is, Can this sea oscillate in a period approximating 24 hours? Were the island of Sicily, together with the neighboring shoals, removed, and a depth about equal to that of the remainder of the sea substituted in its place, the period of free oscillation could hardly exceed 12 or 14 hours. As already stated, the period of a half-wave area is considerably lengthened by a contraction near the center or nodal line. An experiment described in § 55 shows that the period can be greatly lengthened by a shoaling along the nodal line. The effect of both combined (the latter being far more important) may be sufficient to cause the free period to approach 24 hours. Accordingly we shall assume that the Mediterranean Sea does constitute an oscillating area. The nodal line should fall not far from Malta. The force diagrams give X as the cotidal hour of the west end and XXII for that of the east.

These inferences are well borne out by observations made at Malta, Toulon, and Marseilles. See values given in § 97. At present there is no information available for the eastern part of the sea.

96. *Fractional oscillating areas for diurnal tides.*

One area of this kind has already been mentioned, viz., the Caribbean Sea and the Gulf of Mexico. Imagine a body like the China Sea to be connected with the real China Sea through the strait between Luzon and Formosa. The free period of such a body would probably be not far from 24 hours, if we take into consideration the contraction and shoaling at the strait (§§ 54, 55). Hence the China Sea and the strait constitute a fractional area of critical length $\frac{1}{4}\lambda$. The tides in the sea should be $\frac{1}{4}\tau$ or 6 hours later than the tides outside. Hence the cotidal hour for the China Sea should be XII, and the range of tide may there be considerable.

The Gulf of St. Lawrence, with Cabot Strait and the channel outside, constitute a fractional area a little more than $\frac{1}{4}\lambda$ in length. Hence the cotidal hour for the gulf should differ by 12 from the cotidal hour at the edge of deep water in the Atlantic; that is, it should be V + 12 = XVII.

Some observed values with which to compare these inferences are given in the next section.

97. *Intervals, ranges, cotidal hours, etc., derived from harmonic constants.*

In the accompanying table the arbitrary serial number refers to the charts of tide stations (Figs. 21, 22). The table is intended to include all stations where some form of harmonic analysis has been made and the results are available (see § 145, Part I). At a few of the places given, no analysis has yet been made, although suitable records for the purpose exist. This accounts for a few blank spaces in the table. The cotidal hour of the semidiurnal tide has reference to the constituent M_2 and that of the diurnal to K_1 and O_1, as shown in the heading. We have

$$\text{Cotidal } M_2 \text{ hour} = \frac{M_2^\circ}{30} \pm \begin{matrix}\text{west longitude of station,}\\ \text{east longitude of station,}\end{matrix} \tag{323}$$

$$\text{Cotidal } (K_1 + O_1) \text{ hour} = \frac{K_1^\circ + O_1^\circ}{30} \pm \begin{matrix}\text{west longitude of station,}\\ \text{east longitude of station,}\end{matrix} \tag{324}$$

where the longitude is expressed in time. It is supposed that $-180^\circ < K_1^\circ - O_1^\circ < 180^\circ$.

No.	Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
	EAST COAST OF AMERICA.	° ′ North.	° ′ West.	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
6	Beechey Island, Barrow Str	74 43	92 00	6 08	2·00	347	11·57	0·69	34	0·43	315	0·90
7	Port Leopold, Barrow Str	73 50	90 25	6 02	2·00	338	11·27	0·64	29	0·42	306	0·90
10	Port Laperrière, Digges I	62 34	78 01	5 12	3·09	257	8·57	1·24	316	......	......	0·14
11	Port Boucherville, Nottingham I	63 12	77 28	5 10	4·74	260	8·67	1·77	321	......	......	0·22
12	Stupart Bay	61 35	71 32	4 46	9·02	227	7·57	3·05	289	......	......	0·47
13	Ashe Inlet	62 33	70 35	4 42	11·00	234	7·80	3·98	296	......	......	0·52
14	Port Burwell, Ungava Bay	60 25	64 46	4 19	7·12	263	8·77	2·33	305	......	......	0·48
15	Kingua Fiord	66 36	67 20	4 29	7·43	159	5·30	2·67	202	1·20	144	0·27
18	Nennortalik	60 08	45 16	3 01	2·88	161	5·37	1·24	203	......	......	0·62
20	Godthaab	64 12	51 44	3 27	4·46	193	6·43	1·54	229	0·86	188	0·69
25	Fort Conger, Discovery Harbor	81 44	64 44	4 19	1·96	335	11·17	0·89	19	0·38	309	0·28
28	St. Johns, Newfoundland	47 34	52 41	3 31	1·17	209·6	6·99	0·48	254	0·23	195	0·25
32	Quebec	46 49	71 12	4 45	5·80	186·9	6·23	1·37	236	0·93	158	0·76
36	St. Paul I., Gulf of St. Lawrence	47 14	60 08	4 01	0·98	245·4	8·18	0·33	287	0·18	228	0·26
40	Halifax	44 40	63 35	4 14	2·04	223·5	7·45	0·45	258	0·45	205	0·34
42	St. John, New Brunswick	45 14	66 04	4 24	10·04	324·7	10·82	1·62	4	2·30	295	0·50
44	Eastport	44 54	66 59	4 28	8·58	326·1	10·87	1·40	6	1·72	298	0·48
45	Pulpit Harbor	44 09	68 53	4 36	4·89	320·4	10·68	0·77	355	1·02	291	0·45
46	Portland	43 40	70 14	4 41	4·34	323·6	10·79	0·68	0	0·96	292	0·47
50	Boston	42 22	71 03	4 44	4·44	335·4	11·18	0·71	14	1·02	304	0·44
58	Newport	41 29	71 20	4 45	1·66	217·5	7·25	0·38	237	0·36	200	0·21
59	Bristol	41 40	71 16	4 45	1·90	222·4	7·41	0·34	233	0·42	206	0·21
60	Providence	41 49	71 24	4 46	2·02	228·1	7·60	0·44	252	0·49	218	0·24
63	New London	41 21	72 05	4 48	1·14	274·1	9·14	0·21	288	0·27	247	0·25
66	Willets Point	40 48	73 46	4 55	3·65	328·6	10·95	0·64	352	0·74	304	0·34
67	New York, Governors Island	40 42	74 01	4 56	2·12	231·0	7·70	0·41	257	0·48	213	0·32
70	Sandy Hook, The Horseshoe	40 27	74 00	4 56	2·22	217·6	7·25	0·43	246	0·50	201	0·33
76	Reedy I., Delaware Bay	39 31	75 34	5 02	......	......	......	......	......	......	......	......
77	Philadelphia, Wash. Ave	39 56	75 09	5 01	2·46	43·5	1·45	0·34	82	0·41	20	0·35
85	Old Point Comfort	37 00	76 18	5 05	1·22	248·4	8·28	0·23	269	0·27	226	0·19
90	Washington Navy-Yard, D. C	38 52	77 01	5 08	1·43	227·9	7·60	0·20	271	0·27	202	0·16
95	Baltimore, Fells Point	39 17	76 35	5 06	0·51	190·2	6·34	0·08	225	0·09	163	0·13
98	Wilmington, N. C	34 14	77 57	5 12	1·15	292·1	9·74	0·10	344	0·18	288	0·25
101	Charleston, Custom-house wharf	32 46	79 56	5 20	2·48	213·6	7·12	0·43	240	0·56	196	0·34
103	Savannah Ent., Tybee I. Light	32 02	80 51	5 23	3·22	209·5	6·98	0·59	235	0·68	190	0·34
105	Fernandina, Fort Clinch	30 41	81 28	5 26	2·84	223·3	7·44	0·48	245	0·62	203	0·34
112	Indian Key, Florida	24 53	80 41	5 23	......	......	......	......	......	......	......	......
113	Key West, Fort Taylor	24 33	81 48	5 27	0·56	260·3	8·64	0·17	280	0·12	232	0·27
114	Tortugas Harbor Light	24 38	82 53	5 32	0·48	278·1	9·27	0·17	292	0·10	271	0·37
116	Captiva Pass, Charlotte Har	26 36	82 13	5 29	......	......	......	......	......	......	......	......
117	Egmont Key, Tampa Bay	27 36	82 46	5 31	......	......	......	......	......	......	......	......
118	Bayport, Florida	28 32	82 39	5 31	......	......	......	......	......	......	......	......
119	Cedar Keys	29 08	83 02	5 32	1·06	24·4	0·81	0·42	51	0·16	23	0·53
120	St. Marks Light, Apalachee Bay	30 04	84 11	5 37	1·12	43·5	1·45	0·44	73	0·15	27	0·58
121	Dog Island, St. Georges Sound	29 47	84 40	5 39	......	......	......	......	......	......	......	......
122	St. Vincents I., West Pass, Fla	29 38	85 06	5 40	......	......	......	......	......	......	......	......
125	Warrington NavyYd., Pensacola Bay	30 21	87 16	5 49	0·06	317·0	10·57	0·03	315	0·01	318	0·41
126	Mobile Point Light, Mobile Bay	30 14	88 01	5 52	0·07	300·8	10·03	0·04	313	......	......	0·38
127	Great Point Clear, Mobile Bay	30 29	87 56	5 52	......	......	......	......	......	......	......	......
128	Biloxi Light	30 24	88 54	5 56	0·11	11·3	0·37	0·09	32	0·03	32	0·57
129	Cat Island Light	30 14	89 09	5 57	0·12	11	0·37	0·07	24	0·03	33	0·52

K_1^o.	O_1.	O_1^o.	P_1.	P_1^o.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	$K_1 + O_1$.	$S_2^o - M_2^o$.	$M_2^o - N_2^o$.	$K_1^o - O_1^o$.	$\frac{1}{2}(K_1^o + O_1^o)$. De-grees.	$\frac{1}{2}(K_1^o + O_1^o)$. Lunar hours.	Cotidal hour. Semi-diur-nal.	Cotidal hour. Diur-nal.	No.
°	*Ft.*	°	*Ft.*	°	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	°	°	°	°	*h.*	*h.*	*h.*	
243	0·49	162	0·22	222	0·35	0·22	0·54	0·24	1·39	47	32	81	202·5	13·50	5·70	19·63	6
216	0·44	164	0·22	218	0·32	0·21	0·49	0·24	1·34	51	32	52	190	12·67	5·30	18·70	7
64	0·04	126	0·05	64	0·40	......	0·29	0·36	0·18	59	......	−62	95	6·33	1·77	11·53	10
91	0·25	17	0·07	91	0·37	......	1·14	0·32	0·47	61	......	74	54	3·60	1·84	8·77	11
103	0·31	6	0·16	103	0·34	......	0·66	0·34	0·78	62	......	97	54·5	3·63	12·34	8·40	12
108	0·21	349	0·17	108	0·36	......	0·40	0·33	0·73	62	......	119	48·5	3·23	12·50	7·93	13
114	0·19	157	0·16	114	0·33	......	0·40	0·33	0·67	42	......	−43	135·5	9·03	1·09	13·35	14
32	0·88	47	0·84	38	0·36	0·16	3·26	3·11	1·15	43	15	−15	39·5	2·63	9·78	7·11	15
114	0·36	74	......	......	0·43	......	0·58	......	0·98	42	......	40	94	6·27	8·39	9·29	18
127	0·30	81	0·23	125	0·35	0·19	0·44	0·34	0·99	36	5	46	104	6·93	9·88	10·38	20
222	0·09	199	0·08	233	0·45	0·19	0·32	0·29	0·37	44	26	23	210·5	14·03	3·49	18·35	25
108	0·23	77	0·08	86	0·41	0·20	0·92	0·32	0·48	44	15	31	92·5	6·17	10·51	9·69	28
274	0·71	246	0·18	283	0·24	0·16	0·93	0·24	1·47	49	29	28	260	17·33	10·98	22·08	32
236	0·28	205	0·08	231	0·34	0·19	1·08	0·31	0·54	42	17	31	220·5	14·70	12·20	18·72	36
60	0·16	38	0·10	63	0·22	0·22	0·47	0·30	0·50	34	18	22	49	3·27	11·68	7·52	40
129	0·37	109	0·14	130	0·16	0·23	0·74	0·28	0·87	39	30	20	119	7·93	3·23	12·33	42
129	0·38	111	0·14	134	0·16	0·20	0·79	0·29	0·86	40	28	18	120	8·00	3·34	12·47	44
130	0·36	103	0·15	131	0·16	0·21	0·80	0·33	0·81	35	29	27	116·5	7·77	3·28	12·37	45
131	0·35	109	0·14	132	0·16	0·22	0·72	0·30	0·81	36	32	22	120	8·00	3·47	12.68	46
141	0·36	120	0·15	137	0·16	0·23	0·82	0·34	0·80	39	31	21	130·5	8·70	3·91	13·43	50
96	0·16	124	0·07	115	0·23	0·22	0·76	0·33	0·37	20	18	−28	110	7·33	12·00	12·08	58
94	0·16	131	0·09	94	0·18	0·22	0·76	0·43	0·37	11	16	−37	113·5	7·57	12·16	12·32	59
98	0·16	117	0·09	103	0·22	0·24	0·67	0·38	0·40	24	20	−19	107.5	7·17	12·37	11·94	60
112	0·18	137	0·07	113	0·18	0·24	0·72	0.28	0·43	14	27	−25	124·5	8·30	1·94	13·10	63
119	0·20	150	0·09	134	0·18	0·20	0·59	0·27	0·54	23	25	−31	134·5	8·97	3·87	13·89	66
117	0·16	106	0·10	108	0·19	0·23	0·50	0·31	0·48	26	18	11	111·5	7·43	12·63	12·36	67
102	0·17	98	0·10	105	0·19	0·23	0·52	0·30	0·50	28	17	4	100	6·67	12·18	11·60	70
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	76
214	0·26	195	0·07	193	0·14	0·17	0·74	0·20	0·61	38	24	19	204·5	13·63	6·47	18·65	77
119	0.14	143	0·06	114	0·19	0·22	0·74	0·32	0·33	21	22	−24	131	8·73	1·36	13·81	85
274	0·11	293	0·03	264	0·14	0·19	0·69	0·19	0·27	43	26	−19	283·5	18·90	12·73	0·03	90
299	0·11	321	0·05	314	0·16	0·18	0·85	0·38	0·24	35	27	−22	310	20·67	11·44	1·77	95
130	0·16	169	0·08	132	0·09	0·16	0·64	0·32	0·41	52	4	−39	149·5	9·97	2·94	15·17	98
122	0·25	125	0·11	120	0·17	0·23	0·74	0·32	0·59	26	18	−3	123·5	8·23	12·45	13·56	101
114	0·24	120	0·12	114	0·18	0·21	0·71	0.35	0·58	26	20	−6	117	7·80	12·36	13·18	103
120	0·24	126	0·12	118	0·17	0·22	0·71	0·35	0·58	22	20	−6	123	8·20	12·87	13·63	105
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	112
274	0·29	273	0·09	273	0·30	0·21	1·07	0·33	0·56	20	28	1	273·5	18·23	2·13	23·68	113
275	0·36	271	0·11	274	0·35	0·21	0·97	0·30	0·73	14	7	4	273	18·20	2·80	23·73	114
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	116
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	117
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	118
314	0·49	309	0·16	314	0·40	0·15	0·92	0·30	1·02	27	1	5	311·5	20.77	6·34	2·30	119
319	0·51	308	0·17	320	0·39	0·13	0.88	0·29	1·09	30	16	11	313·5	20·90	7·07	2·52	120
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	121
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	122
320	0·41	310	0·12	324	0·48	0·16	1·00	0·29	0·82	−2	−1	10	315	21·00	4·39	2·82	125
318	0·37	308	......	......	0·56	......	0·97	......	0·75	12	......	10	313	20·87	3·90	2·74	126
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	127
319	0·51	309	0·15	313	0·80	0·27	0·89	0·26	1·08	21	−21	10	314	20·93	6·30	2·86	128
325	0·48	315	0·16	321	0·58	0·25	0·92	0·31	1·00	13	−22	10	320	21·33	6·32	3·28	129

No.	Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
	EAST COAST OF AMERICA—continued.	° ′ *North.*	° ′ *West.*	*h. m.*	*Ft.*	°	*h.*	*Ft.*	°	*Ft.*	°	*Ft.*
130	Southwest Pass Light, Miss. R	28 58	89 24	5 58								
131	Port Eads, South Pass, Miss. R	29 01	89 10	5 57	0·06	316·5	10·53	0·04	298	0·02	341	0·44
132	Last (Dernière) Island, La	29 04	90 57	6 04								
140	Galveston, Doswell's wharf	29 19	94 47	6 19	0·22	124·5	4·15	0·04	134	0·05	111	0·35
143	Tampico	22 16	97 49	6 31	0·08	62·6	2·09	0·03	73			0·35
145	Vera Cruz	19 12	96 08	6 25	0·20	74·6	2·49	0·06	355	0·06	67	0·54
148	Campeche	19 50	90 32	6 02								
152	Manzanillo, Cuba	20 19	77 10	5 09								
156	San Juan, Porto Rico	18 29	66 07	4 24								
157	Ponce, Port of, Porto Rico	17 59	66 40	4 27								
158	St. Thomas Island	18 25	64 58	4 20	0·12	208	6·93	0·03	243			0·30
165	Colon, or Aspinwall	9 18	79 51	5 19								
		South.										
175	Pernambuco (Recife Arsenal)	8 04	34 54	2 20	2·49	133·6	4·45	0·87	151	0·44	126	0·13
184	Montevideo, La Plata River	34 53	56 12	3 45								
186	Buenos Ayres, La Plata Riv	34 36	58 22	3 54	0·81	184·7	6·16	0·17	266	0·34	149	0·25
190	South Georgia (Royal Bay)	54 31	36 01	2 24	0·74	213	7·10	0·38	236	0·16	199	0.17
195	Port Louis, Berkeley Sound	51 29	58 00	3 52	1·54	157	5·23	0·49	195	0·34	130	0·36
	WEST COAST OF AMERICA.											
200	C. Horn, St. Martin C., Hermite I	55 51	67 33	4 30	2·02	105	3·50	0·22	148	0·31	72	0·56
205	Valparaiso, Chile	33 02	71 39	4 47	1·41	279·2		0·47	300	0·36	248	0·50
		North.										
210	Panama (Naos I)	8 55	79 32	5 18	5·93	86·7	2·89	1·66	144	1·30	54	0·44
214	Manzanillo	19 03	104 21	6 57								
215	Mazatlan	23 11	106 27	7 06	1·08	265·2	8·83	0·74	254	0·24	254	0·64
217	Magdalena Bay	24 34	112 09	7 29	1·59	244	8·13	1·01	253	0·39	246	0·79
218	San Juanico Bay	26 15	112 28	7 30	1·72	246	8.20	1·02	252	0·34	247	0·41
219	Abreojos Pt., Ballenas Bay	26 43	113 34	7 34	2·14	261	8·70	1·07	275	0·70	202	0·43
221	San Diego, La Playa, Cal	32 42	117 14	7 49	1·70	276·6	9·22	0·70	275	0·41	257	1·07
224	San Francisco Entr., Fort Point	37 49	122 29	8 10	1·70	330·7	11·02	0·38	335	0·36	304	1·22
225	Sausalito	37 51	122 29	8 10	1·57	336·7	11·22	0·35	348	0·33	310	1·16
227	Astoria, Oregon	46 11	123 50	8 15	2·97	8·6	0·29	0·77	39	0·59	346	1·32
230	Port Townsend	48 07	122 45	8 11	2·22	105·6	3·52	0·55	130	0·47	75	2·51
234	Esquimalt, Victoria Har	48 26	123 27	8 14								
235	Victoria Harbor	48 25	123 23	8 14	1·22	68·8	2·29	0·33	86	0·30	44	2·07
240	Vancouver, Burrard Inlet	49 17	123 11	8 13	3·00	163·2	5·44	0·78	177			2·45
241	Sand Heads, Fraser Riv	49 05	123 16	8 13								
242	Garry Point, Fraser Riv	49 07	123 11	8 13								
243	New Westminster, Fraser Riv	49 13	122 54	8 12								
246	Seymour Narrows, Discovery P	50 08	125 23	8 22	2·93	70·9	2·36	0·62	100	0·59	37	2·95
250	Sitka, Baranof Island	57 03	135 20	9 01	3·58	2·5	0·08	1·14	34	0·76	335	1·51
251	Sergius Narrows	57 24	135 31	9 02								
253	Barlow Cove, Lynn Canal	58 20	134 53	9 00								
255	Kokinhenic I., Copper R. Delta	60 18	145 03	9 40								
256	Pete Dahl Slough, Copper R. Delta	60 29	145 24	9 42								
258	Eyak River	60 28	145 40	9 43								
259	Orca, Prince Wm. Sound	60 35	145 41	9 43								
260	Orca Inlet (Cape Whiteshed)	60 28	145 55	9 44								
265	Kodiak (St. Paul) Kadiak I	57 48	152 21	10 09	3·23	7·7	0·26	1·08	40	0·68	342	1·33
276	Kripniyuk	62 20	165 19	11 01								

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	$K_1 + O_1$.	$S_2° - M_2°$.	$M_2° - N_2°$.	$K_1° + O_1°$.	$\frac{1}{2}(K_1° + O_1°)$. De-grees.	Lunar hours.	Cotidal hour. Semi-diur-nal.	Diur-nal.	No.
°	*Ft.*	°	*Ft.*	°	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	°	°	°	°	*h.*	*h.*	*h.*	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	130
293	0·41	295	0·14	294	0·67	0·34	0·93	0·32	0·85	−18	−25	−2	294	19·60	4·48	1·55	131
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	132
321	0·33	312	0·13	319	0·18	0·22	0·94	0·37	0·68	10	14	9	316·5	21·10	10·47	3·42	140
293	0·28	290	....	....	0·38	....	0·80	....	0·63	10	....	3	291·5	19·43	8·61	1·95	143
282	0·63	320	0·18	285	0·30	0·30	1·17	0·33	1·17	−80	8	−38	301	20·07	8·91	2·49	145
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	148
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	152
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	156
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	157
171	0·24	153	0·08	176	0·25	0·17	0·80	0·27	0·54	35	20	18	162	10·80	11·26	15·13	158
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	165
289	0·17	149	....	....	0·35	0·18	1·31	....	0·30	17	8	140	219	14·60	6·78	16·93	175
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	184
18	0·45	211	0·12	20	0·21	0·42	1·80	0·48	0·70	81	36	167	294·5	19·63	10·06	23·63	186
52	0·33	18	0·05	50	0·51	0·22	1·94	0·30	0·50	23	14	34	35	2·33	9·50	4·73	190
37	0·45	4	0·14	87	0·32	0·22	1·25	0·39	0·81	38	27	33	20·5	1·37	9·10	5·24	195
55	0·41	345	0·19	55	0.11	0.15	0·73	0·34	0·97	43	33	70	20	1·33	8·00	5·83	200
330	0·33	286	0·16	322	0·33	0·26	0·66	0·32	0·83	21	31	44	308	20·53	2·09	1·31	205
340	0·14	344	0.12	342	0·28	0·22	0·32	0·27	0·58	57	33	−4	342	22·80	8·19	4·10	210
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	214
72	0·45	75	0·26	69	0·69	0·22	0·70	0·41	1·09	−11	11	−3	73·5	4·90	3·94	12·00	215
71	0·56	77	0·26	71	0·64	0·25	0·71	0·33	1·35	9	−2	−6	74	4·93	3·61	12·41	217
93	0·29	55	0·13	93	0·59	0·20	0·71	0·32	0·70	6	−1	38	74	4·93	3·70	12·43	218
90	0·17	86	0·14	90	0·50	0·33	0·40	0·33	0·60	14	59	4	88	5·87	4·27	13·38	219
95	0·70	79	0·36	94	0·41	0·24	0·66	0·34	1·77	−2	20	16	87	5·80	5·04	13·62	221
106	0·77	88	0·37	104	0·22	0·21	0·63	0·30	1·99	4	27	18	97	6·47	7·19	14·64	224
110	0·72	94	0·37	109	0·22	0.21	0·62	0·32	1·88	11	27	16	102	6·80	7·39	14·97	225
129	0·78	114	0·37	126	0·26	0·20	0·59	0·28	2·10	30	23	15	121·5	8·10	8·54	16·35	227
148	1·45	127	0·80	147	0·25	0·21	0·58	0·32	3·96	24	31	21	137·5	9·17	11·70	17·35	230
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	234
145	1·22	124	0·67	140	0·27	0·25	0·59	0·32	3·29	17	25	21	134·5	8·97	10·52	17·20	235
178	1·60	167	....	....	0·26	....	0·65	....	4·05	14	....	11	172·5	11·50	1·66	19·72	240
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	241
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	242
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	243
147	1·62	137	....	....	0·21	0·20	0·55	....	4·57	29	34	10	142	9·47	10·73	17·84	246
125	0·90	110	0·46	124	0·32	0·21	0·60	0·31	2·41	32	28	15	117·5	7·83	9·10	16·85	250
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	251
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	253
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	255
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	256
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	258
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	259
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	260
139	0·90	122	0·44	134	0·33	0·21	0·68	0·33	2·23	33	26	17	130.5	8·70	10·41	18·85	265
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	276

No.	Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
		° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
	WEST COAST OF AMERICA—cont'd.	North.	West.									
277	Nioklakowik	62 32	164 57	11 00	...	...	...	...	...	...	...	...
278	Kwiklokchun	62 34	164 51	10 59	...	...	...	...	...	...	...	...
280	St. Michael	63 29	162 02	10 48	0.53	235.2	7.84	0.07	216	0.14	174	1.32
295	Point Barrow	71 18	156 40	10 27	...	...	...	...	...	...	...	...
297	Chicago	41 50	87 38	5 51	...	...	...	...	...	...	...	...
298	Milwaukee	43 02	87 55	5 52	...	...	...	...	...	...	...	...
299	Duluth	46 48	92 06	6 08	...	...	...	...	...	...	...	...
	EAST COAST OF ASIA.		East.									
310	Shakotan, Japan	43 52	146 49	9 47	0.81	103.2	3.44	0.39	135	...	...	0.58
312	Taraku Sima	43 38	146 20	9 45	0.80	101.9	3.40	0.46	147	...	...	0.68
314	Shuisho Sima	43 27	145 52	9 43	1.01	110.1	3.67	0.43	144	...	...	0.67
316	Nemuro	43 27	145 40	9 43	0.50	102.9	3.43	0.54	155	...	...	0.68
318	Akkeshi	43 02	144 51	9 39	0.98	106.6	3.55	0.42	149	...	...	0.76
320	Kushiro	43 00	144 22	9 37	0.81	105.7	3.52	0.40	156	...	...	0.76
325	Mororan, Endermo Har.	42 20	141 07	9 24	1.13	102.6	3.42	0.52	138	...	...	0.79
327	Otaru, Sea of Japan	43 12	140 54	9 24	0.17	110.9	3.70	0.07	144	...	...	0.18
328	Moura	40 57	140 52	9 23	0.58	105.0	3.50	0.29	134	...	...	0.18
329	Ominato	41 15	141 09	9 25	0.66	103.9	3.46	0.30	134	...	...	0.18
340	Tateyama (Yokohama Ent.)	34 59	139 51	9 19	1.18	147.1	4.90	0.59	174	...	...	0.73
342	Yokohama (Nishihatoba)	35 26	139 39	9 19	1.57	154.3	5.14	0.73	185	0.24	145	0.80
344	Yenoura	35 03	138 54	9 16	1.33	170.2	5.67	0.66	191	...	...	0.62
346	Shimidzu	35 01	138 31	9 14	1.29	169.8	5.66	0.57	198	...	...	0.62
348	Sakushima	34 44	137 02	9 08	1.71	176.9	5.90	0.85	204	...	...	1.10
350	Yokkaichi	34 57	136 38	9 07	2.13	176.2	5.87	0.95	204	...	...	0.78
352	Toba	34 29	136 50	9 07	1.68	173.5	5.78	0.70	179	...	...	0.73
354	Matoya	34 22	136 52	9 07	1.41	169.8	5.66	0.64	199	...	...	0.64
356	Hamashima	34 18	136 45	9 07	1.59	184.8	6.16	0.66	194	...	...	0.70
358	Shimotsui, Inland Sea	34 26	133 48	8 55	2.94	327.3	10.91	1.10	22	...	...	1.07
360	Tomo, Inland Sea	34 23	133 22	8 53	3.52	326.6	10.89	1.39	6	...	...	1.17
362	Onomichi, Inland Sea	34 24	133 12	8 53	3.44	320.6	10.69	1.22	357	...	...	1.10
364	Setozaki, Sea of Japan	34 24	131 12	8 45	0.63	316.5	10.55	0.34	340	...	...	0.32
366	Hagi, Sea of Japan	34 25	131 24	8 46	0.54	326.4	10.88	0.28	338	...	...	0.30
368	Yesaki, Sea of Japan	34 39	131 39	8 47	0.35	338.6	11.29	0.17	348	...	...	0.26
370	Tonoura, Sea of Japan	34 54	132 04	8 48	0.27	353.4	11.78	0.12	2	...	...	0.17
372	Sagiura, Sea of Japan	35 26	132 41	8 51	0.22	33.0	1.10	0.09	47	...	...	0.14
374	Yonago, Sea of Japan	35 22	133 18	8 53	0.14	140.5	4.68	0.05	153	...	...	0.13
376	Shibayama, Sea of Japan	35 39	134 39	8 59	0.20	61.4	2.05	0.07	82	...	...	0.16
378	Tsuiyama, Sea of Japan	35 39	134 50	8 59	0.20	71.6	2.39	0.07	92	...	...	0.16
380	Ao, Sea of Japan	36 53	136 59	9 08	0.22	80.0	2.67	0.07	109	...	...	0.19
382	Naoyedzu, Sea of Japan	37 11	138 14	9 13	0.18	81.0	2.70	0.08	106	...	...	0.15
384	Amaze, Sea of Japan	37 32	138 41	9 15	0.19	75.5	2.52	0.08	104	...	...	0.15
386	Funakawa, Sea of Japan	39 54	139 51	9 19	0.18	90.2	3.01	0.10	140	...	...	0.26
387	Urado	33 30	133 35	8 54	1.56	185.5	6.18	0.61	220	...	...	0.63
388	Susaki, Nomi Harbor	33 23	133 17	8 53	1.65	171.5	5.72	0.71	196	...	...	0.68
389	Aoshima, Inland Sea	33 44	132 29	8 50	3.03	250.2	8.34	1.24	284	...	...	0.51
390	Kakaji, Inland Sea	33 40	131 31	8 46	3.08	258.4	8.61	1.33	286	...	...	0.97
391	Kabashima	32 44	129 47	8 39	2.83	229(?)	7.63	1.18	259	...	...	0.82
392	Nagasaki	32 34	129 51	8 39	2.84	228.9	7.63	1.17	259	0.54	213	0.79
393	Matsushima	32 56	129 36	8 38	2.81	230.0	7.67	1.33	260	...	...	0.82
394	Tawaranoura	33 07	129 40	8 39	2.73	235.3	7.84	1.33	262	...	...	0.72

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	$K_1 + O_1$.	$S_2° - M_2°$.	$M_2° - N_2°$.	$K_1° - O_1°$.	½ ($K_1° + O_1°$). Degrees.	Lunar hours.	Cotidal hour. Semi-diurnal.	Diurnal.	No.
°	Ft.	°	Ft.	°	Ft.	Ft.	Ft.	Ft.	Ft.	°	°	°	°	h.	h.	h.	
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	277
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	278
295	0·76	248	0·44	295	0·13	0·26	0·58	0·33	2·08	−19	61	47	271·5	18·10	6·64	4·90	280
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	295
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	297
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	298
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	299
157	0.49	155	0·20	157	0·48	......	0·84	0·34	1·07	32	......	2	156	10·40	5·66	0·62	310
149	0·51	125	0·23	149	0·58	......	0·75	0·34	1·19	45	......	24	137	9·13	5·65	23·38	312
171	0·75	157	0.22	171	0·43	......	1·12	0·33	1·42	34	......	14	164	10·93	5·95	1·21	314
165	0·56	121	0·23	165	1·08	......	0·82	0·34	1·24	52	......	44	143	9·53	5·71	23·81	316
149	0·54	150	0·26	149	0.43	......	0·71	0·34	1·30	42	......	−1	149.5	9·97	5·90	0·32	318
156	0.54	133	0·26	15[illegible]	0·49	......	0·71	0·34	1·30	50	......	23	144·5	9·63	5·90	0·01	320
153	0.68	149	0·26	153	0·46	......	0·86	0.33	1·47	35	......	4	151	10·07	6·02	0·67	325
340	0·16	322	0·06	340	0·41	......	0·89	0·33	0·34	33	......	18	331	22·07	6·30	12·67	327
145	0·08	140	0·06	145	0·50	......	0·44	0·33	0·26	29	......	5	142·5	9·50	6·12	0·12	328
157	0·14	142	0·06	157	0·45	......	0·18	0.33	0·92	30	......	15	149·5	9·97	6·04	0·55	329
161	0·60	156	0·24	161	0·50	......	0·82	0·33	1·33	27	......	5	158·5	10·57	7·58	1·25	340
179	0·62	161	0·30	175	0·47	0·15	0·78	0·38	1·42	31	9	18	170	11·33	7·82	2·01	342
167	0·45	161	0·21	167	0·50	......	0·73	0·34	1·07	21	......	6	164	10·93	8·40	1·66	344
168	0·50	160	0·20	168	0·44	......	0·81	0·32	1·12	28	......	8	164	10·93	8·43	1·70	346
167	0·65	164	0·37	167	0·50	......	0·59	0·34	1·75	27	......	3	165·5	11·03	8·77	1·90	348
166	0·55	177	0·26	166	0·45	......	0·71	0·33	1·33	28	......	−11	171·5	11·43	8·75	2·31	350
172	0·57	165	0·24	172	0·42	......	0·78	0·33	1·30	5	......	7	168·5	11·23	8·66	2·11	352
172	0·52	170	0·21	172	0·46	......	0·81	0·33	1·16	29	......	2	171	11·40	8·54	2·26	354
170	0·53	171	0·23	170	0·42	......	0·76	0·33	1·23	9	......	−1	170·5	11·37	9·04	2·25	356
220	0·85	209	0·36	220	0·37	......	0·79	0·34	1·92	55	......	11	214·5	14·30	1·99	5·38	358
223	0·81	208	0·39	223	0·40	......	0·69	0·33	1·98	39	......	15	215·5	14·37	2·01	5·49	360
223	0·81	212	0·37	223	0·36	......	0·74	0·34	1·91	36	......	11	217·5	14·50	1·81	5·62	362
320	0·38	301	0·11	320	0·54	......	1·19	0·34	0·70	24	......	20	311	20·73	1·80	11·98	364
321	0·38	303	0·10	321	0·52	......	1·27	0·33	0·68	12	......	18	312	20·80	2·11	12·03	366
325	0·35	309	0·09	325	0·49	......	1·35	0·35	0·61	9	......	16	317	21·13	2·51	12·35	368
335	0.28	330	0·06	335	0·44	......	1.65	0.35	0·45	9	......	5	332·5	22·17	2·98	13·37	370
345	0·15	337	0·05	345	0·41	......	1.07	0·36	0·29	14	......	8	341	22·73	4·25	13·88	372
357	0.15	352	0·04	357	0.36	......	1·15	0·30	0·28	12	......	5	354·5	23·63	7·80	14·75	374
327	0·16	315	0·05	327	0·35	......	1·00	0·31	0·32	21	......	12	321	21·40	5·07	12·42	376
329	0·18	311	0·05	329	0·35	......	1·12	0·31	0·34	20	......	18	320	21·33	5·41	12·35	378
339	0·20	318	0·06	339	0·32	......	1·05	0·32	0·39	29	......	21	328·5	21·90	5·54	12·77	380
338	0·17	324	0·05	338	0·44	......	1·13	0·33	0·32	25	......	14	331	22·07	5·48	12·85	382
337	0·16	320	0·05	337	0·43	......	1·07	0·33	0·31	28	......	17	328·5	21·90	5·27	12·65	384
337	0·24	327	0·08	337	0·56	......	0·92	0·31	0·50	50	......	10	332	22·13	5·69	12·81	386
182	0·53	117	0·22	182	0·39	......	0·84	0·35	1·16	34	......	65	149·5	9·97	9·28	1·07	387
173	0·54	171	0·23	173	0·43	......	0·80	0·34	1·22	24	......	2	172	11·47	8·84	2·59	388
193	0·73	183	0·17	193	0·41	......	1·43	0·33	1·24	34	......	10	188	12·53	11·51	3·70	389
202	0·68	189	0·32	202	0·43	......	0·70	0·33	1·65	28	......	13	195·5	13·03	11·84	4·26	390
190	0·63	187	0·27	190	0·42	......	0·77	0·33	1·45	30	......	3	188·5	12·57	10·98	3·92	391
193	0·62	183	0·26	193	0·41	......	0·78	0·33	1·41	30	......	10	188	12·53	10·98	3·88	392
196	0·63	186	0·27	196	0·47	......	0·77	0·33	1·45	30	......	10	191	12·73	11·04	4·10	393
203	0·74	188	0·24	203	0·48	......	1·03	0·33	1·46	27	......	15	195·5	13·03	11·19	4·38	394

No.	Station.	Geographic position. Latitude.		Longitude. Arc.		Longitude. Time.		M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
		°	′	°	′	h.	m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
	EAST COAST OF ASIA—continued.	North.		East.											
395	Fukushima, Korea Str.	33	21	129	49	8	39	2.35	254.4	8.48	1.03	282	......	......	0.60
396	Kariya, Korea Str.	33	28	129	50	8	39	2.10	271.8	9.06	0.94	287	......	......	0.59
397	Hirugaura, Korea Str.	34	19	129	16	8	37	2.17	259.1	8.64	1.04	288	......	......	0.40
398	Miyako Sima	24	48	125	18	8	21	1.66	215.9	7.20	0.69	240	......	......	0.55
410	Petropavlovsk, Avatcha Bay	53	00	158	43	10	35	......	......	......	......	......	......	......	......
420	Chemulpho, inner harbor	37	29	126	36	8	26	9.43	107.8	3.59	3.84	187	1.67	80	0.80
425	Tientsin Ent., Taku Lightship	38	55	117	50	7	51	3.47	94.4	3.15	0.53	157	0.18	74	1.33
430	Shanghai, Wusung Bar	31	21	121	30	8	06	3.11	30.3	1.01	1.03	77	0.40	2	0.66
431	Shanghai Ent., Tungsha Lightship	31	08	122	01	8	08	......	......	......	......	......	......	......	......
435	Amoy, inner harbor	24	23	118	10	7	53	6.12	1.2	0.04	1.34	57	0.78	332	0.87
440	Hongkong	22	17	114	10	7	37	1.43	266	8.87	0.56	292	0.26	255	1.19
450	Hai-Phong Do-Sou	20	52	106	39	7	07	0.13	83	2.77	0.13	121	......	......	2.26
460	Quin-Hone, Cochin China	13	48	109	13	7	17	0.56	305	10.17	0.23	344	......	......	0.98
470	St. Jacques, Can Gion	10	19	107	05	7	08	2.62	54	1.80	1.05	95	......	......	2.30
490	Singapore	1	20	103	47	6	55	2.60	300	10.00	1.07	348	0.45	272	0.95
	OCEANICA.	South.													
505	Tanjong Kalean, Banka Str.	1	58	105	07	7	00	0.83	186	6.20	0.39	241	0.18	166	3.10
506	Pulu Besar Str	2	54	106	06	7	04	0.74	167	5.57	0.35	53	0.19	112	2.42
507	Telok Betong	5	27	105	16	7	01	1.05	222	7.40	0.45	262	0.18	192	0.51
512	Padang, Emma Harbor	0	58	100	18	6	41	1.09	175	5.83	0.47	219	0.24	157	0.42
		North.													
513	Ajerbangies	0	12	99	24	6	38	0.90	160	5.33	0.48	203	0.15	141	0.54
		South.													
514	Pulu Tello	0	06	98	18	6	33	0.85	168	5.60	0.40	202	0.17	151	0.34
		North.													
515	Natal	0	36	99	06	6	36	0.95	175	5.83	0.45	206	0.20	157	0.39
516	Gunung Sitoli	1	18	97	36	6	30	0.52	156	5.20	0.34	190	0.09	127	0.28
517	Siboga	1	42	98	48	6	35	0.33	162	5.40	0.10	138	0.04	170	0.45
518	Baroo	2	00	98	24	6	34	0.81	166	5.53	0.53	200	0.17	171	0.42
519	Singkel	2	18	97	48	6	31	0.76	189	6.30	......	......	......	......	......
521	Melabuh	4	06	96	06	6	24	0.46	194	6.47	0.31	218	0.09	192	0.27
522	Pulu Rajah	4	48	95	24	6	22	0.12	216	7.20	0.18	193	0.04	133	0.28
523	Oleh-leh	5	36	95	18	6	21	0.75	285	9.50	0.44	329	0.10	286	0.21
524	Sabang-bay (Weh or Waai)	5	54	95	20	6	21	1.53	266	8.87	0.79	310	0.27	265	0.30
525	Segli	5	18	96	00	6	24	1.11	273	9.10	0.75	313	0.28	287	0.45
526	Telok Semawé	5	12	97	12	6	29	1.68	281	9.37	......	......	......	......	......
527	Edi	4	54	97	48	6	31	1.56	315	10.50	0.77	356	0.22	304	0.56
528	Belawan Deli	3	48	98	42	6	35	1.50	29	0.97	0.96	76	0.26	16	0.36
529	Tandjong Tiram	3	18	99	30	6	38	2.34	78	2.60	1.12	124	0.49	68	0.35
530	Bagan Api-Api	2	12	100	48	6	43	5.30	322	10.73	......	......	......	......	......
531	Bengkalis	1	30	102	06	6	48	2.52	208	6.93	1.28	282	0.34	213	0.19
		South.													
533	Kuala Ladjan	0	24	103	36	6	54	2.96	98	3.27	0.87	145	0.52	65	1.80
535	Tandjong Buton	0	12	104	36	6	58	0.62	34	1.13	0.44	124	0.13	15	2.02
540	Duizend Eilanden	5	36	106	30	7	06	0.03	266	8.87	0.18	11	0.02	314	0.92
541	Edam Island	6	00	106	48	7	07	0.16	294	9.80	0.12	273	0.05	322	0.50
542	Tandjong-Priok Harbor	6	06	106	54	7	08	0.17	352	11.73	0.18	291	0.07	317	0.88
543	Batavia	6	06	106	50	7	07	0.15	347	11.57	0.19	294	0.06	311	0.91
544	Boompjes Island	5	54	108	24	7	14	0.38	323	10.77	0.19	219	0.11	293	0.52
546	Karimon Djawa Isles	5	54	110	24	7	22	0.07	246	8.20	0.17	344	0.03	42	0.76
547	Semarang	7	00	110	24	7	22	0.15	283	9.43	0.11	160	0.05	256	0.60

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	$K_1 + O_1$.	$S_2° - M_2°$.	$M_2° - N_2°$.	$K_1° - O_1°$.	½ ($K_1° + O_1°$). De-grees.	½ ($K_1° + O_1°$). Lunar hours.	Cotidal hour. Semi-diur-nal.	Cotidal hour. Diur-nal.	No.
°	Ft.	°	Ft.	°	Ft.	Ft.	Ft.	Ft.	Ft.	°	°	°	°	h.	h.	h.	
234	0·52	209	0·20	234	0·44	......	0·87	0·33	1·12	28	....	25	221·5	14·77	11·83	6·12	395
240	0·53	241	0·20	240	0·45	......	0.90	0·34	1·12	15	....	− 1	240·5	16·03	12·41	7·38	396
198	0·31	197	0·13	198	0·48	......	0·78	0.32	0·71	29	....	1	197·5	13·17	12·02	4·55	397
235	0·51	212	0·18	235	0·42	......	0·93	0·33	1·06	24	....	23	223·5	14·90	10·85	6·55	398
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	410
307	0·71	239	0·50	307	0·41	0·18	0·89	0·62	1·51	79	28	68	273	18·20	7·16	9·77	420
157	0·95	126	0·44	155	0·15	0·05	0·71	0·33	2·28	63	20	31	142	9·47	7·32	1·62	425
207	0·46	149	0·22	207	0·33	0·13	0·70	0·33	1·12	47	28	58	178	11·87	4·91	3·77	430
......	......	......	......	....	......	......	......	......	......	......	......	......	......	......	......	......	431
274	0·64	252	0·29	272	0·22	0·13	0·74	0·33	1·51	56	29	22	263	17·53	4·16	9·65	435
297	0·86	248	0·38	285	0·39	0·18	0·72	0·32	2·05	26	11	49	272·5	18·17	1·25	10·55	440
81	2·30	32	0·75	81	1·00	......	1·02	0·33	4·56	38	....	49	56·5	3·77	7·65	20·65	450
295	0·95	262	0·33	295	0·40	......	0·97	0·34	1·93	39	....	33	278·5	18·57	2·89	11·29	460
309	1·44	274	0·75	309	0·40	......	0·63	0·34	3·74	41	....	35	291·5	19·43	6·67	12·30	470
100	0·95	53	0·29	93	0·41	0·17	1·00	0·30	1·90	48	28	47	76·5	5·10	3·10	22·20	490
159	1·79	93	0·88	151	0·47	0·22	0·58	0·28	4·89	55	20	66	126	8·40	11·20	1·40	505
153	1·39	107	0·51	145	0·47	0·26	0·58	0·21	3·81	−114	55	46	130	8·67	10·50	1·60	506
269	0·26	265	0·14	231	0·43	0·17	0·51	0·28	0·77	40	30	4	267	17·80	12·38	10·78	507
277	0·25	265	0·13	277	0·43	0·22	0·60	0·31	0·67	44	18	12	271	18·07	11·15	11·39	512
272	0·19	240	0·14	198	0·53	0·16	0·35	0·26	0·73	43	19	32	256	17·07	10·70	10·44	513
278	0·17	255	0.10	288	0·47	0·20	0·50	0·30	0·51	34	17	23	266·5	17·77	11·05	11·12	514
276	0·20	258	0·06	273	0·47	0·21	0·51	0.15	0·59	31	18	18	267	17·83	11·23	11·23	515
279	0·10	236	0·04	313	0·65	0·17	0·36	0·14	0·38	34	29	43	257·5	17·17	10·70	10·67	516
293	0·16	268	0·12	321	0·30	0·12	0·36	0·27	0·61	− 24	− 8	25	280·5	18·67	10·82	12·09	517
286	0·18	250	0·20	269	0·65	0·21	0·43	0·48	0·60	34	− 5	36	268	17·87	10·96	11·30	518
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	11·78	......	519
301	0·15	283	0·09	345	0·67	0·19	0·56	0·33	0·42	24	2	18	292	19·47	12·07	13·07	521
311	0·04	244	0·26	156	1·50	0·33	0·14	0·93	0·32	− 23	83	67	277·5	18·50	12·83	12·13	522
318	0·08	323	......	......	0·58	0·13	0·38	......	0·29	44	− 1	− 5	320·5	21·37	3·15	15·02	523
291	0·12	274	0·07	10	0·52	0·18	0·40	0·23	0·42	44	1	17	282·5	18·83	3·52	12·48	524
309	0.14	288	0·14	84	0·68	0·25	0·31	0·31	0·59	40	− 14	21	298·5	19·90	2·70	13·50	525
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2·89	......	526
321	0·17	289	0·18	89	0·49	0·14	0·30	0·32	0·73	41	11	32	305	20·33	3·98	13·81	527
336	0·10	257	0·18	216	0·64	0·17	0·28	0·50	0·46	47	13	79	296·5	19·77	6·39	13·39	528
276	0·02	144	0·58	155	0·48	0·21	0·06	1.66	0·37	46	10	132	210	14·03	7·97	7·40	529
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4·01	......	530
118	0·77	127	0·41	77	0.51	0·13	4·05	2·16	0·96	74	− 5	− 9	122·5	8·17	12·13	1·37	531
182	1·63	108	0·42	171	0·29	0·18	0·91	0·23	3·43	47	33	74	145	9·67	8·37	2·77	533
151	1·51	74	0·71	136	0·71	0·21	0·75	0·35	3·53	90	19	77	112·5	7·50	6·16	0.53	535
165	0·22	138	0·35	157	6·00	0·67	0·24	0·38	1·14	105	− 48	27	151·5	10·10	1·77	3·00	540
142	0·25	129	0·20	125	0·76	0·32	0·50	0·40	0·75	− 21	− 28	13	135·5	9·03	2·68	1·81	541
143	0·45	119	0·24	143	1·03	0.40	0·51	0·27	1·33	− 61	35	24	131	8·73	4·60	1·61	542
144	0·45	121	0·24	146	1·23	0·39	0·49	0·26	1·36	− 53	36	23	132.5	8·83	4·45	1·71	543
102	0·24	116	0.10	85	0·50	0·29	0·46	0.19	0·76	−104	30	−14	109	7·27	3·54	0·04	544
357	0·12	262	0.30	327	2·46	0·43	0·16	0·39	0·88	98	−156	95	309·5	20·63	12·83	13·26	546
26	0·14	254	0·12	10	0·71	0·32	0·23	0·20	0·74	−123	27	132	320	21·33	2·06	13·96	547

No.	Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
		° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
	OCEANICA—continued.	South.	East.									
549	Bawean Island	5 54	112 42	7 31	0.13	72	2.40	0.15	16	0.11	116	1.41
550	Udjong Pangka	6 54	112 36	7 30	0.10	133	4.43	0.19	12	0.07	109	1.66
551	Arisbaya	6 54	112 48	7 31	0.08	104	3.47	0.21	9	0.07	93	1.69
552	Sembilangan	7 06	112 42	7 31	0.59	356	11.87	0.52	5	0.11	348	1.54
553	Surabaya	7 12	112 44	7 31	1.45	351	11.70	0.87	355	0.30	337	1.54
554	Gading	7 12	112 54	7 32	1.94	344	11.47	1.00	346	0.40	325	1.51
555	Karang Kleta	7 18	112 48	7 31	1.94	341	11.37	0.96	346	0.52	317	1.48
556	Pasuruan	7 38	112 54	7 32	1.96	340	11.33	1.00	343	0.37	332	1.46
557	Zwaantjes-droogte	7 30	113 06	7 32	1.49	333	11.10	0.77	344	0.27	322	1.55
559	Pulu Sapudi	7 06	114 18	7 37	0.85	339	11.30	0.43	342	0.17	318	1.21
560	Meinderts-droogte	7 36	114 24	7 38	0.83	326	10.87	0.35	335	0.16	312	1.17
561	Banjuwangi	8 13	114 24	7 38	1.40	293	9.77	1.04	348	0.34	257	0.89
563	Tjilatjap	7 42	109 00	7 16	1.63	249	8.30	0.82	311	0.32	224	0.62
564	Wynkoops-bay	7 00	106 30	7 06	0.91	223	7.43	.....	.....	.....	.....	.....
565	Labuan, Java	6 24	105 48	7 03	0.70	196	6.53	0.28	240	0.10	180	0.26
566	Java Fourth Point	6 06	105 54	7 04	0.79	210	7.00	0.42	280	0.13	190	0.22
570	Pulu Langkuas	2 30	107 36	7 10	0.50	144	4.80	0.10	43	0.58	96	1.96
571	Ondiepwater Island	3 18	107 12	7 09	0.25	66	2.20	0.24	42	0.09	- 69	1.74
580	Sukadana	1 12	109 54	7 20	0.36	328	10.93	0.29	350	0.04	345	2.00
582	Pontianak	0 00	109 18	7 17	0.41	173	5.77	0.17	175	0.10	152	1.08
583	Sungei Kakap	0 06	109 12	7 17	0.48	106.	3.53	.....	.....	.....	.....	.....
		North.										
584	Pemangkat	1 12	109 00	7 16	0.85	111	3.70	0.15	177	0.22	86	0.44
586	Labuan, Borneo	5 12	115 12	7 41	0.74	294	9.80	.....	.....	0.15	281	1.52
587	Gaya	6 06	116 06	7 44	0.64	278	9.27	.....	.....	0.14	260	1.43
588	Kudat	6 54	116 48	7 47	0.66	270	9.00	.....	.....	0.13	238	1.11
589	Sandakan	5 54	118 06	7 52	1.23	305	10.16	.....	.....	0.21	271	1.89
		South.										
595	Kotta Baru	3 12	116 42	7 47	1.21	160	5.33	1.61	216	.....	.....	1.35
597	De Bril	6 06	118 54	7 56	0.69	19	0.63	0.15	155	0.16	348	0.94
598	Makasser	5 06	119 24	7 57	0.26	68	2.27	0.38	191	0.09	330	0.92
600	Donggala	0 42	119 42	7 59	0.76	158	5.27	1.41	209	0.09	123	1.04
		North.										
602	Tontoli	1 00	120 54	8 04	0.58	223	7.43	1.10	192	0.13	145	0.61
603	Kema	1 24	125 06	8 20	0.69	161	5.37	0.99	192	0.05	186	0.58
604	Gorontalo	0 30	123 06	8 12	0.50	117	3.90	0.67	173	0.06	78	0.82
		South.										
605	Posso	1 24	120 54	8 04	0.79	125	4.17	0.69	167	0.06	102	0.53
607	Kadjang	5 24	120 18	8 01	1.23	3	0.10	0.58	89	0.20	336	0.69
608	Bonthain	5 36	119 54	8 00	0.28	44	1.47	0.67	154	0.13	54	0.73
609	Saleyer	6 06	120 30	8 02	1.25	359	11.97	0.40	61	0.35	336	1.23
610	Bonerate	7 24	121 12	8 05	0.47	358	11.93	0.18	131	0.06	353	0.36
612	Bima	8 24	118 42	7 55	0.96	8	0.27	0.45	42	0.10	304	1.09
614	Kupang	10 12	123 36	8 14	1.71	322	10.73	0.92	22	0.27	301	0.76
616	Dammer	7 06	128 42	8 35	1.55	29	0.97	0.71	92	0.21	359	1.01
618	Tual	5 36	132 42	8 51	1.44	43	1.43	.....	.....	.....	.....	.....
620	Banda	4 30	129 54	8 40	1.85	36	1.20	0.72	101	0.34	2	0.95
622	Amboina	3 42	128 12	8 33	1.45	25	0.83	0.55	90	0.33	5	0.97
624	Batjan	0 36	127 30	8 30	0.26	79	2.63	0.44	172	0.06	117	0.70
		North.										
626	Gamsungi	0 12	128 48	8 35	0.44	140	4.67	0.56	189	0.04	151	0.51
627	Ternate	0 48	127 24	8 30	1.02	163	5.43	0.76	197	0.14	143	0.51

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	K_1+O_1.	$S_2°-M_2°$.	$M_2°-N_2°$.	$K_1°-O_1°$.	$\frac{1}{2}(K_1°+O_1°)$.		Cotidal hour.		No.
													Degrees.	Lunar hours.	Semi-diurnal.	Diurnal.	
°	*Ft.*	°	*Ft.*	°	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	°	°	°	°	*h.*	*h.*	*h.*	
326	0·81	300	0·41	297	1·17	0·85	0.58	0·29	2·22	− 56	− 44	26	313	20·87	6·88	13·35	549
326	0·78	279	0·54	343	1·94	0·70	0·47	0·33	2.44	−121	24	47	302·5	20·17	8·93	12·67	550
326	0·80	262	0·38	335	2·80	0·93	0·47	0·22	2·49	− 95	11	64	294	19·60	7·85	12·08	551
318	0·82	277	0·38	313	0·88	0·18	0·53	0·25	2·36	9	8	41	297·5	19·83	4·35	12·28	552
318	0·89	284	0·47	321	0·60	0·21	0·58	0·31	2·43	4	14	34	301	20·67	4·18	13·15	553
308	0·85	269	0·46	306	0·51	0·21	0·56	0·30	2.36	2	19	39	288·5	19·23	3·94	11·60	554
304	0·89	275	0·47	326	0·50	0·27	0·60	0·32	2·37	5	24	29	289·5	19·30	3·85	11·78	555
304	0·86	276	0·48	302	0·51	0·19	0·59	0·33	2·32	3	8	28	290	19·33	3·80	11·80	556
307	0·71	273	0·27	295	0·52	0·18	0·46	0·17	2·26	11	11	34	290	19·33	3·57	11·80	557
306	0·79	279	0·37	297	0·51	0·20	0·65	0·31	2·00	3	21	27	292·5	19·50	3·68	11·88	559
303	0·69	272	0·26	295	0·42	0·19	0·59	0·22	1·86	9	14	31	287·5	19·17	3·24	11·54	560
300	0·48	263	0·22	342	0·74	0·24	0·55	0·25	1·37	55	36	37	281·5	18·77	2·14	11·14	561
279	0·38	268	0·15	274	0·50	0·20	0·61	0·24	1·00	62	25	11	273·5	18·23	1·03	10·86	563
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12·33	......	564
242	0·18	227	0·06	19	0·40	0·14	0·69	0·23	0·44	44	16	15	234·5	15·63	11·48	7·55	565
226	0·11	216	0·06	171	0·53	0·16	0·50	0·28	0·33	70	20	10	221	14·73	11·93	7·66	566
142	1·24	86	0·52	135	0·20	0·16	0·63	0·27	3·20	−101	48	56	114	7·60	9·63	0·43	570
144	0·92	99	0·39	143	0·96	0·36	0·53	0·22	2·66	− 24	− 3	45	121·5	8·10	7·05	0·95	571
141	1·19	98	0·23	137	0·81	0·11	0·59	0·12	3·19	22	17	43	119·5	7·97	3·60	0·64	580
147	0·88	73	0·30	148	0·42	0·24	0·82	0.28	1·96	2	21	74	110	7·33	10·49	0·05	582
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	8·25	......	583
54	0·51	8	0·15	220	0·18	0·26	1·16	0·34	0·95	66	25	46	31	2·07	8·43	18·80	584
312	0·93	276	0·62	345	......	0·20	0·61	0·41	2·45	......	13	36	294	19·60	2·12	11·92	586
302	0·89	274	0·34	355	......	0·22	0·62	0·24	2·32	......	18	28	288	19·20	1·54	11·47	587
325	0·86	275	0·84	310	......	0·20	0·78	0·76	1·97	......	32	50	300	20·00	1·22	12·22	588
282	0·83	299	1·27	182	......	0·17	0·44	0·67	2·72	......	34	−17	290·5	19·37	2·30	11·46	589
339	0·47	313	0·45	308	1·33	......	0·35	0·33	1·82	56	......	26	326	21·73	9·56	13·96	595
296	0·59	275	0·27	272	0·22	0·23	0·63	0·29	1·53	136	31	21	285·5	19·03	4·70	11·10	597
303	0·54	269	0·32	300	1·45	0·34	0·59	0·35	1·46	123	98	34	286	19·07	6·32	11·12	598
288	0·24	258	0·54	340	1·86	0·12	0·23	0·52	1·28	51	35	30	273	18·20	9·29	10·22	600
254	0·40	238	0·20	67	1·89	0·22	0·66	0·33	1·01	−31	78	16	246	16·40	11·36	8·33	602
254	0·37	252	0·46	211	1·43	0·07	0·64	0·79	0·95	31	−25	2	253	16·87	9·04	8·54	603
293	0·40	237	0·18	5	1·33	0.12	0·49	0.22	1·22	56	39	56	265	17·67	7·70	9·47	604
265	0·48	186	0·37	269	0·88	0·08	0·91	0·70	1·01	42	23	79	225·5	15·03	8·10	6·96	605
303	0·50	266	0·49	282	0·47	0·16	0.72	0·71	1·19	86	27	37	284·5	18·97	4·08	10·95	607
325	0·13	266	0·53	260	2·35	0·46	0·18	0·73	0·86	110	−10	59	295·5	19·70	5·47	11·70	608
291	0·76	279	0·28	246	0·32	0·28	0.62	0·23	1·99	62	23	12	285	19·00	3·94	10·97	609
42	0·30	236	0·63	303	0·38	0·13	0·83	1·75	0·66	133	5	166	319	21·27	3·85	13·19	610
318	0·38	253	0·25	318	0·47	0·10	0·35	0·23	1·47	34	64	65	285·5	19·03	4·35	11·11	612
294	0·34	331	0·23	107	0·54	0·16	0·45	0·30	1·10	60	21	37	312·5	20·83	2·50	12·60	614
315	0·46	288	0·19	300	0·46	0·14	0·46	0·19	1·47	63	30	27	301·5	20·10	4·39	11·52	616
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4·58	......	618
310	0·61	299	0·30	275	0·39	0·18	0·64	0·32	1·56	65	34	11	304·5	20·30	4·53	11·63	620
314	0·70	304	0·30	310	0·38	0·23	0·72	0·31	1·67	65	20	10	309	20·60	4·28	12·05	622
261	0·30	213	0·30	258	1·70	0·32	0·43	0·43	1·00	93	−38	48	237	15·80	6·13	7·30	624
274	0·27	210	0·16	288	1·27	0·09	0·53	0·31	0·78	49	−11	64	242	16·13	8·09	7·55	626
247	0·35	237	0·23	267	0·75	0·14	0·69	0·45	0·86	34	20	10	242	16·13	8·93	7·63	627

No.	Station.	Geographic position. Latitude.		Longitude. Arc.		Longitude. Time.		M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
		°	′	°	′	h.	m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
	OCEANICA—continued.	North.		East.											
628	Galela	1	48	127	48	8	32	0·98	191	6·37	1·08	234	0·17	188	0·18
630	Lirong	3	54	126	42	8	27	1·31	171	5·70	.....	.....	.....	.....	.....
632	Taruna	3	42	125	30	8	22	1·37	169	5·63	0·77	209	0·18	166	0·28
640	Manila, Philippine Is.	14	36	120	57	8	04	0·55	326·3	10·87	0·16	356	0·11	310	1·05
				West.											
660	Honolulu, Oahu I.	21	18	157	52	10	31	0·52	109·4	3·65	0·16	109	0·09	98	0·48
		South.													
670	Apia, Upolu I.	13	46	171	44	11	27	1·24	186·0	6·20	0·29	184	0·30	166	0·10
				East.											
680	Port Russell, Bay of Islands	35	16	174	08	11	37	2·54	215·9	7·20	0·39	276	0·46	198	0·19
685	Sydney, Fort Denison	33	51	151	15	10	05	1·60	250·9	8·36	0·41	272	0·31	246	0·47
687	Melbourne (Williamstown)	37	53	144	55	9	40	0·81	69·4	2·31	0·10	164	0·09	65	0·29
689	Port Adelaide (Semaphore)	34	51	138	30	9	14	1·70	120·0	4·00	1·68	181	0·09	246	0·83
690	Freemantle, Swan. Riv. Entr	32	03	115	45	7	43	0·16	286·0	9·53	0·14	292	0·04	340	0·64
	INDIAN OCEAN.	North.													
710	Mergui (Bay of Bengal)	12	26	98	36	6	34	5·50	310·0	10·33	2·92	349	1·04	307	0·52
720	Amherst, Moulmein Riv.	16	05	97	34	6	30	6·32	67·3	2·24	2·71	102	1·28	52	0·71
722	Moulmein, Moulmein Riv.	16	29	97	37	6	30	3·79	113·5	3·78	1·36	149	0·67	99	0·44
725	Elephant Point, Rangoon Riv.	16	30	96	18	6	25	5·90	103·0	3·44	2·37	140	1·18	87	0·76
726	Rangoon, Rangoon Riv.	16	46	96	10	6	25	5·78	131·4	4·38	2·09	170	1·05	116	0·68
730	Diamond Is.	15	52	94	15	6	17	.....	.....	.....	.....	.....	.....	.....	.....
735	Akyab	20	08	92	54	6	12	2·56	278·1	9·27	1·13	308	0·52	271	0·45
740	Chittagong	22	20	91	50	6	07	4·44	35·2	1·17	1·57	69	0·84	25	0·59
745	Dublat, Hoogly Riv.	21	38	88	06	5	52	4·61	290·8	9·70	2·11	328	0·89	285	0·49
746	Diamond Har., Hoogly Riv.	22	11	88	12	5	53	5·16	344·6	11·49	2·23	26	0·96	340	0·50
747	Calcutta (Kidderpore)	22	32	88	20	5	53	3·63	57·7	1·92	1·50	100	0·66	44	0·39
748	False Point	20	23	86	47	5	47	2·25	269	8·97	1·01	302	0·45	264	0·41
755	Vizagapatam	17	41	83	17	5	33	1·47	253·7	8·46	0·65	286	0·31	248	0·36
756	Cocanada	16	56	82	15	5	29	1·51	252·6	8·42	0.64	286	0·32	245	0·35
763	Madras	13	05	80	18	5	21	1·03	250·8	8·36	0·44	280	0·24	242	0·29
765	Negapatam	10	46	79	51	5	19	0·71	251·2	8·37	0·27	283	0·16	239	0·22
770	Pamban Pass, Rámesvaram I.	9	16	79	09	5	17	0·58	47·2	1·57	0·37	92	0·08	31	0·29
772	Tuticorin	8	48	78	09	5	13	0·66	43·4	1·45	0·47	84	0·08	33	0·30
773	Trincomalee, Ceylon	8	33	81	13	5	25	0·58	241·0	8·03	0·20	265	0·14	225	0·21
775	Point de Galle, Ceylon	6	02	80	13	5	21	0·53	56·9	1·90	0·36	94	0·06	46	0·17
776	Colombo, Ceylon	6	56	79	50	5	19	0·58	49·9	1·66	0·39	95	0·07	34	0·24
780	Port Blair, Andaman Is.	11	41	92	45	6	11	2·00	280·0	9·33	0·96	316	0·40	274	0·40
785	Cochin	9	58	76	15	5	05	0·73	332·1	11·07	0·26	29	0·16	303	0·59
787	Beypore	11	10	75	48	5	03	0·94	328·3	10·94	0·33	17	0·20	303	0·71
793	Kárwár	14	48	74	06	4	56	1·74	301·8	10·06	0·62	335	0·41	282	1·00
795	Goa or Mormugõa	15	25	73	48	4	55	1·81	300·2	10·01	0·64	332	0·43	282	1·02
800	Bombay	18	55	72	50	4	51	4·04	330·3	11·01	1·61	4	1·00	314	1·40
802	Bhávnagar	21	48	72	09	4	49	10·90	134·2	4·47	3·47	176	2·43	114	2·32
805	Port Albert Victor	20	58	71	33	4	46	2·97	55·0	1·83	1·21	81	0·76	34	1·61
807	Probandar	21	37	69	37	4	38	.....	.....	.....	.....	.....	.....	.....	.....
809	Okha Point and Bet Harbor	22	28	69	05	4	36	3·82	347	11·57	1·22	14	0·78	322	1·41
810	Navanar	22	44	69	42	4	39	.....	.....	.....	.....	.....	.....	.....	.....
811	Hanstal	22	55	70	21	4	41	.....	.....	.....	.....	.....	.....	.....	.....
815	Karachi	24	47	66	58	4	28	2·54	293·7	9·79	0·95	323	0·60	277	1·29
820	Minikoi Light	8	16	73	01	4	52	0·86	329·4	10·98	0·35	20	0·18	302	0·69
825	Bushire	29	00	50	52	3	23	1·03	210·2	7·01	0·38	261	0·22	183	0·96

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	K_1+O_1.	$S_2°-M_2°$.	$M_2°-N_2°$.	$K_1°-O_1°$.	$\frac{1}{2}(K_1°+O_1°)$. De-grees.	$\frac{1}{2}(K_1°+O_1°)$. Lunar hours.	Cotidal hour. Semi-diur-nal.	Cotidal hour. Diur-nal.	No.
°	*Ft.*	°	*Ft.*	°	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	°	°	°	°	*h.*	*h.*	*h.*	
261	0·30	206	0·23	355	1·10	0·17	1·67	1·28	0·48	43	3	55	233·5	15·57	9·84	7·04	628
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	9·25	......	630
109	0·33	227	0·99	303	0·56	0·13	1·18	3·54	0·61	40	3	−118	168	11·20	9·26	2·83	632
321	0·86	288	0·35	321	0·29	0·20	0·82	0·33	1·91	30	16	33	304·5	20·30	2·80	12·23	640
72	0·26	60	0·14	66	0.31	0·17	0·54	0·29	0·74	0	11	12	66	4·40	2·17	14·92	660
254	0·07	248	0·03	252	0·23	0·24	0·70	0·30	0·17	−2	20	6	251	16·73	5·65	4·18	670
205	0·04	140	0·06	205	0·15	0·18	0·21	0·32	0·23	60	18	65	172·5	11·50	7·58	23·88	680
119	0·28	98	0·16	117	0·26	0·19	0·60	0·34	0·75	21	5	21	108·5	7·23	10·28	21·15	685
132	0·22	95	0·10	129	0·12	0·11	0·76	0·35	0·51	95	4	37	113·5	7·57	4·64	21·90	687
52	0·52	32	0·22	56	0·99	0·53	0·63	0·27	1·35	61	−126	20	42	2·80	6·77	17·57	689
300	0·37	291	0·16	297	0·88	0·25	0·58	0·25	1·01	6	−54	9	295·5	19·67	1·81	11·95	690
334	0·21	315	0·15	335	0·53	0·19	0·40	0·29	0·73	39	2	19	324·5	21·63	3·76	15·06	710
4	0·32	343	0·19	352	0·43	0·20	0·45	0·27	1·03	35	15	21	353·5	23·57	7·74	5·07	720
42	0·26	50	0·13	57	0·36	0·18	0·59	0·30	0·70	35	14	−8	46	3·07	9·28	20·17	722
19	0·33	5	0·19	30	0·40	0·20	0·43	0·25	1·09	37	16	14	12	0·80	9·01	18·38	725
35	0·29	27	0·16	56	0·36	0·18	0·43	0·24	0·97	39	15	8	31	2·07	9·96	19·65	726
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	730
343	0·18	336	0·14	345	0·44	0·20	0.40	0·31	0·63	30	7	7	339·5	22·63	3·07	16·43	735
22	0·29	12	0·20	31	0·35	0·19	0·49	0·34	0·88	34	10	10	17	1·13	7·05	19·01	740
352	0·19	338	0·15	347	0·46	0·19	0·39	0·31	0·68	37	6	14	345	23·00	3·83	17·13	745
14	0·23	346	0·18	10	0·43	0·19	0·46	0·36	0·73	41	5	28	0	0·00	5·61	18·12	746
54	0·21	22	0·14	44	0·41	0·18	0·54	0·36	0·60	42	14	32	38	2·53	8·04	20·65	747
344	0·18	334	0·14	345	0·45	0·20	0·44	0.35	0·59	33	5	10	339	22·60	3·19	16·82	748
342	0·14	332	0·10	340	0·44	0·21	0·39	0·28	0·50	32	6	10	337	22·47	2·91	16·92	755
339	0·14	333	0·10	343	0·42	0·21	0·40	0·29	0·49	33	8	6	336	22·40	2·94	16·92	756
342	0·10	327	0·09	345	0·43	0·23	0·35	0.31	0·39	29	9	15	334.5	22·30	3·01	16·95	763
347	0.09	322	0·08	345	0·38	0·23	0·41	0·36	0·31	32	12	25	334·5	22·30	3·05	16·98	765
46	0·11	46	0·11	47	0·63	0·14	0·38	0·38	0·40	45	16	0	46	3·07	8·29	21·79	770
27	0·12	47	0·07	9	0·71	0·12	0·40	0·23	0·42	41	10	− 20	37	2·47	8·23	21·25	772
331	0·06	308	0·07	338	0·35	0·24	0·29	0·33	0·27	24	16	23	319.5	21·30	2·61	15·88	773
18	0·05	76	0·05	22	0.68	0·11	0·30	0·30	0·22	37	11	− 58	47	3·13	8·55	21·78	775
33	0·09	62	0·07	26	0·67	0·12	0·38	0·30	0·33	45	16	− 29	47·5	3·17	8·34	21·85	776
328	0·16	302	0·13	326	0·48	0·20	0·40	0·33	0·56	36	6	26	315	21·00	3·15	14·82	780
52	0·31	58	0·17	50	0·36	0·22	0·53	0·29	0·90	57	29	− 6	55	3·67	5·99	22·59	785
51	0·34	57	0·20	52	0·35	0·21	0·48	0·28	1.05	49	25	− 6	54	3.60	5·89	22·55	787
46	0·50	49	0·28	42	0·36	0·24	0·50	0·28	1·50	33	20	− 3	47·5	3·17	5·13	22·24	793
46	0·52	49	0·30	44	0·35	0·24	0·51	0·29	1·54	32	18	− 3	47·5	3·17	5·09	22·25	795
45	0·66	48	0·41	44	0·40	0·25	0·47	0·29	2·06	34	16	− 3	46·5	3·10	6·16	22·25	800
91	0·98	84	0·68	94	0·32	0·22	0·42	0·29	3·29	42	20	7	87·5	5·83	11·80	1·16	802
66	0·72	66	0·44	71	0·41	0·26	0·45	0·27	2·33	26	21	0	66	4·40	9·06	23·63	805
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	807
53	0·69	57	0·38	50	0·32	0·20	0·49	0·27	2·10	27	25	− 4	55	3·67	6·97	23.07	809
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	810
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	811
46	0·05	47	0·39	46	0·37	0·24	0·50	0·29	1·94	29	−94	− 1	46·5	3·10	5·32	22·63	815
51	0·34	59	0·22	48	0·41	0·21	0·49	0·32	1·03	51	27	− 8	55	3·67	6·11	22·80	820
280	0·64	244	0·28	272	0·37	0·21	0·67	0·29	1·60	51	27	36	262	17·47	3·62	14·09	825

No.	Station.	Geographic position. Latitude.	Longitude. Arc.	Longitude. Time.	M_2.	$M_2°$. Degrees.	$M_2°$. Lunar hours.	S_2.	$S_2°$.	N_2.	$N_2°$.	K_1.
		° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	Ft.
	INDIAN OCEAN—continued.	*North.*	*East.*									
830	Maskat	23 37	58 35	3 54	2.07	276.2	9.21	0.78	306	0.51	258	1.27
840	Aden	12 47	44 59	3 00	1.57	226.5	7.55	0.69	246	0.43	221	1.30
845	Suez	29 58	32 32	2 10	.....	.....	.....	.....	.....	.....	.....	.....
850	Perim Id. (Str. Babel Mandeb)	12 38	43 24	2 54	.....	.....	.....	.....	.....	.....	.....	.....
851	Djibonti	11 35	43 12	2 53	1.74	220	7.33	0.75	239	.....	.....	1.34
		South.										
860	Hellville	13 20	48 12	3 13	3.74	121	4.03	1.77	168	.....	.....	0.46
862	Majunga	15 43	46 23	3 06	4.10	119	3.97	2.13	167	.....	.....	0.46
870	Port Louis, Mauritius I	20 08	57 29	3 50	0.43	23	0.77	0.33	26	0.14	32	0.24
880	Betsy Cove, Kerguelen I	49 09	70 12	4 41	1.42	9	0.30	0.80	52	0.24	330	0.14
890	Durban, Port Natal	29 53	31 04	2 04	1.72	115	3.83	0.95	150	0.30	102	0.17
895	Port Elizabeth, Algoa Bay	33 58	25 37	1 42	1.76	97	3.23	0.83	128	.....	.....	0.16
	WEST COAST OF AFRICA AND EUROPE.											
900	Cape Town, Table Bay	33 54	18 25	1 14	1.60	44.5	1.48	0.67	88	0.34	22	0.18
		North.										
920	Port Pola	44 53	13 48	0 55	.....	.....	.....	.....	.....	.....	.....	.....
923	Valetta Harbor, Malta	35 54	14 31	0 58	0.20	93	3.10	0.12	100	0.03	114	0.04
925	Toulon	43 05	5 55	0 24	0.19	252	8.40	0.09	250	0.05	240	0.12
926	Marseilles	43 18	5 21	0 21	0.22	228	7.60	0.08	247	0.04	221	0.10
			West.									
932	Lisbon	38 41	9 06	0 36	3.83	59.1	1.97	1.50	83	0.98	41	0.19
938	Socoa	43 24	1 41	0 07	4.37	89.1	2.97	1.56	121	0.93	68	0.20
942	Boyard	46 00	1 13	0 05	5.82	92.3	3.08	2.11	126	1.22	72	0.21
943	Rochelle	46 09	1 09	0 05	.....	.....	.....	.....	.....	.....	.....	.....
946	Brest	48 23	4 29	0 18	6.76	99.2	3.31	2.47	139	1.39	80	0.21
948	St. Malo	48 39	2 02	0 08	12.45	173.7	5.79	4.80	225	2.38	155	0.30
950	Cherbourg	49 39	1 37	0 06	6.16	225.3	7.51	2.26	269	1.29	206	0.30
			East.									
952	Havre	49 29	0 06	0 00	8.74	285.5	9.52	2.89	333	1.70	262	0.30
			West.									
956	West Hartlepool	54 41	1 12	0 05	5.16	95.9	3.28	1.74	137	0.99	71	0.38
			East.									
958	Sheerness	51 27	0 45	0 03	6.30	0.5	0.02	1.75	56	1.05	337	0.38
			West.									
960	London Bridge	51 30	0 07	0 00	8.31	55.0	1.83	1.64	110	1.47	25	0.30
			East.									
962	Ramsgate	51 20	1 25	0 06	6.14	342.4	11.37	1.88	34	1.08	313	0.22
964	Dover	51 07	1 19	0 05	7.20	336.1	11.20	2.07	28	1.36	320	0.14
			West.									
966	Portland Breakwater	50 31	2 24	0 10	2.05	189.4	6.31	1.07	239	0.48	180	0.30
970	Helbre Island, Mersey R	53 24	3 00	0 12	9.76	313.5	10.45	3.13	356	1.86	289	0.39
971	Liverpool, Mersey R	53 24	3 00	0 12	9.98	320.6	10.89	3.16	6	1.90	299	0.36
978	Greenock	55 57	4 45	0 19	4.36	337	11.23	1.04	42	0.71	309	0.19
			East.									
982	Ostende	51 14	2 56	0 12	5.92	12.3	0.41	1.80	64	1.00	1	0.18
986	Wilhelmshaven, Jude R	53 31	8 09	0 33	5.34	358.4	11.95	1.35	71	0.80	334	0.23
987	Rothen Sande	53 51	8 05	0 32	4.00	338.5	11.28	1.09	53	0.68	308	0.22
990	Helgoland Island	54 11	7 53	0 32	3.18	334.8	11.16	0.83	40	0.51	304	0.20
995	Copenhagen, Baltic Sea	55 42	12 36	0 50	0.20	277	9.23	0.09	249	0.06	248	0.38

$K_1°$.	O_1.	$O_1°$.	P_1.	$P_1°$.	$\frac{S_2}{M_2}$.	$\frac{N_2}{M_2}$.	$\frac{O_1}{K_1}$.	$\frac{P_1}{K_1}$.	K_1+O_1.	$S_2°-M_2°$.	$M_2°-N_2°$.	$K_1°-O_1°$.	$\frac{1}{2}(K_1°+O_1°)$. De-grees.	$\frac{1}{2}(K_1°+O_1°)$. Lunar hours.	Cotidal hour. Semi-diur-nal.	Cotidal hour. Diur-nal.	No.
°	*Ft.*	°	*Ft.*	°	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	°	°	°	°	*h.*	*h.*	*h.*	
39	0·66	41	0·39	37	0·38	0·25	0·52	0·31	1·93	30	18	− 2	40	2·67	5·31	22·77	830
35	0·66	37	0·39	31	0·43	0·27	0·51	0·30	1·96	20	5	− 2	36	2·40	4·55	23·40	840
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	845
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	850
30	0·66	35	0·43	30	0·43	......	0·49	0·32	2·00	19	......	− 5	32·5	2·17	4·45	23·29	851
51	0·26	57	0·16	51	0·47	......	0·57	0·35	0·72	47	......	− 6	54	3·60	0·81	0·38	860
56	0·23	56	0·16	56	0·52	......	0·50	0·35	0·69	48	......	0	56	3·73	0·87	0·63	862
121	0·14	98	0·06	132	0·76	0·32	0·58	0·25	0·38	3	− 9	23	109·5	7·30	8·94	3·47	870
289	0·22	292	0·04	287	0·56	0·17	1·57	0·29	0·36	43	39	− 3	290·5	19·37	7·62	14·69	880
180	......	......	......	......	0·55	0·17	......	......	......	35	13	......	......	......	1·76	......	890
146	0·05	280	0·05	146	0·47	......	0·31	0·31	0·21	31	......	−134	213	14·20	1·53	12·50	895
127	0·05	243	0·05	114	0·42	0·21	0·28	0·28	0·23	44	23	−116	185	12·33	0·25	11·10	900
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	920
43	0·02	83	0·01	58	0·61	0·15	0·50	0·25	0·06	7	−21	− 40	63	4·20	2·13	3·23	923
3	0·06	302	0·04	0	0·47	0·25	0·50	0·33	0·18	− 2	12	61	332·5	22·17	8·00	21·77	925
181	0·07	106	0·04	182	0·36	0·18	0·70	0·40	0·17	19	7	75	143·5	9·57	7·25	9·22	926
39	0·20	309	0·06	39	0·39	0·26	1·05	0·32	0·39	24	18	90	354	23·60	1·37	0·20	932
66	0·24	317	0·06	50	0·36	0·21	1·20	0·30	0·44	32	21	109	11·5	0·77	2·85	0·89	938
67	0·23	321	0·09	58	0·37	0·21	1·10	0·43	0·44	34	20	106	14	0·93	3·00	1·01	942
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	943
69	0·22	324	0·07	60	0·37	0·21	1·05	0·33	0·43	40	19	105	16·5	1·10	3·01	1·40	946
95	0·29	343	0·11	96	0·39	0·19	0·96	0·37	0·59	51	19	112	39	2·60	5·66	2·14	948
104	0·21	351	0·11	95	0·37	0·21	0·70	0·37	0·51	44	19	113	47·5	3·17	7·41	3·27	950
119	0·16	7	0·09	103	0·33	0·19	0·53	0·30	0·46	47	24	112	63	4·20	9·52	4·20	952
246	0·43	84	0·11	231	0·34	0·19	1·13	0·29	0·81	41	25	162	165	11·00	3·20	11·08	956
14	0·45	193	0·14	350	0·28	0·18	1·17	0·37	0·83	56	24	−179	103·5	6·90	11·97	6·85	958
41	0·40	220	0·10	18	0·20	0·18	1·33	0·33	0·70	55	30	−179	130·5	8·70	1·83	8·70	960
21	0·34	183	0·07	356	0·31	0·18	1·55	0·32	0·56	52	29	−162	99	6·60	11·27	6·50	962
48	0·19	186	0·05	21	0·29	0·19	1·29	0·36	0·32	52	16	−139	115·5	7·70	11·04	7·62	964
112	0·16	351	0·11	106	0·52	0·23	0·55	0·38	0·45	50	9	121	51·5	3·43	6·47	3·59	966
185	0·37	38	0·15	171	0·32	0·19	0·95	0·38	0·76	43	24	147	114·5	7·63	10·85	7·43	970
192	0·37	38	0·13	182	0·32	0·19	1·03	0·36	0·73	45	21	153	117·5	7·83	11·09	7·63	971
224	0·24	54	0·06	137	0·24	0·16	1·26	0·32	0·43	65	28	170	139	9·27	11·55	9·59	978
354	0·32	173	0·08	332	0·30	0·17	1·78	0·44	0·50	52	11	−179	83·5	5·57	0·21	5·37	982
44	0·31	253	0·11	43	0·25	0·15	1·35	0·48	0·54	73	24	151	328·5	21·90	11·40	21·35	986
26	0·27	233	0·08	27	0·27	0·17	1·23	0·36	0·49	75	30	153	309·5	20·63	10·75	20·10	987
32	0·26	246	0·09	33	0·26	0·16	1·30	0·45	0·46	65	31	146	319	21·27	10·63	20·74	990
23	0·07	9	0·01	......	0·46	0·31	0·18	0·03	0·45	−28	29	14	16	1·07	8·40	0·24	995

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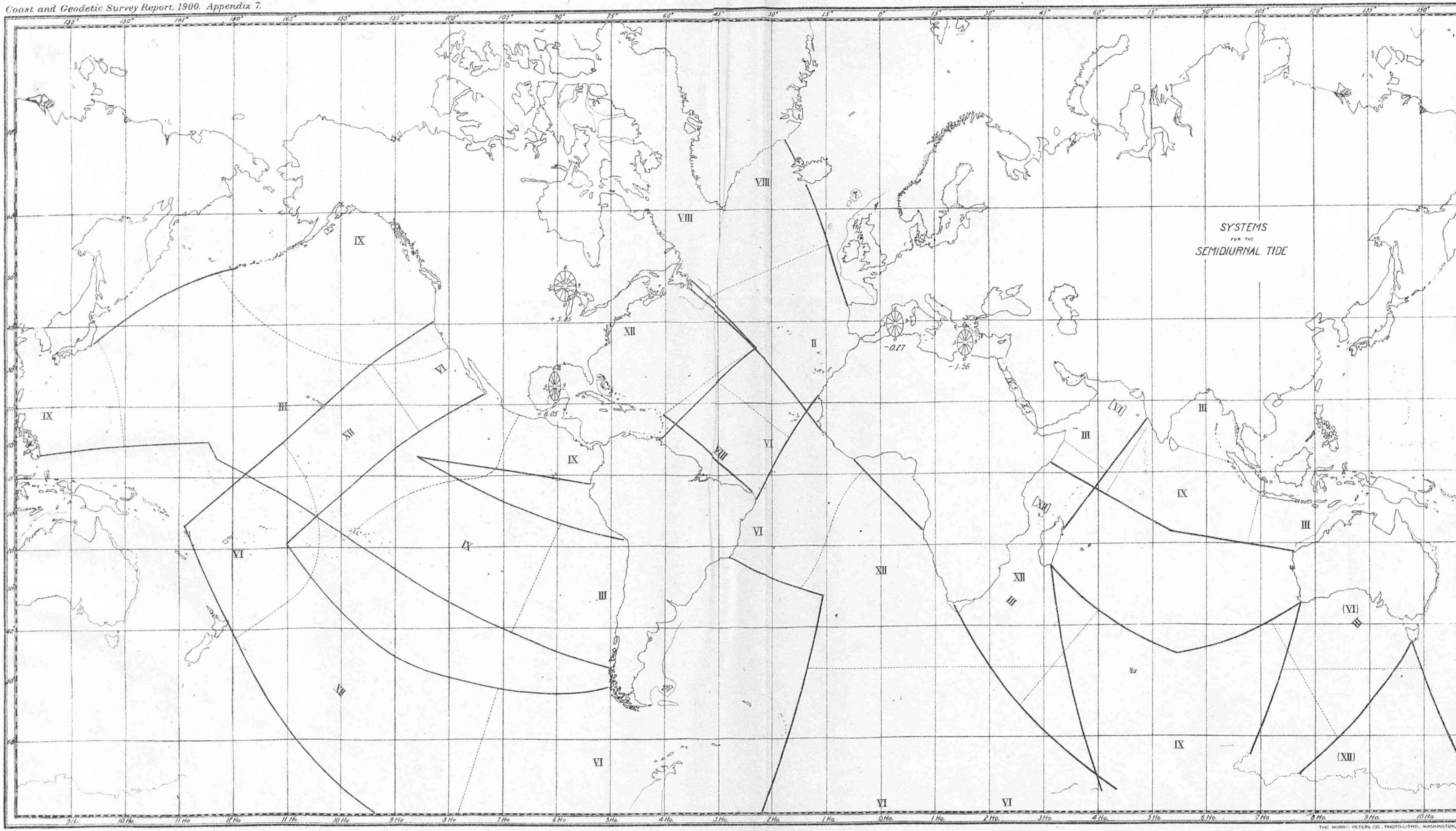
CHART OF SOUNDINGS
FROM
B.A. CHARTS – 2935, 2936, 2937, SUPPLEMENTED BY RECENT DATA
SOUNDINGS IN FATHOMS
100 FM. LINE
1000 " "
2000 " "
3000 " "
4000 " "


CHART OF SOUNDINGS
FROM
B.A. CHARTS – 2935, 2936, 2937 SUPPLEMENTED BY RECENT DATA
SOUNDINGS IN FATHOMS
100 FM. LINE
1000 " "
2000 " "
3000 " "
4000 " "
Over 3000 Fathoms


MAP OF
TIDAL STATIONS


MAP OF
TIDAL STATIONS



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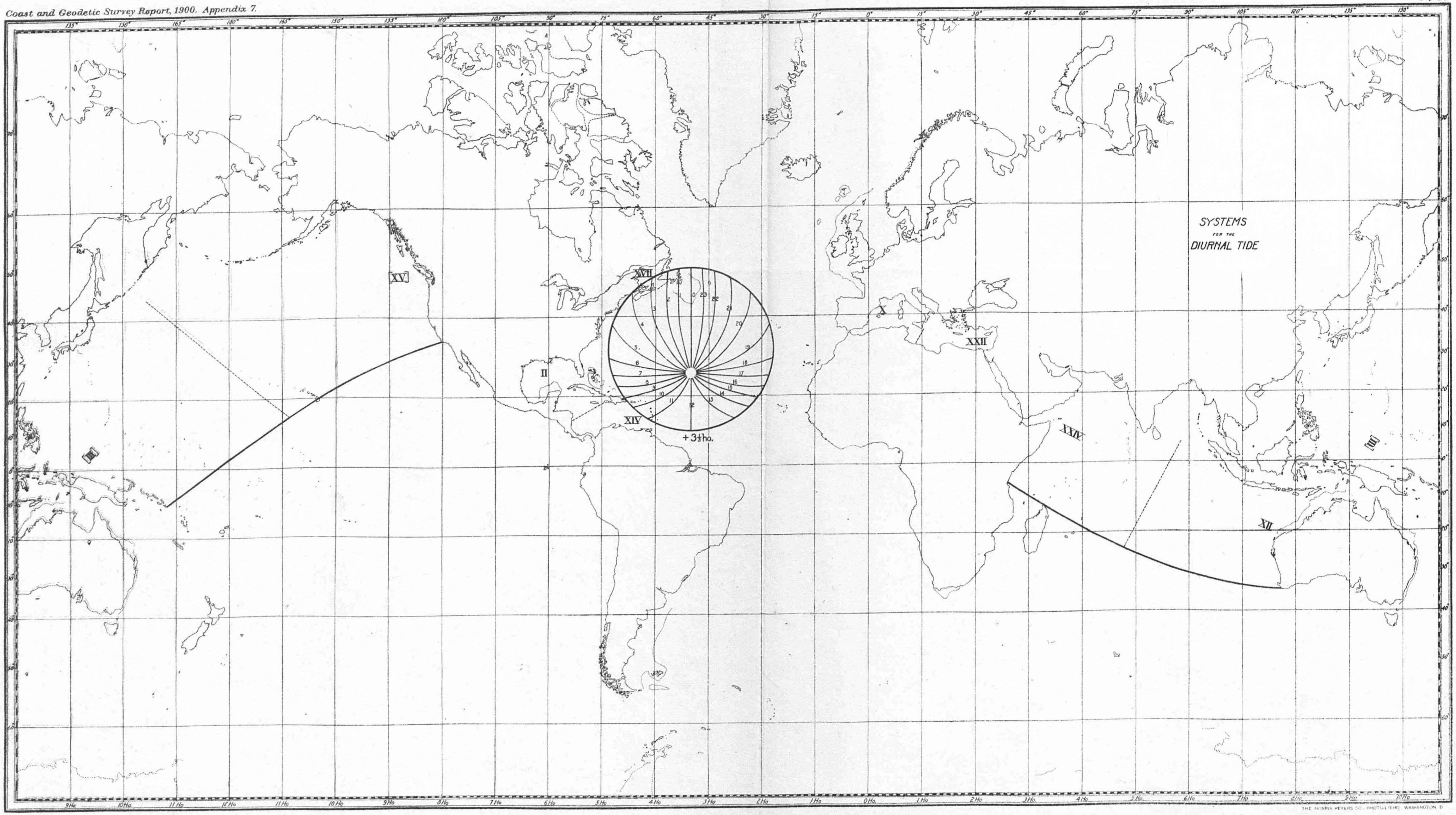
SYSTEMS
FOR THE
DIURNAL TIDE
XV
II
XVII
XIV
+3½ho.
X
XXII
XXIV
XII
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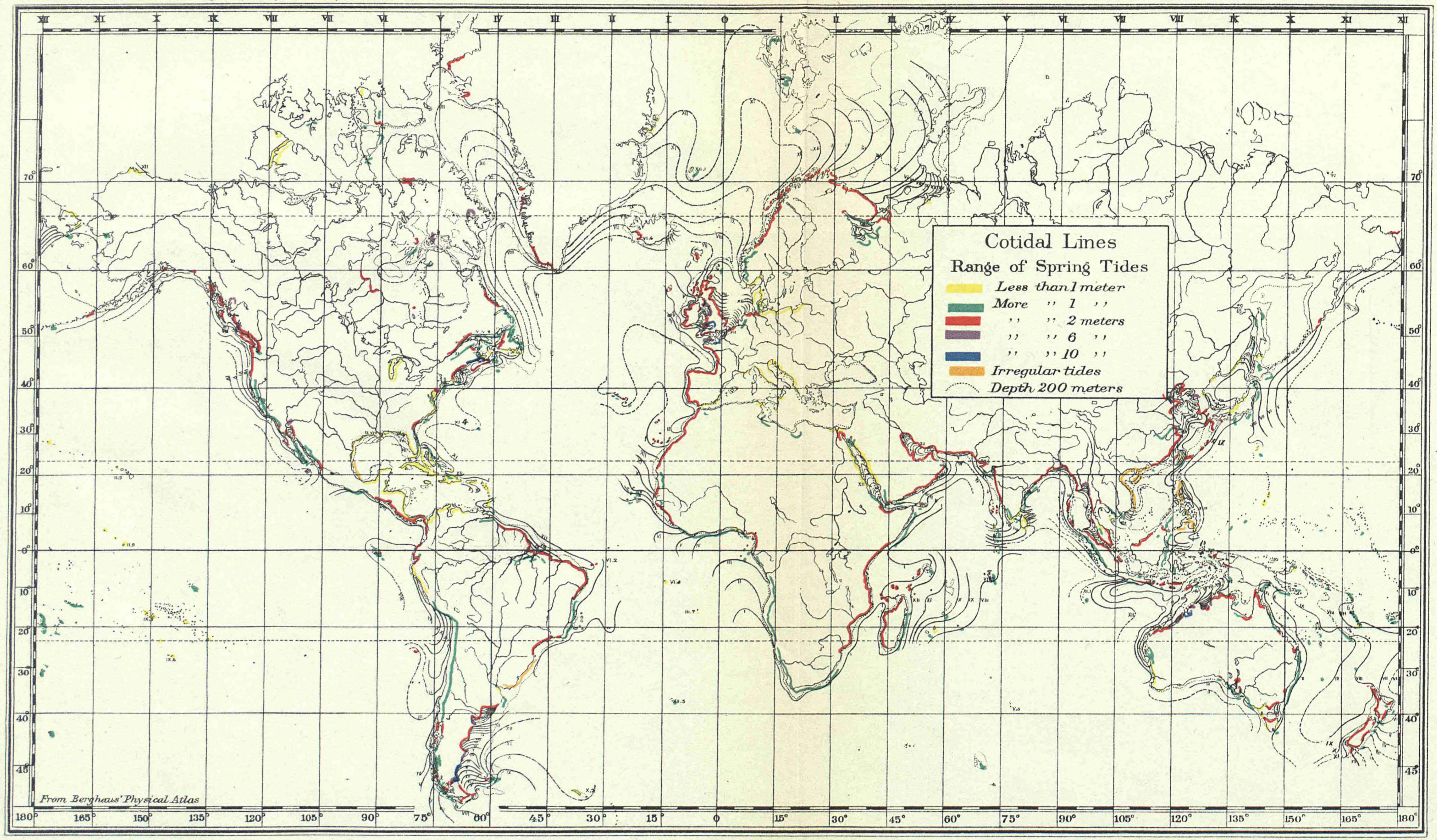

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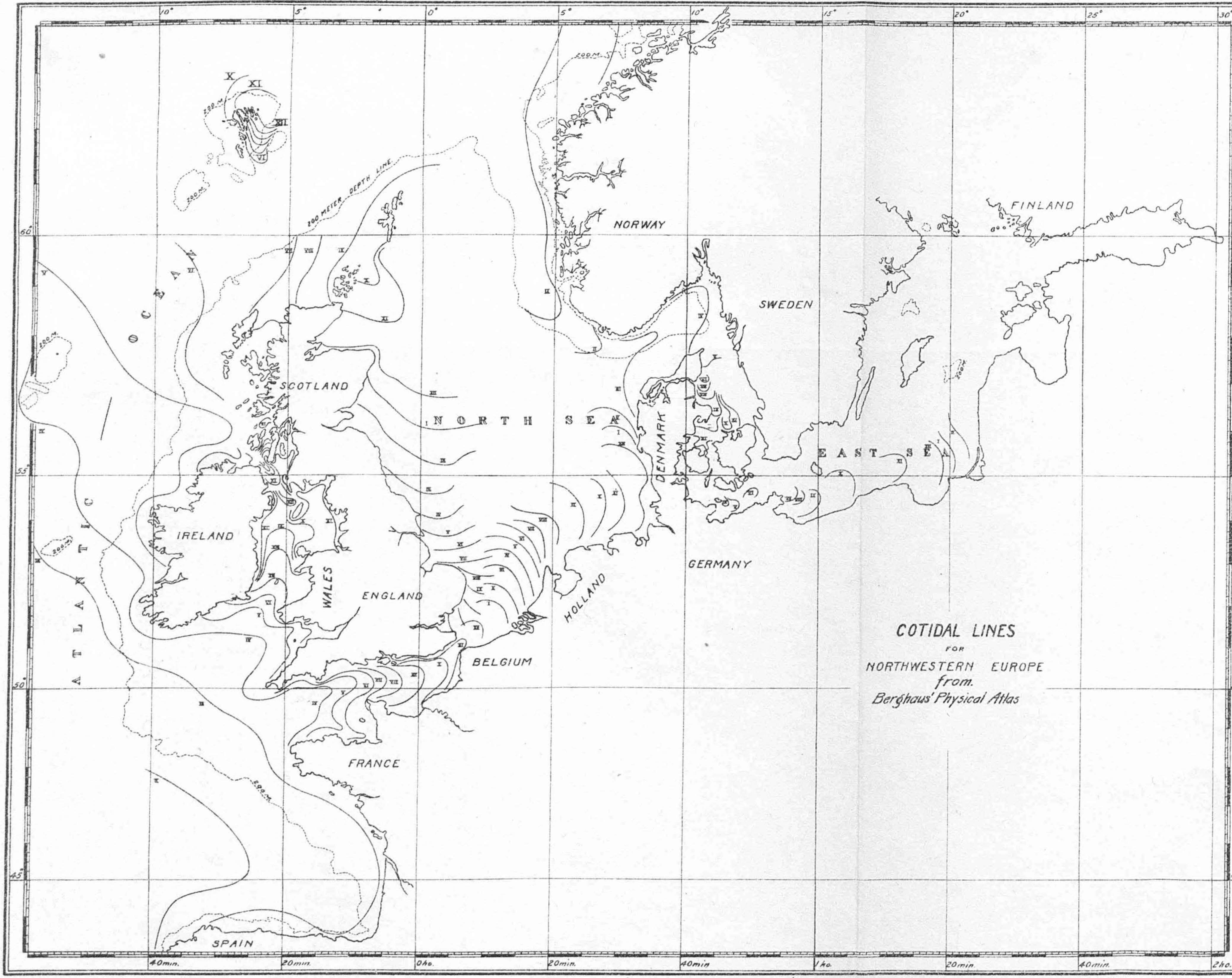

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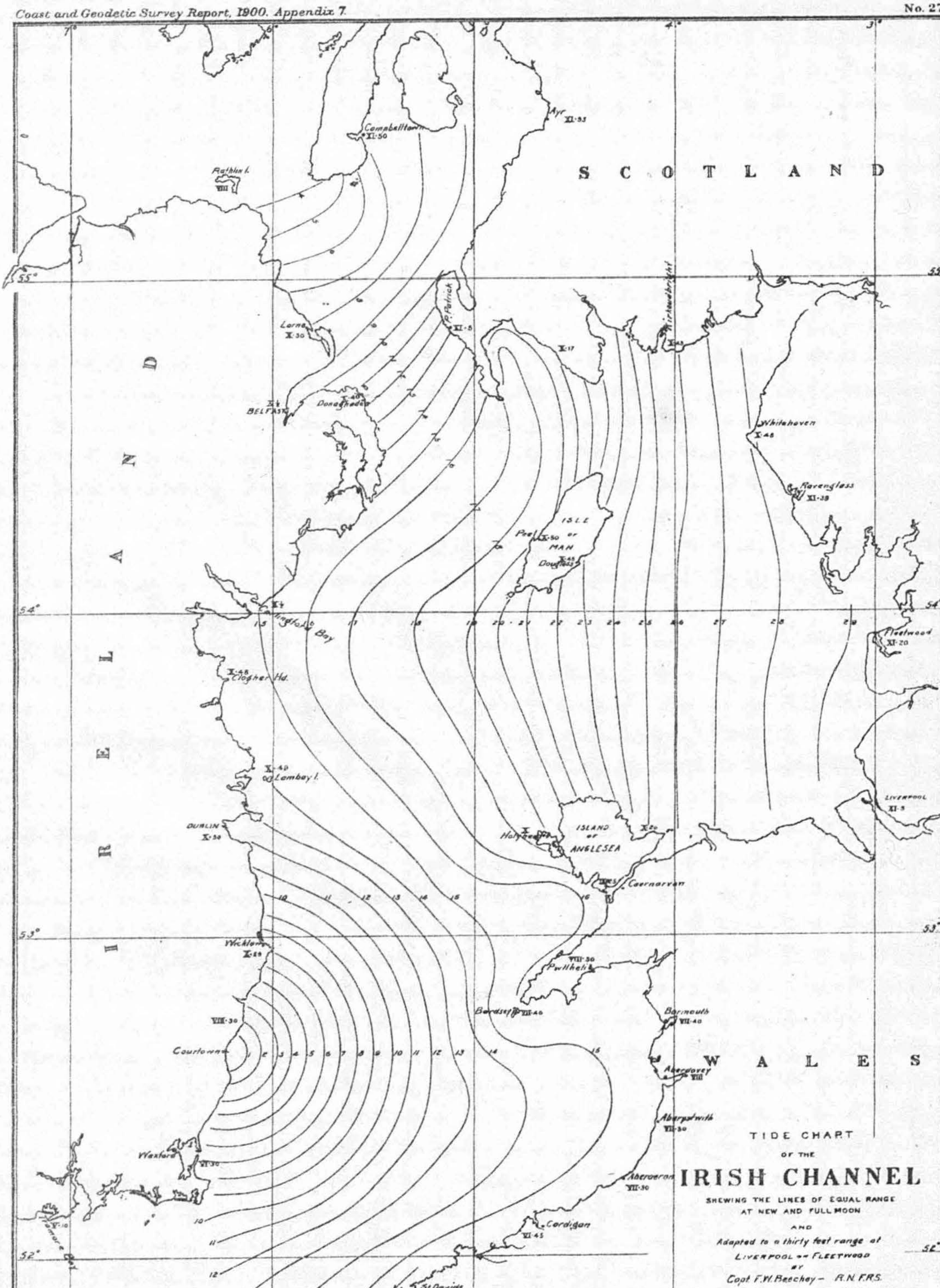
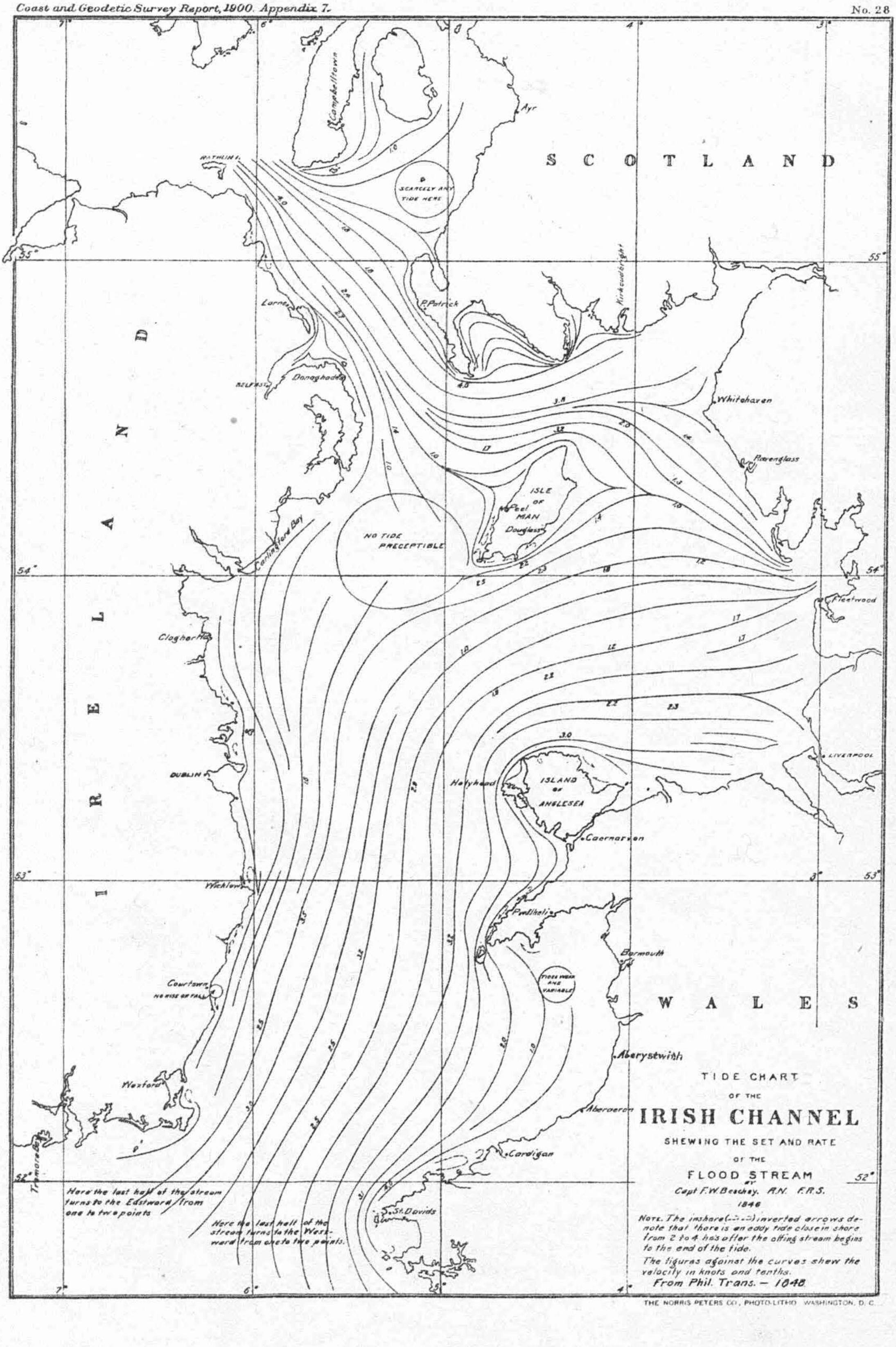

SCOTLAND
WALES
TIDE CHART
OF THE
IRISH CHANNEL
SHEWING THE LINES OF EQUAL RANGE
AT NEW AND FULL MOON
AND
Adapted to a thirty feet range at
LIVERPOOL or FLEETWOOD
BY
Capt. F.W. Beechey - R.N. F.R.S.
From Phil. Trans. - 1848
Campbelltown
Ayr
Rathlin I.
Larne
Belfast
Donaghadee
P. Patrick
Kirkcudbright
Whitehaven
Ravenglass
ISLE OF MAN
Peel
Douglas
Fleetwood
Clogher Hd.
Lambay I.
Dublin
ISLAND OF ANGLESEA
Holyhead
Caernarvon
Liverpool
Wicklow
Pwllheli
Bardsey
Barmouth
Courtown
Aberdovey
Aberystwith
Wexford
Aberaeron
Cardigan
St. Davids
55°
54°
53°
52°



TIDE CHART
OF THE
IRISH CHANNEL
SHEWING THE SET AND RATE
OF THE
FLOOD STREAM
BY
Capt. F. W. Beechey, R.N. F.R.S.
1846

NOTE. The inshore inverted arrows denote that there is an eddy tide close in shore from 2 to 4 hrs after the offing stream begins to the end of the tide.
The figures against the curves shew the velocity in knots and tenths.

From Phil. Trans. — 1848

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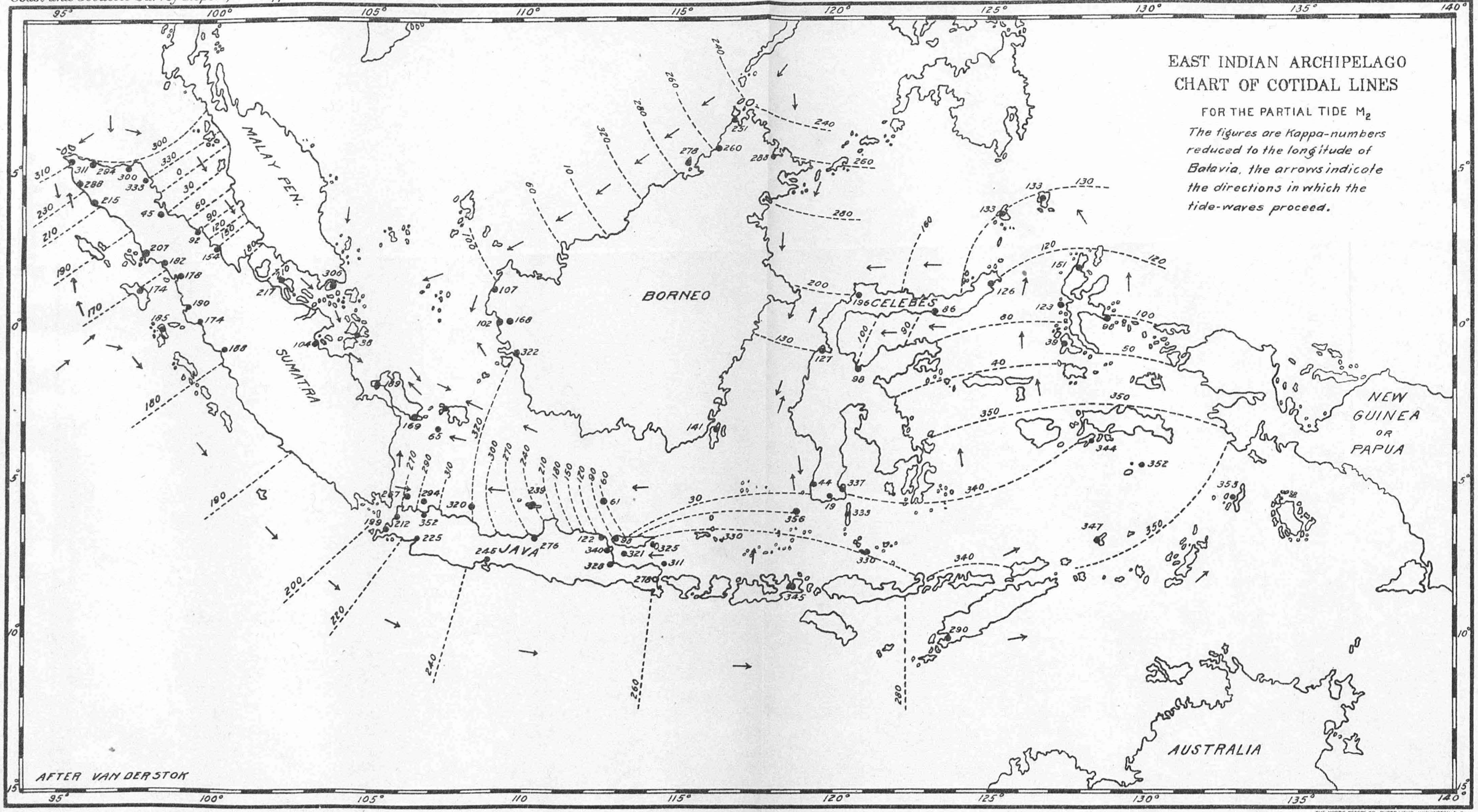

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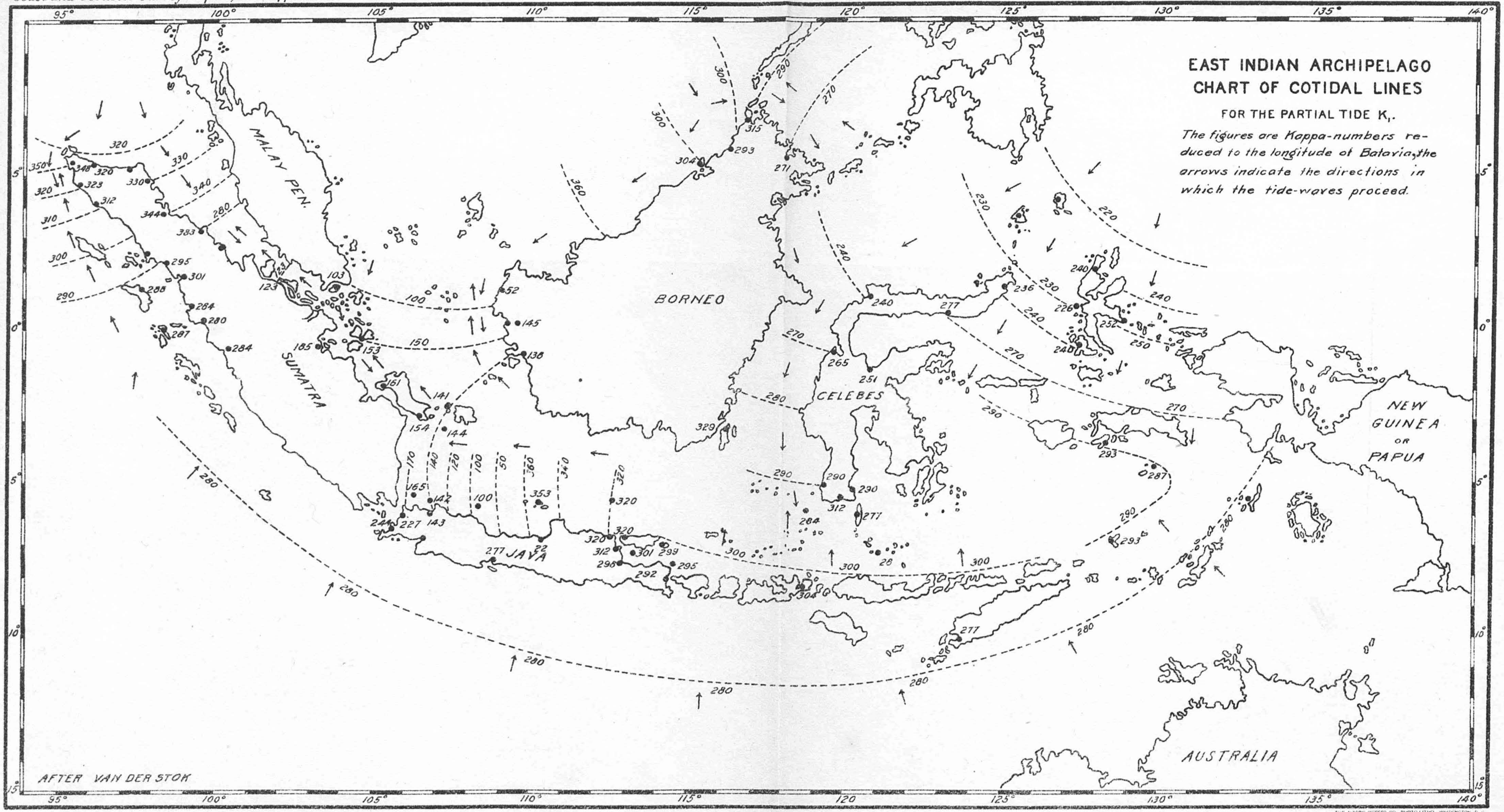

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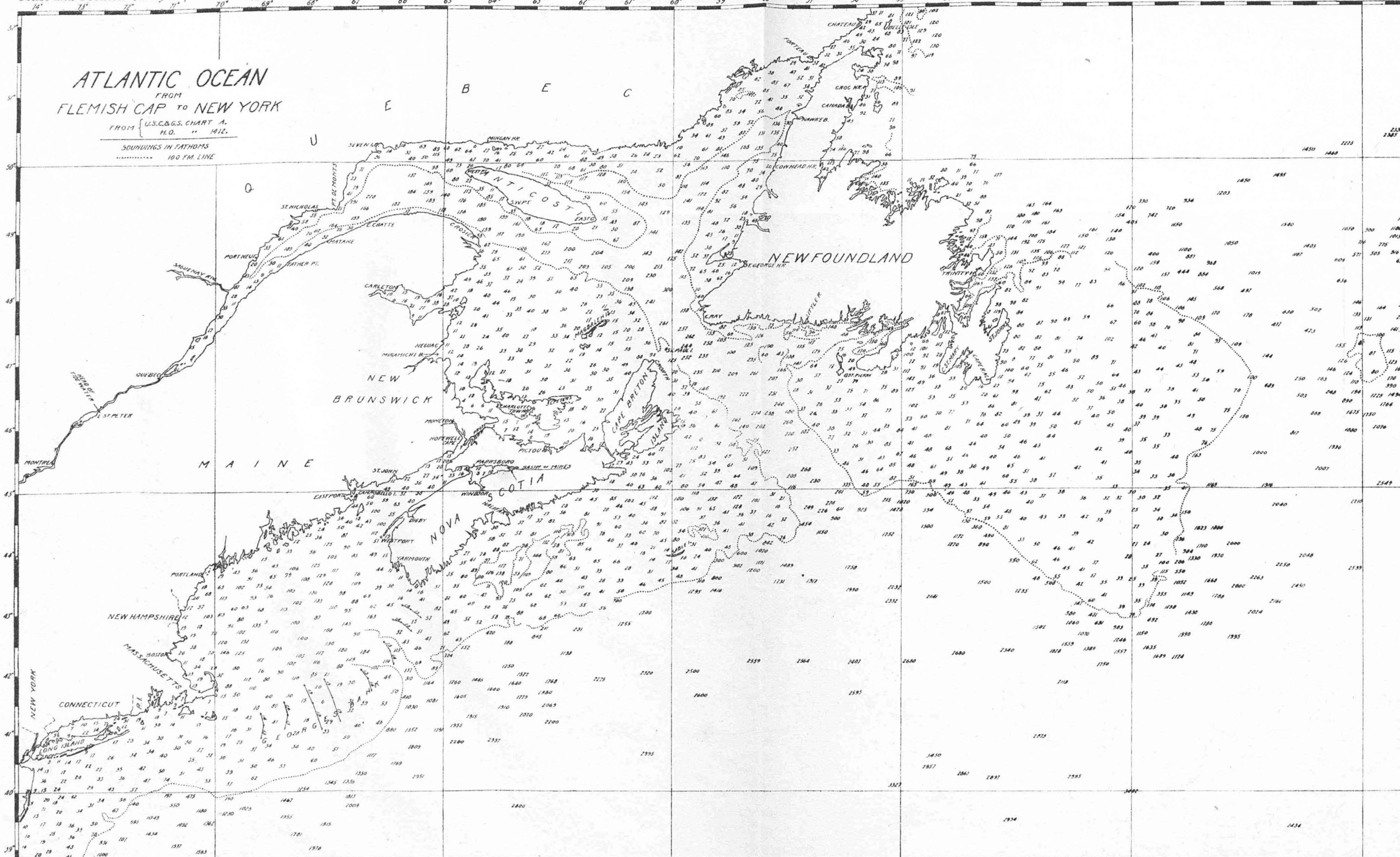
No. 31



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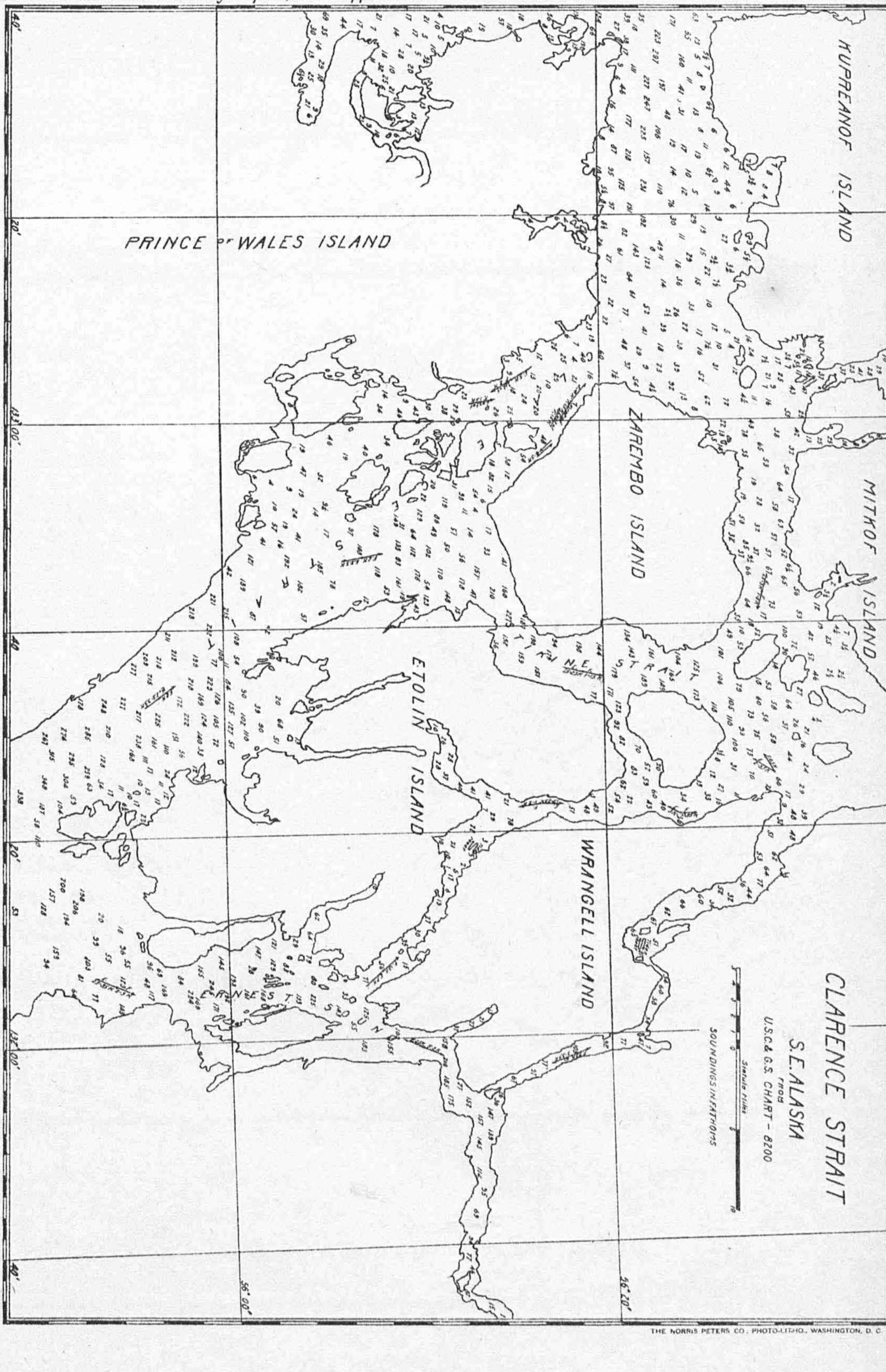
NORTH AMERICA
PACIFIC COAST
FROM OLYMPIA TO HARBOR POINT
SOUNDINGS IN FATHOMS
50 FM. LINE
100 " "
FROM
U.S. C.&G. CHART 8001
B.A. " 1917
ALASKA
BRITISH POSSESSIONS
ADMIRALTY ISLAND
BARANOF ISLAND
CHICHAGOF ISLAND
CHATHAM STRAIT
KUPREANOF I.
KUIU
PRINCE OF WALES ISLAND
PORTLAND CANAL
DIXON ENTRANCE
HECATE STRAIT
GRAHAM ISLAND
ROSE PT.
GRENVILLE CHANNEL
PITT ISLAND
BANKS ISLAND
PRINCESS ROYAL I.
HARBOR POINT
CAPE SPENCER
CAPE CROSS
CAPE OMMANEY
CAPE MUZON
CAPE SCOTT
VANCOUVER

No. 32


BRITISH POSSESSIONS
VANCOUVER ISLAND
WASHINGTON
HECATE STRAIT
DIXON ENTRANCE
GRAHAM ISLAND
BANKS ISLAND
PITT ISLAND
PRINCESS ROYAL I.
GRENVILLE CHANNEL
PORTLAND CANAL
REVILLAGIGEDO I.
OF WALES ISLAND
CAPE MUZON
ROSE PT.
CAPE SCOTT
DISCOVERY PASSAGE
VANCOUVER
CAPE FLATTERY
OLYMPIA
CAPE DISAPPOINTMENT



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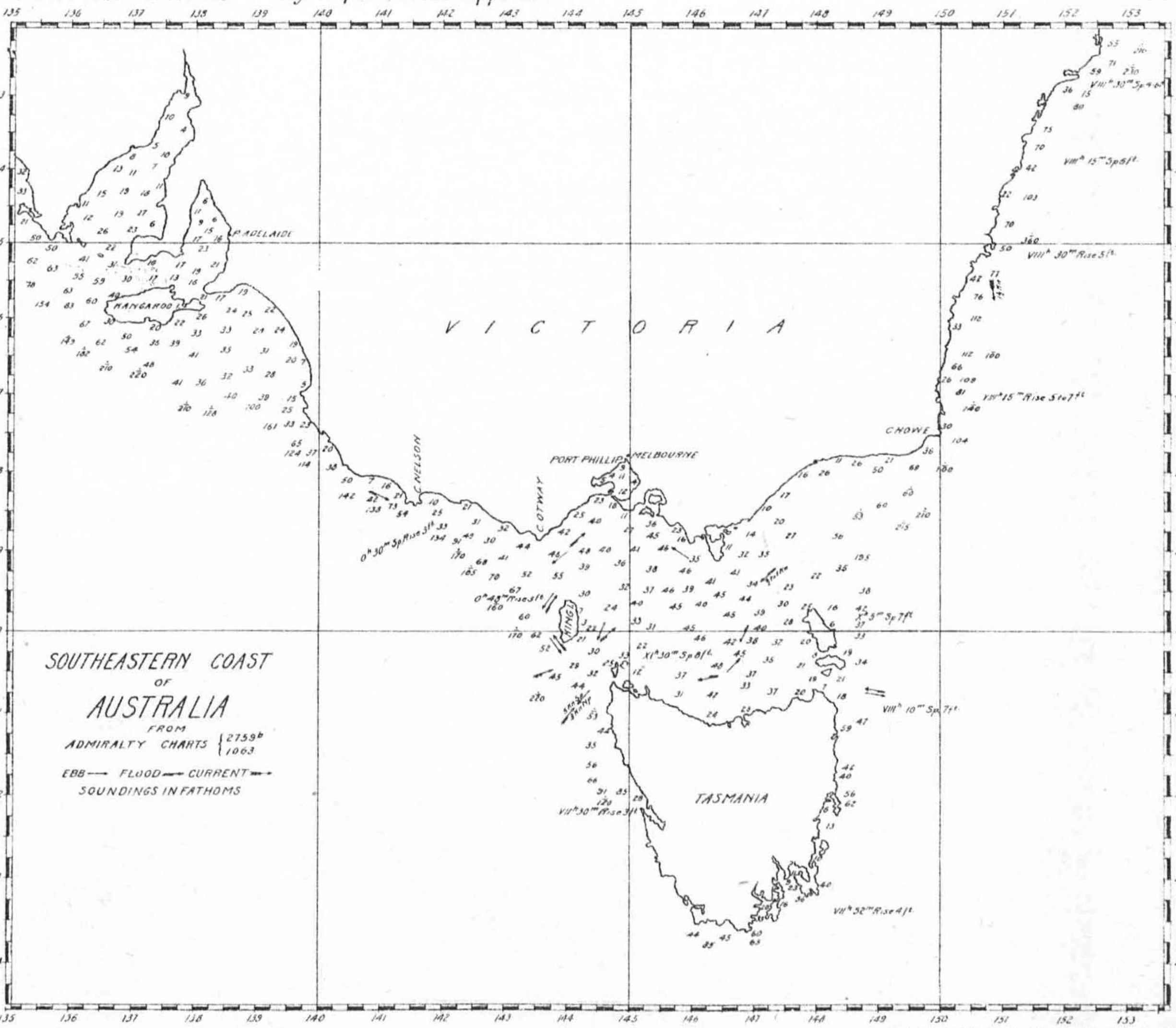

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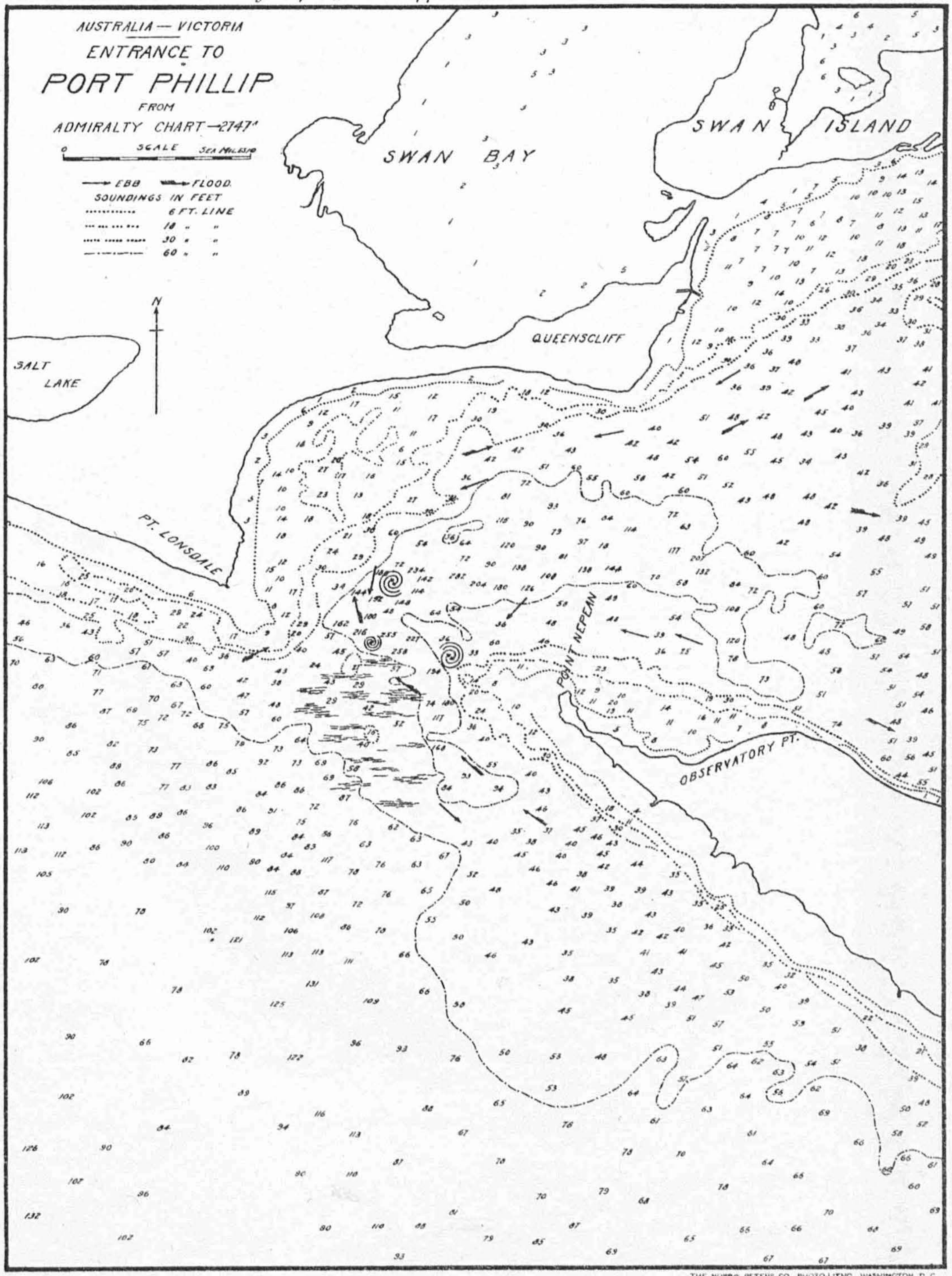

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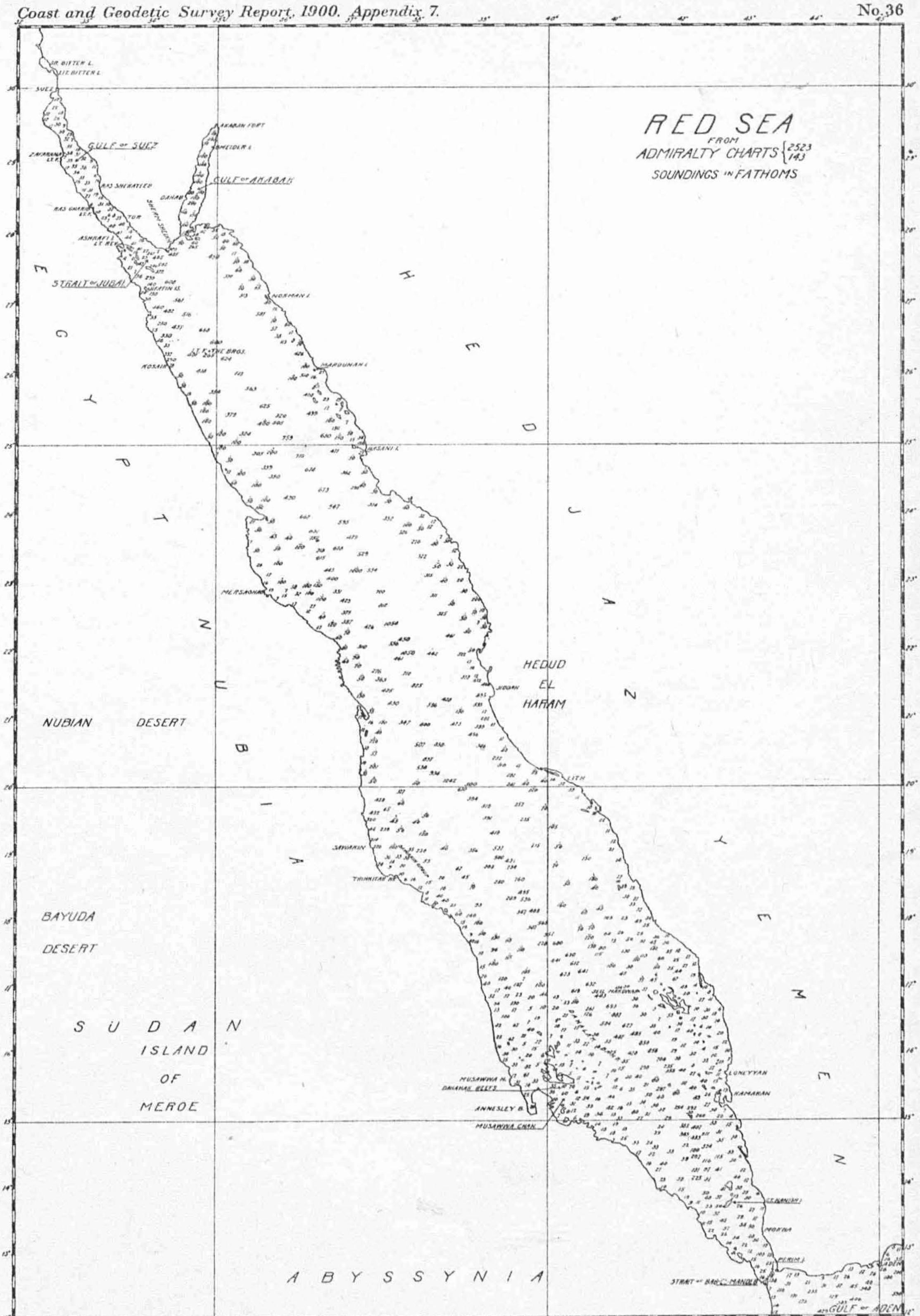

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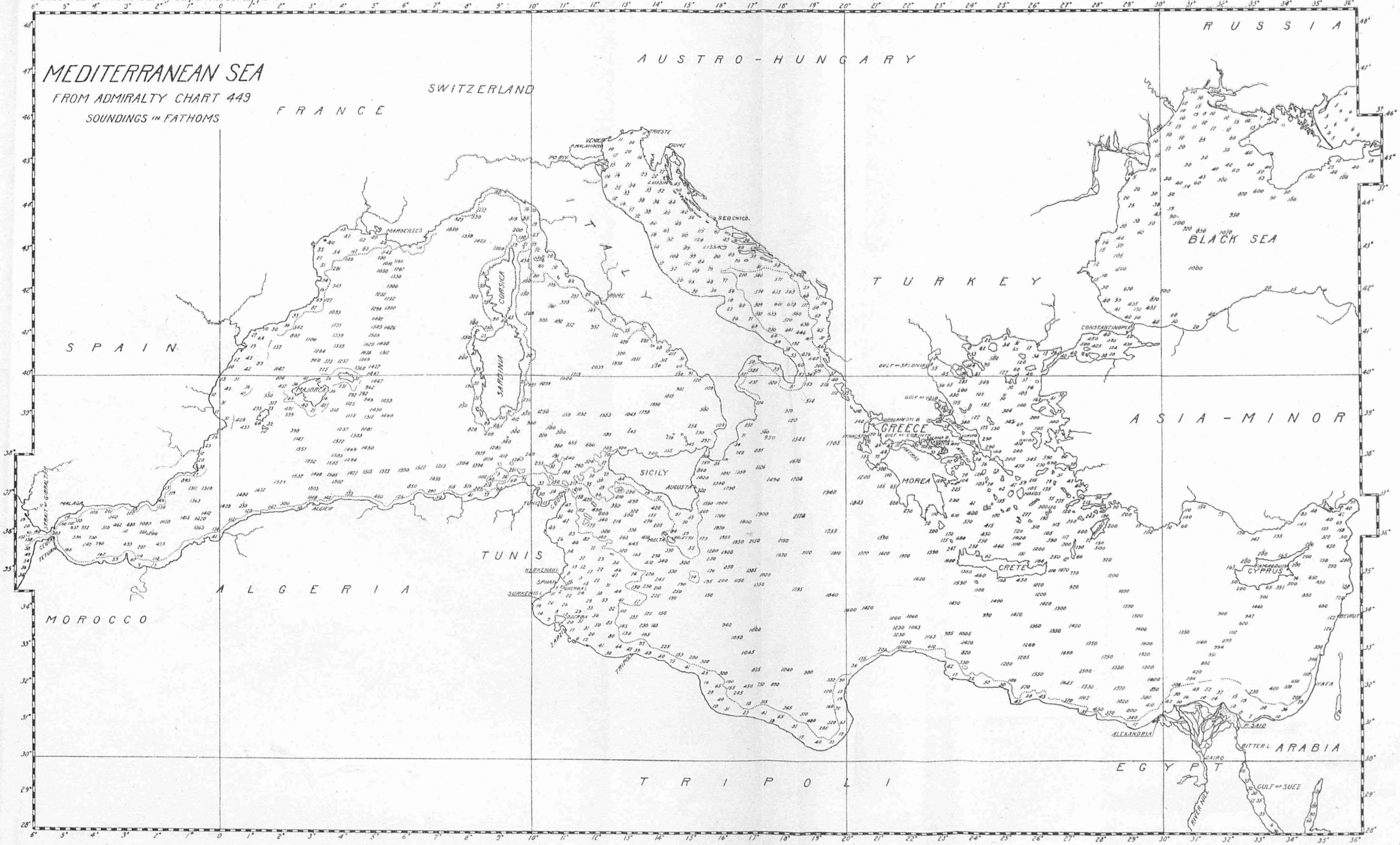

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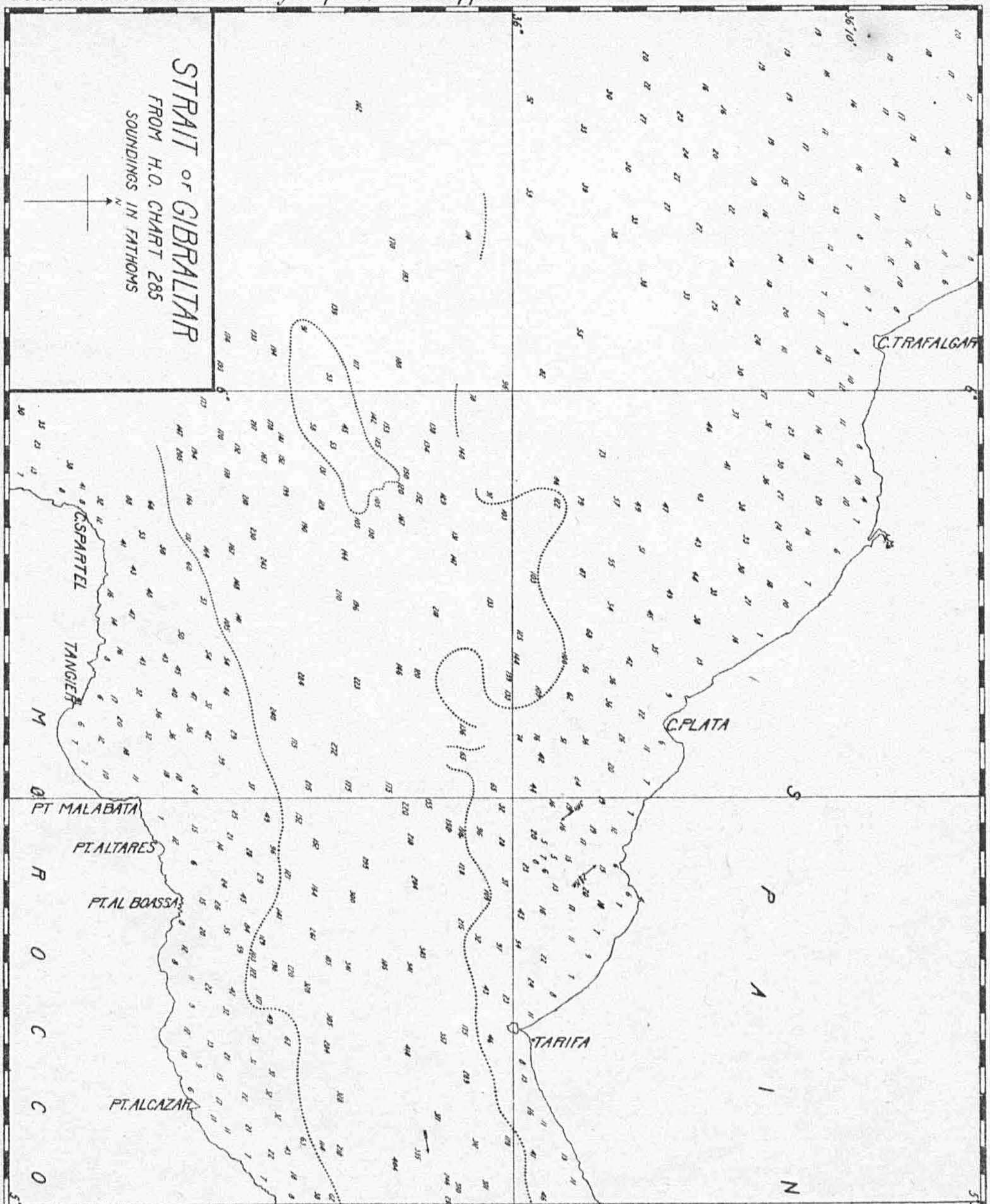

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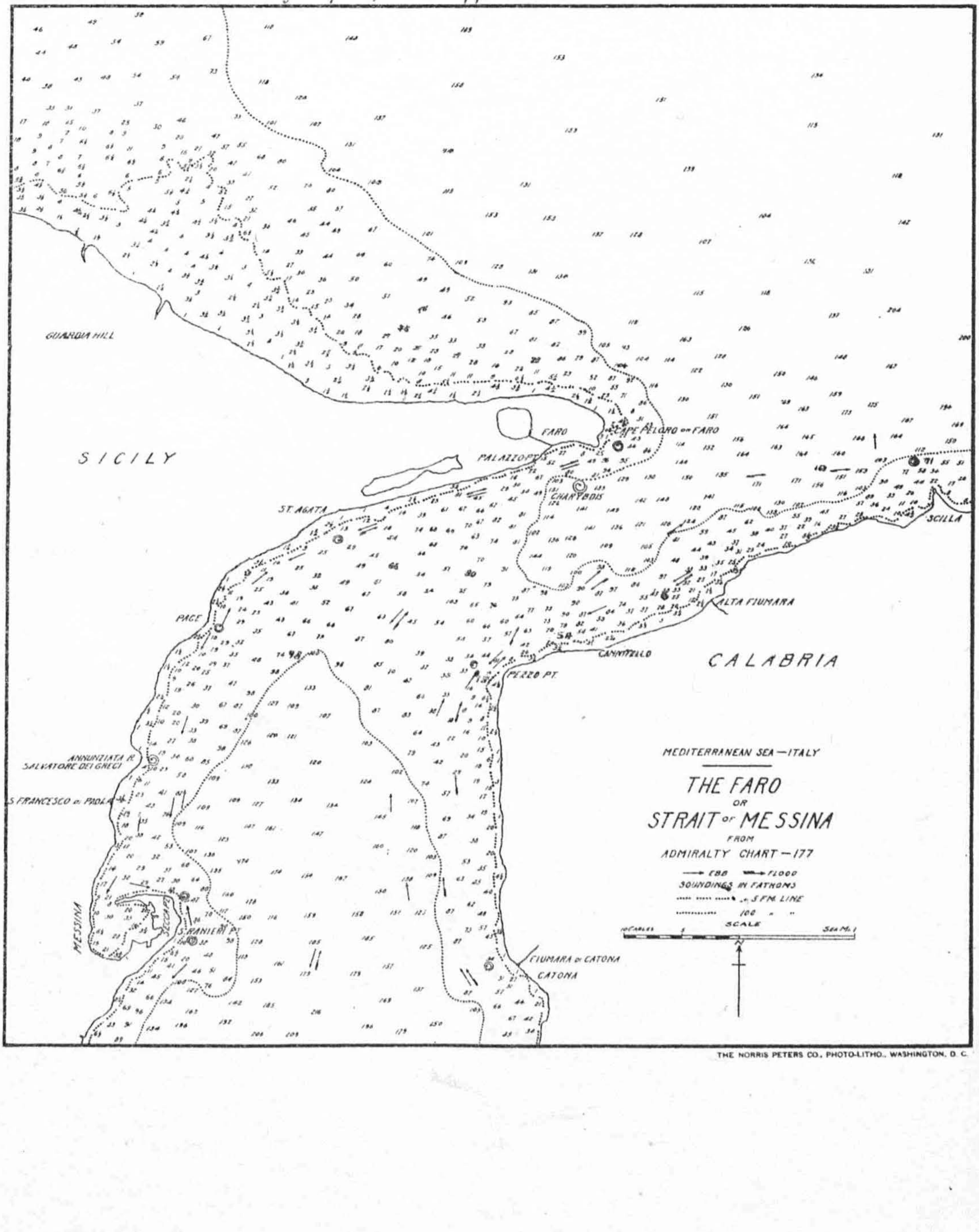

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CHAPTER VIII.

ON THE CLASSIFICATION OF RIVERS, STRAITS, BAYS, ETC., WITH REFERENCE TO THEIR TIDAL MOVEMENTS.

98. In this chapter attention will be called to certain simple or typical cases of liquid motion and to those natural bodies of water which serve to exemplify the same in a measure, or in certain respects. As usual, the depth will be assumed to be so great in comparison with the range of tide that shallow-water components due to the want of such depth need not be considered. Friction is not taken into consideration. The various cases or types which seem important are for convenience given an arbitrary numbering. Sometimes a given body of water may fall under two or more cases, and sometimes it may not closely resemble any of the types mentioned. Some of the natural bodies of water instanced below serve well as illustrations, while others lie outside the limits assigned in the cases under which they are given.

The more detailed study of movements of this kind, together with comparisons with observations, will be given at some future time.*

CASE I.—*Tidal river; cross section not greatly altered in small part of wave length.*

The motion is given by the equations

$$\xi = A \sin (at - lx + \alpha), \tag{325}$$

$$\begin{aligned} \zeta = Alh \cos (at - lx + \alpha), &= Aa\sqrt{\frac{h}{g}} \cos (at - lx + \alpha), \\ &= A' \cos (at - lx + \alpha), \qquad (326) \\ a^2 &= ghl^2. \end{aligned}$$

Tidal phenomena.—The tide progresses at the rate due to depth, which is $\frac{a}{l} = \frac{\lambda}{\tau} = \sqrt{(gh)}$. Partial tides also progress at the rate $\sqrt{(gh)}$; and so the ages of all inequalities are increased by the time of transmission. h denotes average depth of cross section at any given point. The amplitude A' of the tide does not change rapidly from point to point, since by hypothesis the cross section changes slowly and the constancy of the wave energy makes $A' \doteq \frac{\text{a constant}}{w^{\frac{1}{2}}\, h^{\frac{1}{4}}}$, w here denoting, for the moment, the width

*The last paragraph of § 15, Part I, is faulty, and should be either stricken out or recast in accordance with this chapter.

The second paragraph of § 77, Part II, is faulty. It may be amended by replacing "all multiplied by the same constant" by "each divided by a constant proportional to its speed," and "This shows that" by "In certain straits, etc. (see § 34, Part I)."

of the river. By constant is meant constant for a given component at different points of the river. This shows that the amplitude of any partial tide varies as the range of tide varies; in other words, the ratios of the amplitudes of the partial tides remain constant. (See § 33, Part I.)

The ratio of the amplitudes of any two tidal components, or of any two velocity components, or of any one tidal and one velocity component, remains the same at each point of the river. Again, for any one component

$$\dot{\xi} : \zeta = \sqrt{\frac{g}{h}}. \tag{327}$$

But on the contrary,

$$A' : A = lh, \ B' : B = mh, \quad . \quad . \quad . \tag{328}$$

where

$$a^2 = ghl^2, \ b^2 = ghm^2, \quad . \quad . \quad . \quad .$$

For M_2, $m_2 = a = 0{\cdot}000\ 140\ 5$ radian per second, and so $A' : A = 0{\cdot}000\ 024\ 77 \sqrt{h}$ for the ratio of the amplitude of the vertical to the amplitude of the horizontal displacement. The strength of flood occurs at the time of mean level rising.

Examples.—The foregoing statements approximately apply to many tidal rivers, channels, etc. For those rivers here named the application should be fairly satisfactory, although in no instance have observations been obtained sufficient for making a thorough test in all respects: Hudson, Potomac, James, Savannah, St. Johns, Mississippi, Rio Grande, Columbia, Yukon, Zambesi, Kongo, Niger, Senegal, Tagus, Thames, Rhine, Elbe.

99. CASE 2.—*Short tidal river or canal of uniform cross section abruptly contracted or terminated.*

The motion is given by the equations

$$\xi = Al(L - x) \cos (at + \alpha), \tag{329}$$

$$\zeta = Alh \cos (at + \alpha) = Aa\sqrt{\frac{h}{g}} \cos (at + \alpha) = A' \cos (at + \alpha), \tag{330}$$

$$a^2 = ghl^2.$$

L denotes the length; the origin is taken at the mouth. See equations (61), (62), Part I.

Tidal phenomena.—The tide wave is stationary. High water within is simultaneous with the high water at the mouth. The amplitude is constant from the mouth to the head. The same is true of the partial tides, and so of course the amplitude ratios are the same everywhere.

The velocity of the water particles is $\dot{\xi} = - Aal\ (L - x) \sin (at + \alpha)$; that is, it varies as the distance from the head of the canal. The ratio of the amplitudes of $\dot{\xi}$ to that of ζ is $\frac{a}{h}\ (L - x)$; for any other component, say C, the ratio would be $\frac{c}{h}\ (L - x)$. Consequently this ratio depends upon the speed of the component directly. For a diurnal it is about one-half as great as for a semidiurnal. Hence the comparative smallness in the diurnal component of the velocity. On the other hand, the quarter and one-sixth diurnals become conspicuous in the velocity. Flood of the tide (or of any compenent) begins at the time of low water (or component low water) at the mouth. $\xi/\zeta = \frac{A}{h}(L-x)$, which is independent of the speed of the partial tide.

Example.—Alaskan canals; Gulf of Akabah; harbors abruptly terminated.

100. CASE 3.—*Tidal river or canal abruptly contracted or terminated.*

The motion is given, except for critical lengths, by the equations

$$\xi = \frac{A}{\cos lL} \sin [l(L-x)] \cos (at+\alpha), \tag{331}$$

$$\zeta = \frac{Alh}{\cos lL} \cos [l(L-x)] \cos (at+\alpha), \tag{332}$$

$$a^2 = ghl^2.$$

At the mouth, where $x = 0$,

$$\zeta = Alh \cos (at+\alpha) = A' \cos (at+\alpha);$$

at the head, where $x = L$,

$$\zeta = \frac{Alh}{\cos lL} \cos (at+\alpha) = A'' \cos (at+\alpha).$$

For the value of l, see last 3 columns of Table 50. Use value in last column for l in the numerator here.

Tidal phenomena.—The tide wave is stationary. High or low water within is simultaneous with high water at the mouth. The amplitude is greatest where the distance from the barrier multiplied by l, i. e., $l(L-x)$, is 0, π, 2π, ... It is zero where $l(L-x) = \frac{1}{2}\pi, \frac{3}{2}\pi, \frac{5}{2}\pi$, . . . The amplitude or height of the tide, or of any partial tide, is obtained by multiplying its value at the mouth by $\cos [l(L-x)]/\cos lL$, and so its variation from point to point depends upon the speed of the partial tide as well as upon the position of the point. Consequently the nodes travel some distance up and down the canal according to the length of tidal day.

The velocity of the water particles is $\dot{\xi} = -\frac{Aa}{\cos lL} \sin [l(L-x)] \sin (at+\alpha)$; that is, it depends upon the distance of the point considered from the head of the canal. The ratio of the amplitude of $\dot{\xi}$ to that of ζ at the point x is $\sqrt{\frac{g}{h}} \tan [l(L-x)]$, while to the amplitude of ζ at the mouth it is $\frac{a}{lh} \frac{\sin [l(L-x)]}{\cos lL}$. These ratios involve l and so a the speed of A. Flood begins at the time of high water or low water. At the mouth flood begins at the time of low water or high water according as lL falls in an odd or even quadrant.

Examples.—Gulf of Suez, Irish Sea, English Channel, Gulf of Georgia and Strait of Fuca, Gulf of Mexico and Caribbean Sea (diurnal tide).

101. CASE 4.—*Tidal river or canal abruptly contracted or terminated and of a critical length.*

According to § 34 the motion is given by the equations

$$\xi = k \frac{A}{\sin lL} \sin [l(L - x)] \cos (at + \alpha - 90^\circ) = kA \cos lx \cos (at + \alpha - 90^\circ), \quad (333)$$

$$\zeta = k \frac{Alh}{\sin lL} \cos [l(L - x)] \cos (at + \alpha - 90^\circ) = kAlh \sin lx \cos (at + \alpha - 90^\circ), \quad (334)$$

where $lL = 90^\circ$ or $L = \frac{1}{4}\lambda$; as usual,

$$a^2 = ghl^2.$$

Here k denotes the factor by which the horizontal displacement is increased because of the reënforcement made possible by the critical length. The outside water as it approaches the shore has a progressive tide whose motion is given by the equations

$$\xi = A \sin (at - lx + \alpha),$$

$$\zeta = Alh \cos (at - lx + \alpha).$$

Tidal phenomena.—The tide wave is stationary. High water in the canal is $\frac{1}{4}\tau$ later than high water outside. The amplitude of the tide within becomes great especially as the head of the canal is approached. This is, in a degree, true of those partial tides whose periods are nearly equal to the period for which the length of the canal becomes critical. Hence the amplitude ratios of the partial tides within approach the corresponding ratios outside, only as the speeds approach equality.

The velocity of the water particles is—

$$\dot{\xi} = -\frac{kAa}{\sin lL} \sin [l (L - x)] \sin(at + \alpha - 90^\circ).$$

This is greatest at the mouth, where $x = 0$. The ratio of the amplitude of $\dot{\xi}$ at any point to the amplitude of ζ at the head is $\frac{a}{lh} \sin [l(L - x)]$ or $\sqrt{\frac{g}{h}} \sin [l (L - x)]$.

Flood begins at the time of low water throughout the canal, i. e., $\frac{1}{4}\tau$ after low water at the mouth or just outside. Near the mouth of the canal the progressive part of the tide is unusually apparent because, by hypothesis, it there sustains the stationary oscillation.

Proceed similarly for cases when $L = \frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, etc.

Examples.—Gulf of Maine; Long Island Sound; Bahia Grande; Cook Inlet (?); China Sea (diurnal tide).

102. CASE 5.—*A strait connecting two independently tided bodies, the length of the strait being, say, 6 or more times the amplitude of the maximum horizontal displacement in it.*

According to § 35 the motion is given by the equations

$$\xi = -\frac{A_{,}}{\sin lL} \cos l (L - x) \cos (at + \alpha_{,}) + \frac{A_{,,}}{\sin lL} \cos lx \cos (at + \alpha_{,,}), \quad (335)$$

$$\zeta = \frac{A_{,} lh}{\sin lL} \sin l (L - x) \cos (at + \alpha_{,}) + \frac{A_{,,} lh}{\sin lL} \sin lx \cos (at + \alpha_{,,}). \quad (336)$$

$A_{,}$ refers to the end from which x is reckoned.

Tidal phenomena.—The time of high water at any point in the strait is given by the equation

$$\tan at' = -\frac{A_, \sin l(L-x)\sin\alpha_, + A_{,,}\sin lx \sin\alpha_{,,}}{A_, \sin l(L-x)\cos\alpha_, + A_{,,}\sin lx\cos\alpha_{,,}}. \qquad (337)$$

The times of high water just outside the ends are $-\alpha_,/a$ and $-\alpha_{,,}/a$. The rate of propagation is

$$\frac{l}{a}\frac{A_, A_{,,}\sin lL \sin(\alpha_, - \alpha_{,,})}{A_,^2\sin^2 l(L-x) + A^2_{,,}\sin^2 lx + 2A_, A_{,,}\sin l(L-x)\sin lx\cos(\alpha_, - \alpha_{,,})}. \qquad (338)$$

Since $0 < x < L$, the rate is either positive or negative throughout the strait according as $\alpha_, - \alpha_{,,}$ lies in the first or second semicircle. The wave is stationa y if $\alpha_, \sim \alpha_{,,} = 0$ or 180°. The amplitude of the tide is

$$\frac{lh}{\sin lL}\sqrt{[A_,^2\sin^2 l(L-x) + A^2_{,,}\sin^2 lx + 2A_,A_{,,}\sin l(L-x) \sin lx\cos(\alpha_, - \alpha_{,,})]}. \qquad (339)$$

The velocity of the water particles is $\dot{\xi}$. This becomes zero at the time t'' where

$$\tan at'' = \frac{-A_,\cos l(L-x)\sin\alpha_, + A_{,,}\cos lx\sin\alpha_{,,}}{A_,\cos l(L-x)\cos\alpha_, - A_{,,}\cos lx\cos\alpha_{,,}}. \qquad (340)$$

From $\ddot{\xi} = 0$ we obtain t''', the time of strength of flood or ebb; viz.,

$$\tan at''' = \frac{A_,\cos l(L-x)\cos\alpha_, - A_{,,}\cos lx\cos\alpha_{,,}}{A_,\cos l(L-x)\sin\alpha_, - A_{,,}\cos lx\sin\alpha_{,,}}. \qquad (341)$$

The amplitude of the horizontal displacement is

$$\frac{1}{\sin lL}\sqrt{\left[A^2_,\cos^2 l(L-x) + A^2_{,,}\cos^2 lx - 2A_,A_{,,}\cos l(L-x)\cos lx \cos(\alpha_, - \alpha_{,,})\right]}. \qquad (342)$$

Example.—Florida Strait (diurnal tide).

103. CASE 6.—*A strait leading from a tided body of water to one with practically no tide, the length of the strait being, say, six or more times the amplitude of the maximum horizontal displacement in it.*

The motion is given by the equations

$$\xi = -\frac{A_,}{\sin lL}\cos l(L-x)\cos(at + \alpha_,), \qquad (343)$$

$$\zeta = \frac{A_, lh}{\sin lL}\sin l(L-x)\cos(at+\alpha_,), \qquad (344)$$

which are obtained from the preceding case by making $A_{,,} = 0$.

Tidal phenomena.—High water throughout the strait (which is assumed to be less than $\frac{1}{4}\lambda$ in length) occurs at the time of high water outside. The amplitude or height of the tide, or of any partial tide, is obtained by multiplying its value at the mouth (where $x = 0$) by $\sin l(L-x)/\sin lL$, and so its variation from point to point depends upon the "speed" of the partial tide as well as upon the position of the point. But the amplitudes of all partial tides become zero at the inner end of the strait, where $x = L$.

The velocity of the water particles is $\dot{\xi} = \frac{A_{,}a}{\sin lL} \cos l(L-x) \sin (at + \alpha_{,})$. It is greatest where $x = L$. The ratio of the amplitude of the velocity to the amplitude of the tide at the same point is $\sqrt{\frac{g}{h}} \cot l(L-x)$ and to the amplitude of the tide at the mouth of the strait where $x = 0$ it is $\sqrt{\frac{g}{h}} \frac{\cos l(L-x)}{\sin lL}$.

$\left(\text{When } lL \text{ is a small angle, the last ratio becomes } \sqrt{\frac{g}{h}} \frac{1}{lL} \text{ or } \frac{g}{a} \frac{1}{L}\right)$. Flood begins at the time of high water outside.

Supposing the practically tideless sea to be deep enough to keep its surface almost level at each instant. The influx through the strait may, in case of a nearly inclosed sea, cause there a perceptible rise and fall, yet so small that its effect upon the motion of the water in the strait can be ignored. In this case high water inside is simultaneous with low water outside. In nature the wave is usually partly stationary and partly progressive. See Case 16.

Examples.—Strait of Gibraltar (§ 84, $\kappa = 0{\cdot}45$ for sea west of Sardinia); Strait of Messina (§ 85, $\kappa = 0{\cdot}07$ for Tyrrhenian Sea); Florida Strait; Bashi and Ballintang Channels [and the deeper part of the China Sea]; Korea Strait [and the Sea of Japan]. In many instances the values of κ are given, although of no use as criteria because of the extent and shallowness of the gulfs and seas.

104. CASE 7.—*A short strait of not exceedingly small cross section leading to an otherwise inclosed gulf or bay, the latter being deep enough to always have its surface practically a level plane; more accurately, a strait and gulf is such that*

$$\frac{\kappa}{A'^{\frac{1}{2}}} > 10. \tag{345}$$

Here

$$\kappa = \sqrt{(2g)} \frac{\varepsilon}{a} = 1{\cdot}277 \left(\frac{\text{cross section strait}}{\text{area of gulf}}\right) \left(\frac{\text{period of tide in seconds}}{\text{amplitude of tide outside}}\right),$$

$1{\cdot}277 = \sqrt{(2g)}/2\pi$. For M_2 the period is 44714 seconds.

The vertical motion is approximately given by the equation

$$\zeta = Alh \cos (at + \alpha), = A' \cos (at + \alpha) \tag{346}$$

which is the value of ζ outside. For the inner body α must generally be diminished somewhat, so that the tides may be a little later than the tide outside. The amplitude is supposed to suffer no considerable diminution. In the horizontal motion we have, for the integral displacement,

$$\xi = \frac{\zeta}{\varepsilon} \tag{347}$$

where ζ refers to the inner body, and

$$\varepsilon = \frac{\text{cross section of strait}}{\text{area of gulf}}.$$

Tidal phenomena.—This case is, in a certain sense, intermediate between Cases 2 and 8. The water inside keeps upon very nearly the same level as the water outside. The times of tide are delayed a little on account of the narrowness of the opening. For cases found in nature, the want of a sufficiently good reflection causes an imperfect progressive wave and so a delay in the time of the tides. See Case 15. Delay may also result, as in the next case, when $\kappa / A'^{\frac{1}{2}}$ falls much below 10. The partial tides and the ages of the various tidal inequalities have about the same values within and without.

The velocity of the water particles in the strait is $\dot{\xi} = -\frac{a\zeta}{\varepsilon}\tan\,(at+\alpha)$, and so $\dot{\xi}/\zeta = -\frac{a}{\varepsilon}\tan\,(at+\alpha)$. Consequently the ratios of the partial velocities to the corresponding partial tides are proportional to the speeds of the partial tides. For example, the diurnal inequality in the velocity is comparatively but one-half as great as in the tides, whereas the quarter diurnal velocity components would be comparatively twice as great as the quarter diurnal tidal component. Flood begins at the time of low water inside.

Examples.—A float box working properly; most land-locked harbors without long branches, as Havana, Cuba ($\kappa = 25$); Santiago de Cuba (diurnal tide, $\kappa = 18$); Burrard Inlet and Narrows, B. C. ($\kappa = 2{\cdot}7$); San Francisco Bay and the Golden Gate ($\kappa = 4{\cdot}6$); Skjerstadfiord and sound between Strömö and Godö, (Saltström or Saltens Malström); Great Bay and Piscataqua R., N. H., ($\kappa = 7{\cdot}5$).

105. CASE 8.—*A short strait of very small cross section leading to an otherwise inclosed gulf or bay, the latter being deep enough to always have its surface practically a level plane; more accurately, a strait and gulf such that*

$$\frac{\kappa}{A'^{\frac{1}{2}}_{,}} < \frac{1}{10}. \tag{348}$$

Here

$$\kappa = \sqrt{(2g)}\,\frac{\varepsilon}{a} = 1{\cdot}277\left(\frac{\text{cross section of strait}}{\text{area of gulf}}\right)\left(\frac{\text{period of tide in seconds}}{\text{amplitude of tide outside}}\right).$$

The horizontal motion in the strait is given by the equation

$$\text{Velocity} = \sqrt{(2g\zeta_{,})} = \sqrt{(2g)}\,\sqrt{[A'_{,}\cos\,(at+\alpha_{,})]}. \tag{349}$$

Or, if we wish to put partial tides in evidence,

$$\text{Velocity} = \sqrt{(2g)}\,\sqrt{[A'_{,}\cos\,(at+\alpha_{,}) + B'_{,}\cos\,(bt+\beta_{,}) + \quad . \quad . \quad . \quad]} \tag{350}$$

where $\zeta_{,}$ denotes the height of the tide outside; that is, Torricelli's theorem is assumed to apply and the rise and fall within is assumed to have no sensible effect upon the value of the velocity.

$$\therefore\ \xi = \sqrt{(gA'_{,})}\int\sqrt{[\cos\,(at+\alpha_{,})]}\,dt. \tag{351}$$

ξ in this case denotes the integral displacement past a point, but not the displacement of a particle.

For the vertical motion of the inner body we have

$$\zeta = \varepsilon\xi \text{ and } \dot{\zeta} = \varepsilon\dot{\xi}.$$

Although neither $\dot{\xi}$, ξ, nor ζ are simply harmonic, they are nearly so, and have as approximate amplitudes $\sqrt{(2gA'_{,})}$, $\frac{1}{a}\sqrt{(2gA'_{,})}$, and $\frac{\varepsilon}{a}\sqrt{(2gA'_{,})}$, respectively, (Cf. § 36, Part I).

Tidal phenomena.—Partial tides can not be independently considered, for we here have motion not truly oscillatory. High water in the gulf occurs $\frac{1}{4}\tau$ later than high water outside. The range inside is very small. For outside ranges having like values but different durations, the inside ranges are proportional to such durations. Such amplitude ratios as S_2/M_2, N_2/M_2, are, in the limit, but about $\frac{1}{2}$ as great in the gulf as outside. This is found by varying the outside amplitude, $A'_{,}$, under the radical sign. If the diurnal inequality outside be so small that the duration of rise or fall is not much affected thereby, then we may add to the above amplitude ratios the ratio $(K_1 + O_1)/M_2$. A similar statement is true of the velocity amplitude ratios such as $\dot{S}_2/\dot{M}_2$, $\dot{N}_2/\dot{M}_2$, and $(\dot{K}_1 + \dot{O}_1)/\dot{M}_2$. Flood in the strait begins nearly $\frac{1}{4}\tau$ after the time of low water outside. When the diurnal inequality is large then we must say that, in the limit, slack water occurs at the time when $A'_{,} \cos(m_2 t + \alpha_{,}) + B'_{,} \cos(d_1 t + \beta_{,}) = 0$, the second term referring to the diurnal wave. A tidal inequality, which can be represented by a single component outside, will inside require two components for its representation, as does the corresponding velocity inequality (See § 106). A second approximation to the velocity in the strait is $8{\cdot}02\sqrt{(\zeta_{,} \sim \zeta_{,,})}$. Slack occurs when both outer and inner bodies have the same level. In the preceding expression $A'_{,} \cos(m_2 t + \alpha_{,})$ and $B'_{,} \cos(d_1 t + \beta_{,})$ then refer to the difference between the outside and inside levels. See § 9 and Case 9.

Examples.—A float box with openings so small that the range within is nearly destroyed. See § 9. (For Fig. 7, κ or $\sqrt{(2g)}$. $\varepsilon/a = 1{\cdot}321$ and $0{\cdot}757$). New River and New River Inlet, N. C. ($\kappa = 0{\cdot}28$); Port Phillip and Entrance, S. Australia $\kappa = 1{\cdot}6$); Lake Pontchartrain and Rigolets Passes (tide diurnal, $\kappa = 0{\cdot}6$); see also Case 14.

[Torricelli's theorem can be applied to steady motion where it would fail had the motion a reasonably short period; e. g., it applies to the Gulf of Mexico and Florida Strait when the Gulf Stream is to be explained, but it does not help explain the tides in the strait. Coast Survey levels carried across upper Florida make the Gulf 0·8 foot above the ocean.]

106. CASE 9.—*A short strait of very small cross section connecting two independently tided bodies of water.*

The horizontal motion is given by Torricelli's theorem; that is

$$\begin{aligned} \text{Velocity} &= \sqrt{[2g\,(\zeta_{,} \sim \zeta_{,,})]} \\ &= \sqrt{(2g)}\,\sqrt{[A'_{,} \cos(at + \alpha_{,}) \sim A'_{,,} \cos(at + \alpha_{,,})]} \end{aligned} \qquad (352)$$

where, as usual, the subprimes indicate values taken outside or beyond the ends of the strait. Other terms must be written under the radical sign if we wish to put partial tides in evidence. The vertical motion is determined by the vertical motion at each end. The water's surface in the strait at any given instant is, for convenience, assumed to be a plane extending from the surface of one body to the surface of the other. That is, at a point distant x from the first end,

$$\zeta = \frac{\zeta_{,}(L-x)+\zeta_{,,}x}{L} = \frac{(L-x)A'_{,}\cos(at+\alpha_{,})+A'_{,,}\cos(at+\alpha_{,,})}{L}. \quad (353)$$

Tidal phenomena.—The heights in the strait will be a little uncertain on account of the assumption that its surface is a plane. If we regard the tides at the two ends as simply harmonic, and if they happen to differ in phase by $\frac{1}{2}\tau$, there will be no rise and fall at a point which divides the strait into parts proportional to the end amplitudes. In this case it would be high water in one end of the strait, at the time of low water in the other end. From the derivative of ζ, it is readily seen that the time of high water at a given point in the strait must be intermediate between the times of the high waters at the two ends. (See §4, Part III, or §9, Part I.)

From the expression for the velocity of the water particles, it is evident that partial or component velocities can not be independently considered. Such velocity ratios as $\dot{S}_2/\dot{M}_2$ and $\dot{N}_2/\dot{M}_2$ will be, in the limit, about $\frac{1}{2}$ as great as the corresponding tidal ratios for a wave made up of the difference of the end tide waves. If the tides are similar at both ends, these tidal ratios have the end values. The phase inequality in current velocity can not be represented by a single component $\dot{S}_2$ as can, very nearly, the phase inequality in the tides; but such a combination must be used as shall much diminish the inequality in amplitude but not in time. Let $\dot{\mu}_2$ denote the required additional component; let these be made to conspire at about the time of the octants and interfere at the time of spring and neap tides [c f. tide components N_2, L_2]. Since the inequalities in the times of slack water or of maximum velocities are the same as in the times of the tides, we must have

$$\dot{\mu}_2 = \tfrac{1}{3}\dot{S}_2, \ \arg\dot{\mu} = \arg\mu + 180°.$$

When the diurnal wave has to be taken into account, the time of slack water must be found by equating to zero the expression for the difference between the end heights of the water surface, the heights now including diurnal terms.

Examples.—East River, N. Y.; Sergius Narrows, Peril Strait, Alaska (Fig. 32); passages near northern end of Clarence Strait, Alaska (Fig. 33); Seymour Narrows, Discovery Passage, B. C.; Strait of Canso; Kyle Rhea.

107. CASE 10.—*A strait connecting two tided bodies of water, the strait being so large that near the strait the tides of neither body are practically independent of those of the other.*

First, imagine the tide wave to progress from each direction at rate due to depth, meeting, say, in the (virtual) middle of the strait.

Tidal phenomena.—The tide will be in general partly stationary and partly progressive through the strait, depending upon the relative values of the amplitudes and phases in the two bodies. If the waves have equal amplitudes and meet in like phases, the tide in the strait will be stationary and the range will be determined by rules for a stationary wave given under Cases 2 and 3, the length of the canal being one-half the length of the strait. If the waves of equal amplitude meet in opposite phases, the range at the middle of the strait may be destroyed. The wave in the strait will be stationary, having the center as its node.

In general, Case 10 is very difficult because, by hypothesis, the end conditions are not as simple as they are where Case 5 applies.

Example.—Strait of Dover.

108. CASE 11.—*Large strait; gulf reflective, i. e., has a sudden ending or change of cross section.*

Regard the ending or narrowing as the head of a canal and the outer end of the strait as the mouth.

Tidal phenomena.—Strait and gulf give rise to a stationary wave more or less perfect. The general character of the tide can be inferred from Cases 2 and 3; but in estimating the virtual length it must be remembered that it will sometimes exceed the mean geometrical length when about $\frac{1}{4}\lambda$ in length. If about $\frac{1}{2}\lambda$, it will be less than the extreme geometrical length of gulf and strait. (See §§ 54, 55, 91.)

The velocity of the water particles at any given point is

$$\left(\frac{\text{area of gulf above point}}{\text{cross section at point}}\right)\frac{d\bar{\zeta}}{dt}, \tag{354}$$

$\bar{\zeta}$ being the average instantaneous height of the tide of that portion of the gulf which lies above the given point. Flood begins at the time of average low water for this region, i. e., when $\bar{\zeta}$ is a minimum. For the length $\frac{1}{2}\lambda$ the velocity in the strait is zero.

Examples.—The Race and Long Island Sound ($\kappa = 6{\cdot}7$); Yucatan Channel and the Gulf of Mexico (diurnal tide, $\kappa = 16$); Bashi Channel and China Sea (diurnal tide, $\kappa = 10$); Strait of Fuca and Gulf of Georgia ($\kappa = 8$); St. Georges Channel and the Irish Sea; Cabot Strait and Gulf of St. Lawrence ($\kappa = 8$); Korean Strait and Japan Sea (diurnal tide, ($\kappa = 1{\cdot}3$); Mozambique Channel and Arabian Sea. (See Figs. 23, 24, 31, 32.)

109. CASE 12.—*Large Strait; gulf propagative, i. e., has no sudden ending or change in cross section.*

Tidal phenomena.—Strait and gulf are traversed by a progressive wave more or less perfect. (See Case 1.)

Examples.—Strait of Otranto and the Adriatic Sea ($\kappa = 12$); Strait of Ormuz and the Persian Gulf ($\kappa = 0.9$); Davis Strait and Baffin Bay; Minas Channel and Basin ($\kappa = 13$); Yellow Sea.

110. CASE 13.—*Large strait; gulf dissipative, i. e., does not resemble any simple channel or area.*

Tidal phenomena.—Strait and gulf give rise to a very imperfect progressive wave. In a measure, Case 1 applies; but the ratios of the amplitude of the partial tides do not remain constant as we proceed from point to point. The ages of the various inequalities do not all vary by the same amount as the wave proceeds. Similarly for the partial currents. The velocity of the water particles at a given point is

$$\left(\frac{\text{area of gulf above point}}{\text{cross section at point}}\right)\frac{d\bar{\zeta}}{dt}, \tag{355}$$

where $\bar{\zeta}$ denotes the average instantaneous height in that portion of the gulf situated above the given point.

Example.—Chesapeake Bay and entrance.

111. CASE 14.—*Small short strait leading to a gulf, bay, or river, the inner body not being deep enough to always have its surface practically a level plane.*

Tidal phenomena.—Strait and gulf give rise to a very imperfect progressive wave. In a measure Case 1 applies; but the ratios of the amplitudes of the partial tides do not remain constant as we proceed from point to point, for reasons given under Cases 3 and 8. The ages of the various inequalities do not all vary by the same amount as the wave proceeds. The amplitude of the tide in the gulf is often much reduced. The time of tide is generally considerably delayed beyond the delay of transmission at the rate due to depth. In fact, for an extreme case we should almost have Case 8, provided that only that portion of the inner body near the strait be regarded as the inner body; hence the delay in transmission. The excess of downhill over uphill flow is an index of the applicability of Torricelli's theorem.

The velocity of the water particles is small, excepting in the strait, where it may be considerable. Its value may be found as in Case 13.

Examples.—Galveston Harbor and entrance ($\kappa = 0{\cdot}6$); Pamlico Sound and entrance; Great South Bay, L. I., and Fire Island Inlet ($\kappa = 0{\cdot}87$); St. John River, New Brunswick; New River and New River Inlet ($\kappa = 0{\cdot}28$).

112. It is instructive to consider the simplest cases where the tide consists of both a progressive and stationary wave without assuming the predominance of either, for the tides in many natural bodies of water can then be explained in a satisfactory manner. Two cases will be noted here, one where the stationary portion of the wave is due to a reflection, as in Cases 2 and 3, the other where there is a strait leading from the sea to a body having no tide of its own. (See Case 6.)

CASE 15.—*A channel or body which transmits a portion of the wave and reflects a portion.*

The motion is given by the equations

$$\xi_p = A_p \sin\,(at - lx + \alpha_p), \tag{356}$$

$$\zeta_p = A_p lh \cos\,(at - lx + \alpha_p), \tag{357}$$

$$\xi_s = \frac{A_s}{\cos lL} \sin\,[l(L - x)] \cos\,(at + \alpha_s), \tag{358}$$

$$\zeta_s = \frac{A_s lh}{\cos lL} \cos\,[l(L - x)] \cos\,(at + \alpha_s), \tag{359}$$

$$a^2 = ghl^2.$$

For critical lengths, replace (358), (359) by (333), (334) and supply the subscript s. The entire displacements are

$$\xi = \xi_p + \xi_s, \qquad \zeta = \zeta_p + \zeta_s.$$

The subscripts p and s refer to the progressive and stationary portions respectively. For the progressive motion the particles move in elliptical orbits (§ 19, Part I); for the stationary motion they evidently move in rectilinear paths (§ 32, Part I). But if we here eliminate the time angle between the expressions for ξ and ζ we see that the resulting equation involving ξ and ζ represents an ellipse.

Tidal phenomena.—Near the node of the stationary wave (if it have one), the time of the tide is chiefly determined by the progressive part of the wave. Suppose in the first place the length of the channel or body to be less than $\frac{1}{4}\lambda$. Then judging by the stationary wave it should be high water throughout the channel or body at the time of high water outside; judging by the progressive wave the tide in the channel or body should be later than the tide outside by the interval required for a free wave to pass to the point in question. The real time of tide lies between that given by these two suppositions.

The flood velocity in the progressive wave has its maximum value at the time of local high water. The flood velocity in the stationary wave has its maximum value 3 hours before the time of outside high water. The real time of maximum flood at any given point lies between these two times. (For a body $\frac{1}{4}\lambda$ long, see Case 4.) As the shore is approached, the progressive wave which set out from the edge of the deep water is continually meeting with partially reflecting obstructions. Their effect can be seen by imagining the sloping bottom to consist of a series of steps. The whole wave as it leaves deep water is partly progressive and partly stationary, the stationary part being due to the general reflecting effect of the shoaling and shore. Now, as already stated, a good reflector must turn back the wave at nearly one locality; whereas the bottom may be regarded as a series of steps partially turning the wave back at each reflecting surface. Hence there will generally be a progressive wave. Now the shore line may be supposed to form the last of these hypothetical steps. The water adjacent to the shore, provided there are no inlets or great irregularities, constitutes a dependent wave almost entirely stationary, because, so far as this region is concerned, the returning reflected wave from any part of this strip can differ but little in phase from the returning wave from any other part. Hence the flood current near the shore turns very soon after the time of local high water. (Cf. Lamb, Hydrodynamics, §§ 173, 181.) In so far as the stationary character of the wave is developed, the ratios of the amplitudes of the diurnal constituents of the current to those of the semidiurnal will approach one-half the corresponding tidal ratio, while the amplitudes of the quarter and sixth diurnal current constituents will be unduly augmented. See Case 2.

Examples.—For bodies of considerable length may be mentioned Long Island Sound, the Gulf of Maine. For short bodies, imaginary canals leading shoreward from deep water along nearly all coasts and many harbors; in Boston Harbor the wave is nearly all stationary; in New York Lower Bay the wave is part progressive and part stationary. See Current Tables in United States Coast Survey Tide Tables.

113. CASE 16.—*A strait leading from a tided body or ocean to a large and nearly tideless body.*

The motion is given by the equations

$$\xi_p = A_p \sin\,(at - lx + \alpha_p), \tag{360}$$

$$\zeta_p = A_p lh \cos\,(at - lx + \alpha_p), \tag{361}$$

$$\xi_s = -\frac{A_s}{\sin lL} \cos l\,(L - x) \cos\,(at + \alpha_s), \tag{362}$$

$$\zeta_s = \frac{A_s lh}{\sin lh} \sin l\,(L - x) \cos\,(at + \alpha_s), \tag{363}$$

$$a^2 = ghl^2.$$

The entire displacements are

$$\xi = \xi_p + \xi_s, \quad \zeta = \zeta_p + \zeta_s.$$

The subscripts p and s refer to the progressive and stationary portions respectively. For the progressive motion the particles move in elliptical orbits (§ 19, Part I); for the stationary motion they evidently move in rectilinear paths (§ 35, Part IV A). But if we here eliminate the time angle between the expressions for ξ and ζ, we see that the resulting equation involving ξ and ζ represents an ellipse.

Tidal phenomena.—Suppose the inner body to be so large that the stationary portion of the tide in the strait causes no tide in the inner body sufficiently large to influence the stationary wave in the strait. Then towards the inner end of the strait the time of high water will be governed by the progressive part of the tide wave, moving inward from the outer body at the rate due to depth. For the progressive part, the strength of flood occurs at the time of local high water of this part. Throughout the strait the flood for the stationary part begins at the time of high water outside. In straits less than $\frac{1}{4}\lambda$ in length the strength of flood for the entire tide should occur between 0 and 3 hours after high water outside. Consequently for a large and sufficiently deep inner body it should be on the whole high water from 3 to 6 hours after it is high water outside. If the end of the inner sea near the strait be shallow, the tide there is generally about 3 hours later than the tide outside unless the strait is very large. (Cf. Cases 6 and 14.)

Examples.—Korean Strait and the Sea of Japan ($\kappa = 0{\cdot}6$); Strait Bab-el-Mandeb and the Red Sea ($\kappa = 0{\cdot}31$); Florida Strait and Gulf of Mexico ($\kappa = 1{\cdot}6$); Strait of Magellan and inner waters beyond Second Narrows; North Channel and Atlantic Ocean.

The tides in a land-locked harbor or other small body of water, even if the strait leading to it be quite small, are explained by Case 7. It may be here noted that a long-period wave can better reach all harbors with very contracted openings than can a wave of short period. In such a case O_1/K_1 might have approximately its outside value while S_2/M_2 would be much diminished. Port Phillip is an example of this. In a body having a still smaller opening we have Case 8.

114. *Origin of swift tidal currents or races.*

Tidal currents become noticeable and important in localities where their velocity is unusually great. The causes of the swiftness are various and not always apparent. They may be supposed to be divided into two classes, although both are generally interdependent. In the first class we lose sight of the wave or oscillation as a whole and consider merely what local configuration of the shore ought to augment the velocity. So far as the cause is thus regarded, the rules of steady motion apply, and this class will therefore be referred to under that title. In the other class the oscillation is taken into consideration, and the proximity to nodal lines or whether the point considered lie on a shoal or in a strait will generally be an important item in ascertaining comparative velocities.

Steady motion.—This is most nearly realized at the time of maximum velocity. The following cases may be noted

(1) Flow around sharp points or capes caused by the requirements of two-dimensional motion. E. g., off Cape de la Hague; off southeastern Patagonia.

(2) Partial separation of two bodies of water by walls of land or by shoals causing a difference in head so that Torricelli's theorem may, in a measure, be applied. In this

way overfalls may be produced. E. g., East River, New York; Sergius Narrows, Alaska; Seymour Narrows, British Columbia; entrance to Port Phillip, South Australia.

(3) At the outer or concave side of a bend the velocity is increased because of the water's inertia. This effect is best seen in streams which usually flow in but one direction. E. g., the Mississippi River.

Oscillatory motion.—Chapters III–V show how the nodal lines may be ascertained in several forms of areas; they also show how at some contracted or shallow parts of certain areas the velocity is much increased, and the present chapter has treated of closed canals and straits. The following cases of increased velocity may be noted:

(1) The proximity to a nodal line of a canal-like area. E. g., near Tor; Race Rocks, Strait Juan de Fuca.

(2) A shoaling over which a wave is propagated.

(3) In a strait the velocity may be considerable. E. g., Magellan Strait; Golden Gate; Strait of Gibraltar; Strait of Messina; Pentland Firth. All but the last have already been referred to in this chapter. The strong tidal streams in this firth are partly explained by the velocity due to wave motion, viz. $\zeta\sqrt{\frac{g}{h}}$, multiplied by a factor due to the contraction experienced by the wave in passing between Scotland and the Orkneys, and partly by Case 9.

115. *Origin of countercurrents and eddies.*

Discontinuity in the motion of a perfect liquid implies that the latter is endowed with the property of inertia; also that rather sudden changes in the depth or in shore line occur. On one side of a line of discontinuity will be found the main stream; on the other, a mass of water either nearly motionless or circulating round and round, its motion being derived from its relation to, and contact with, the main stream. A double effect is produced by an island or other surrounded object, as a pier. When observed from or near the shore and when existing on a comparatively large scale, the phenomenon is spoken of as a countercurrent; whenever the circulation is tolerably complete and can be readily seen from one point the phenomenon is spoken of as an eddy or whirlpool. The greater the motion of the main stream becomes the greater, as a rule, will be the chance of finding eddies and countercurrents. Hence, in tidal streams flood or ebb may have to run for some time in order to acquire a sufficient velocity and disturbance of level to cause them. Along the shores of some sounds and tidal rivers, the currents turn earlier than in the channel because the backward accelerating force proportional to the instantaneous slope of the surface is there sooner effective. The following classes (generally involving, or modified by, fluid friction or viscosity) may be noted:

(1) Countercurrents or dead water occurring in shallows which border the channel. E. g., edges of Strait of Gibraltar; shallow bights along creeks and rivers.

(2) Countercurrent or eddy occurring along the inner side of a bend in a stream, provided the stream there widens. The outer side, where the main current runs, is by § 12 higher than the inner, the greatest difference of level being at the upstream end of the widening. But the inertia of the water prevents the lateral pressure gradient, i. e., change in pressure on a slender vertical prism in going transverse to the stream, at the upstream end from there setting up the transverse velocity seen further downstream; hence the countercurrent. See equation (92).

(3) Countercurrent due to a projecting cape. They are usually much more conspicuous on the downstream side. E. g., near Cape Peloro and Point Pezzo, Messina Strait (Fig. 39).

(4) Eddy found in a rocky bight. The water may or may not be deep. E. g., almost any rock-bound brook or creek, as the upper Potomac.

(5) Eddies formed just below projecting rocky capes or headlands. They often move to a considerable distance if existing on a small scale in open water. E. g., eddies seen near stone bridge piers; the East River, New York; among the Lofoten Islands; off Scylla; south of Seavys Island, Portsmouth Harbor; off Stroma and Swona Islands, Pentland Firth.

(6) Eddy formed in an inclosed pool whose inlet and outlet are near together and flow in quite different directions; the incoming water having inertia is thereby prevented from an immediate exit. The outward flow is greatest at some considerable depth because the incoming stream is supposed to be very swift at the surface. E. g., the whirlpool below Niagara Falls.*

(7) Eddy formed in a pool at the foot of a waterfall caused by the depression of the surface of the upstream edge of the pool.

It is obvious that in the same locality the effects of flood and ebb in the production of eddies may be quite different. This is well exemplified in the Strait of Messina and Pentland Firth. Again, since eddies in some localities may come into existence only when the velocity of the main tidal stream exceeds a certain limit, the character of the observed motion may there be quite different at the time of spring tides from what it is at the time of neap tides.

For a discussion of countercurrents which accompany ocean drift, or wind currents, the reader is referred to Krümmel, Handbuch der Ozeanographie, Vol. II, pp. 352 et seq.

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*See a paper by G. K. Gilbert, entitled "Niagara Falls and their history," and the references appended thereto. This paper constitutes one of a set of monographs of the National Geographic Society upon the Physiography of the United States.

AUXILIARY TABLES

FOR THE

REDUCTION AND PREDICTION OF TIDES.

[Tables 1 to 50 are appended to Part III, Appendix No. 7, Report for 1894, and to Part II, Appendix No. 8, Report for 1897.]

TABLE 51.—*Velocity and length of tide wave.*

Depth.	Velocity of propagation.						Wave length.					
	Per lunar hour.			Per solar hour.			Lunar.			Solar.		
Fath.	*Degs.*	*Sea miles.*	*Stat. miles.*	*Degs.*	*Sea miles.*	*Stat. miles.*	*Degs.*	*Sea miles.*	*Stat. miles.*	*Degs.*	*Sea miles.*	*Stat. miles.*
25	0.7096	42.57	49.02	0.6855	41.13	47.36	8.515	510.9	588.3	8.226	493.6	568.4
50	1.0035	60.21	69.33	.9695	58.17	66.99	12.042	722.5	832.0	11.634	698.1	803.8
100	1.4191	85.15	98.05	1.3711	82.26	94.73	17.030	1 021.8	1 176.6	16.453	987.2	1 136.8
200	2.0070	120.42	138.66	1.9390	116.34	133.97	24.084	1 445.0	1 664.0	23.268	1 396.1	1 607.6
500	3.1733	190.40	219.24	3.0658	183.95	211.82	38.079	2 284.8	2 630.9	36.790	2 207.4	2 541.8
1 000	4.4877	269.26	310.06	4.3358	260.15	299.56	53.853	3 231.2	3 720.7	52.029	3 121.8	3 594.7
1 500	5.4963	329.78	379.74	5.3102	318.61	366.88	65.955	3 957.3	4 556.9	63.722	3 823.3	4 402.6
2 000	6.3467	380.80	438.49	6.1317	367.90	423.64	76.160	4 569.6	5 261.9	73.580	4 414.8	5 083.7
2 100	6.5033	390.20	449.32	6.2831	376.99	434.10	78.040	4 682.4	5 391.8	75.397	4 523.8	5 209.3
2 200	6.6563	399.38	459.89	6.4309	385.86	444.32	79.876	4 792.6	5 518.7	77.171	4 630.3	5 331.8
2 300	6.8059	408.36	470.23	6.5754	394.53	454.30	81.671	4 900.3	5 642.7	78.905	4 734.3	5 451.6
2 400	6.9523	417.14	480.34	6.7169	403.01	464.08	83.428	5 005.7	5 764.1	80.603	4 836.2	5 568.9
2 500	7.0957	425.74	490.25	6.8554	411.32	473.64	85.148	5 108.9	5 883.0	82.265	4 935.9	5 683.7
2 600	7.2362	434.17	499.96	6.9912	419.47	483.03	86.834	5 210.1	5 999.5	83.894	5 033.6	5 796.3
2 700	7.3740	442.44	509.48	7.1243	427.46	492.23	88.488	5 309.3	6 113.8	85.492	5 129.5	5 906.7
2 800	7.5094	450.56	518.83	7.2551	435.31	501.26	90.113	5 406.8	6 226.0	87.061	5 223.7	6 015.1
2 900	7.6423	458.54	528.01	7.3835	443.01	510.13	91.708	5 502.5	6 336.1	88.602	5 316.1	6 121.6
3 000	7.7729	466.38	537.04	7.5097	450.58	518.85	93.275	5 596.5	6 444.5	90.117	5 407.0	6 226.2
3 100	7.9014	474.09	545.92	7.6339	458.03	527.43	94.817	5 689.0	6 551.0	91.607	5 496.4	6 329.2
3 200	8.0278	481.67	554.65	7.7560	465.36	535.87	96.334	5 780.0	6 655.8	93.072	5 584.3	6 430.4
3 300	8.1523	489.14	563.25	7.8762	472.57	544.18	97.828	5 869.7	6 759.0	94.515	5 670.9	6 530.1
3 400	8.2750	496.50	571.72	7.9947	479.68	552.36	99.299	5 958.0	6 860.7	95.937	5 756.2	6 628.4
3 500	8.3957	503.74	580.07	8.1114	486.69	560.43	100.749	6 044.9	6 960.8	97.337	5 840.2	6 725.1
Feet.												
100	0.5794	34.76	40.03	0.5598	33.58	38.67	6.952	417.1	480.3	6.717	403.0	464.1
500	1.2955	77.73	89.51	1.2516	75.10	86.48	15.546	932.8	1 074.1	15.019	901.2	1 037.7
1 000	1.8321	109.93	126.58	1.7701	106.20	122.30	21.985	1 319.1	1 519.0	21.241	1 274.4	1 467.6
2 000	2.5910	155.46	179.01	2.5032	150.19	172.95	31.091	1 865.5	2 148.1	30.038	1 082.3	2 075.4
3 000	3.1733	190.40	219.24	3.0658	183.95	211.82	38.080	2 284.8	2 630.9	36.790	2 207.4	2 541.8
4 000	3.6642	219.86	253.16	3.5401	212.41	244.59	43.971	2 638.3	3 038.0	42.482	2 548.9	2 935.1
5 000	4.0968	245.80	283.05	3.9580	237.48	273.46	49.161	2 949.7	3 396.6	47.496	2 849.8	3 281.5
6 000	4.4878	269.27	310.06	4.3358	260.15	299.56	53.853	3 231.2	3 720.7	52.029	3 121.8	3 594.8
7 000	4.8473	290.84	334.90	4.6831	280.99	323.56	58.168	3 490.1	4 018.3	56.198	3 371.9	3 882.7
8 000	5.1820	310.92	358.03	5.0065	300.39	345.90	62.184	3 731.0	4 296.3	60.078	3 604.7	4 150.8
9 000	5.4963	329.78	379.74	5.3102	318.61	366.88	65.955	3 957.3	4 556.9	63.722	3 823.3	4 402.6
10 000	5.7936	347.62	400.29	5.5974	335.84	386.73	69.524	4 171.4	4 803.4	67.169	4 030.1	4 640.8
11 000	6.0764	364.58	419.82	5.8706	352.24	405.61	72.917	4 375.0	5 037.9	70.448	4 226.9	4 867.3
12 000	6.3466	380.80	438.49	6.1317	367.90	423.64	76.159	4 569.6	5 261.9	73.580	4 414.8	5 083.7
13 000	6.6058	396.34	456.40	6.3821	382.92	440.94	79.269	4 756.1	5 476.8	76.585	4 595.1	5 291.3
14 000	6.8551	411.31	473 62	6.6230	397.38	457.59	82.261	4 935.7	5 683.5	79.476	4 768.5	5 491.0
15 000	7.0957	425.74	490.25	6.8554	411.32	473.64	85.148	5 108.9	5 883.0	82.265	4 935.9	5 683.7
16 000	7.3284	439.70	506.32	7.0802	424.81	489.18	87.941	5 276.4	6 075.9	84.963	5 097.8	5 870.2
17 000	7.5540	453.24	521.91	7.2982	437.89	504.23	90.647	5 438.8	6 262.9	87.578	5 254.7	6 050.8
18 000	7.7729	466.38	537.04	7.5097	450.58	518.85	93.275	5 596.5	6 444.5	90.116	5 407.0	6 226.2
19 000	7.9859	479.16	551.75	7.7155	462.93	533.07	95.831	5 749.9	6 621.0	92.586	5 555.2	6 396.8
20 000	8.1934	491.60	566.09	7.9159	474.96	546.92	98.320	5 899.2	6 793.0	94.991	5 699.5	6 563.0

TABLE 52.—*Periodic time of oscillations in relatively deep water.*

h	½ λ, in inches.										Great length.
	2	4	6	8	10	12	15	20	25	30	
Inches.											
0·1	·6465	1·2889	1·9323	2·5758	3.2196	3·8633	4·8289	6·4383	8·0478	9·6573	·16095λ
0·2	·4626	·9142	1·3682	1·8228	2·2777	2·7327	3·4153	4·5532	5·6911	6·8291	·11381λ
0·3	·3851	·7503	1·1197	1·4903	1·8613	2·2325	2·7896	3·7184	4·6474	5·5765	·09293λ
0·4	·3419	·6542	·9732	1·2929	1·6138	1·9349	2·4171	3·2212	4·0255	4·8300	·08048λ
0·5	·3151	·5903	·8731	1·1588	1·4455	1·7324	2·1633	2·8822	3·6014	4·3208	·07198λ
0·6	·2973	·5445	·8012	1·0610	1·3218	1·5835	1·9764	2·6322	3·2885	3·9451	·06571λ
0·7	·2851	·5101	·7460	·9855	1·2264	1·4682	1·8316	2·4383	3·0456	3·6533	·06083λ
0·8	·2768	·4835	·7024	·9252	1·1498	1·3756	1·7150	2·2822	2·8500	3·4183	·05691λ
0·9	·2707	·4625	·6669	·8759	1·0872	1·2995	1·6189	2·1532	2·6883	3·2238	·05365λ
1·0	·2665	·4455	·6375	·8349	1·0344	1·2352	1·5383	2·0443	2·5516	3·0594	·05090λ
1·1	·2632	·4318	·6130	·7997	·9896	1·1807	1·4685	1·9506	2·4336	2·9182	·04853λ
1·2	·2611	·4205	·5922	·7701	·9507	1·1331	1·4082	1·8695	2·3320	2·7951	·04646λ
1·3	·2594	·4111	·5744	·7441	·9171	1·0916	1·3556	1·7979	2·2419	2·6867	·04464λ
1·4	·2581	·4034	·5590	·7214	·8873	1·0551	1·3086	1·7344	2·1619	2·5902	·04302λ
1·5	·2575	·3968	·5457	·7014	·8610	1·0225	1·2669	1·6776	2·0899	2·5037	·04156λ
1·6	·2569	·3913	·5341	·6839	·8374	·9930	1·2293	1·6264	2·0252	2·4254	·04024λ
1·7	·2563	·3868	·5239	·6681	·8163	·9669	1·1954	1·5799	1·9666	2·3541	·03904λ
1·8	·2560	·3828	·5150	·6541	·7973	·9431	1·1644	1·5375	1·9128	2·2894	·03794λ
1·9	·2557	·3796	·5071	·6415	·7801	·9215	1·1364	1·4985	1·8636	2·2298	·03692λ
2·0	·2556	·3768	·5002	·6302	·7646	·9016	1·1106	1·4629	1·8180	2·1752	·03599λ
2·1	·2555	·3744	·4940	·6200	·7503	·8836	1·0868	1·4299	1·7763	2·1242	·03512λ
2·2	·2554	·3724	·4886	·6107	·7373	·8669	1·0647	1·3994	1·7373	2·0768	·03432λ
2·3	·2553	·3707	·4836	·6023	·7255	·8517	1·0444	1·3709	1·7011	2·0328	·03356λ
2·4	·2553	·3692	·4793	·5947	·7146	·8376	1·0256	1·3446	1·6674	1·9919	.03285λ
2·5	·2553	·3680	·4755	·5878	·7045	·8244	1·0080	1·3200	1·6356	1·9531	·03219λ
2·6	·2552	·3670	·4720	·5814	·6953	·8123	·9918	1·2970	1·6057	1·9174	·03157λ
2·7	·2552	·3661	·4689	·5756	·6868	·8011	·9765	1·2752	1·5777	1·8830	·03098λ
2·8	·2552	·3652	·4661	·5704	·6789	·7906	·9623	1·2549	1·5516	1·8510	·03042λ
2·9	·2552	·3646	·4637	·5656	·6716	·7809	·9489	1·2356	1·5268	1·8206	·02989λ
3·0	·2552	·3641	·4615	·5612	·6649	·7718	·9364	1·2176	1·5033	1·7917	·02938λ
3·1	·2552	·3636	·4595	·5571	·6586	·7633	·9245	1·2005	1·4812	1·7646	·02891λ
3·2	·2552	·3631	·4577	·5534	·6528	·7554	·9135	1·1842	1·4601	1·7385	·02845λ
3·3	·2552	·3629	·4561	·5501	·6474	·7479	·9031	1·1690	1·4400	1·7140	·02802λ
3·4	·2552	·3626	·4546	·5469	·6424	·7410	·8932	1·1544	1·4210	1·6905	·02760λ
3·5	·2552	·3623	·4534	·5441	·6378	·7345	·8839	1·1407	1·4030	1·6682	·02721λ
3·6	·2552	·3621	·4522	·5414	·6334	·7284	·8752	1·1276	1·3857	1·6469	·02683λ
3·7	·2552	·3619	·4512	·5390	·6294	·7226	·8669	1·1150	1·3691	1·6265	·02646λ
3·8	·2552	·3618	·4502	·5368	·6255	·7172	·8590	1·1033	1·3535	1·6071	·02612λ
3·9	·2552	·3616	·4494	·5347	·6220	·7121	·8516	1·0920	1·3385	1·5885	·02577λ
4·0	·2552	·3615	·4487	·5328	·6187	·7073	·8445	1·0813	1·3240	1·5705	·02545λ
Great depth	·2552	·3609	·4420	·5103	·5706	·6250	·6988	·8069	·9021	·9882	

The time is expressed in seconds.

General formula $\tau^2 = \frac{2\pi\lambda}{g} \Big/ \tanh\frac{2\pi h}{\lambda}$. $\tau = \frac{\lambda}{gh}\left[1 + \frac{1}{6}\left(\frac{2\pi h}{\lambda}\right)^2 - \frac{1}{40}\left(\frac{2\pi h}{\lambda}\right)^4 + \ . \ . \ . \right]$.

g is taken at 386·0664 inches (32·1722 feet); $\sqrt{g} = 19{\cdot}6473$.

For lengths great in comparison with the depth, use last column, or $\tau = \lambda \div \sqrt{gh}$.

For lengths small in comparison with the depth, use last line, or $\tau = (2\pi)^{\frac{1}{2}}\sqrt{\frac{\lambda}{g}}$.

See Tables 47–50.

TABLE 53.—*For converting solar into lunar time.*

Solar hours.	Lunar hours.	Solar minutes.	Lunar hours.	Solar minutes.	Lunar hours.	Solar minutes.	Lunar hours.	Solar hours.	Lunar hours.
0	0·000	0	0·000	20	0·322	40	0·644	0·00	0·000
1	0·966	1	0·016	21	0·338	41	0·660	0·01	0·010
2	1·932	2	0·032	22	0·354	42	0·676	0·02	0·019
3	2·898	3	0·048	23	0·370	43	0·692	0·03	0·029
4	3·865	4	0·064	24	0·386	44	0·709	0·04	0·039
5	4·831	5	0·081	25	0·403	45	0·725	0·05	0·048
6	5·797	6	0·097	26	0·419	46	0·741	0·06	0·058
7	6·763	7	0·113	27	0·435	47	0·757	0·07	0·068
8	7·729	8	0·129	28	0·451	48	0·773	0·08	0·077
9	8·695	9	0·145	29	0·467	49	0·789	0·09	0·087
10	9·661	10	0·161	30	0·483	50	0·805	0·10	0·097
11	10·628	11	0·177	31	0·499	51	0·821		
12	11·594	12	0·193	32	0·515	52	0·837	0·0	0·000
13	12·560	13	0·209	33	0·531	53	0·853	0·1	0·097
14	13·526	14	0·225	34	0·547	54	0·870	0·2	0·193
15	14·492	15	0·242	35	0·564	55	0·886	0·3	0·290
16	15·458	16	0·258	36	0·580	56	0·902	0·4	0·386
17	16·424	17	0·274	37	0·596	57	0·918	0·5	0·483
18	17·390	18	0·290	38	0·612	58	0·934	0·6	0·580
19	18·357	19	0·306	39	0·628	59	0·950	0·7	0·676
20	19·323					60	0·966	0·8	0·773
21	20·289							0·9	0·870
22	21·255							1·0	0·966
23	22·221								
24	23·187								
25	24·153								

TABLE 54.—*For converting lunar into solar time.*

Lunar hours.	Solar hours and minutes.	Solar hours and decimals.	Lunar hours.	Solar minutes.	Lunar hours.	Solar minutes.	Lunar hours.	Solar minutes.	Lunar hours.	Solar minutes.
0	0 00·0	0·000	0·00	0·00	0·25	15·53	0·50	31·05	0·75	46·58
1	1 02·1	1·035	0·01	0·62	0·26	16·15	0·51	31·67	0·76	47·20
2	2 04·2	2·070	0·02	1·24	0·27	16·77	0·52	32·29	0·77	47·82
3	3 06·3	3·105	0·03	1·86	0·28	17·39	0·53	32·91	0·78	48·44
4	4 08·4	4·140	0·04	2·48	0·29	18·01	0·54	33·53	0·79	49·06
5	5 10·5	5·175	0·05	3·10	0·30	18·63	0·55	34·16	0·80	49·68
6	6 12·6	6·210	0·06	3·73	0·31	19·25	0·56	34·78	0·81	50·30
7	7 14·7	7·245	0·07	4·35	0·32	19·87	0·57	35·40	0·82	50·92
8	8 16·8	8·280	0·08	4·97	0·33	20·49	0·58	36·02	0·83	51·54
9	9 18·9	9·315	0·09	5·59	0·34	21·11	0·59	36·64	0·84	52·16
10	10 21·0	10·350	0·10	6·21	0·35	21·74	0·60	37·26	0·85	52·79
11	11 23·1	11·386	0·11	6·83	0·36	22·36	0·61	37·88	0·86	53·41
12	12 25·2	12·421	0·12	7·45	0·37	22·98	0·62	38·50	0·87	54·03
13	13 27·3	13·456	0·13	8·07	0·38	23·60	0·63	39·12	0·88	54·65
14	14 29·4	14·491	0·14	8·69	0·39	24·22	0·64	39·74	0·89	55·27
15	15 31·5	15·526	0·15	9·32	0·40	24·84	0·65	40·37	0·90	55·89
16	16 33·6	16·561	0·16	9·94	0·41	25·46	0·66	40·99	0·91	56·51
17	17 35·7	17·596	0·17	10·56	0·42	26·08	0·67	41·61	0·92	57·13
18	18 37·9	18·631	0·18	11·18	0·43	26·70	0·68	42·23	0·93	57·75
19	19 40·0	19·666	0·19	11·80	0·44	27·32	0·69	42·85	0·94	58·37
20	20 42·1	20·701	0·20	12·42	0·45	27·94	0·70	43·47	0·95	59·00
21	21 44·2	21·736	0·21	13·04	0·46	28·57	0·71	44·09	0·96	59·62
22	22 46·3	22·771	0·22	13·66	0·47	29·19	0·72	44·71	0·97	60·24
23	23 48·4	23·806	0·23	14·28	0·48	29·81	0·73	45·33	0·98	60·86
24	24 50·5	24·841	0·24	14·90	0·49	30·43	0·74	45·95	0·99	61·48
25	25 52·6	25·876							1·00	62·10

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APPENDIX No. 8.

REPORT 1900.

THE DETERMINATION OF THE MEAN VALUE OF A MICROMETER SCREW.

By EDWIN SMITH, Assistant, Coast and Geodetic Survey.

APPENDIX No. 8. 1900.

THE DETERMINATION OF THE MEAN VALUE OF ONE REVOLUTION OF A MICROMETER SCREW AND THE PROGRESSIVE AND PERIODIC ERRORS OF THE SCREW, FROM OBSERVATIONS ON A CIRCUMPOLAR STAR NEAR ITS ELONGATION.

By Edwin Smith, *Assistant, Coast and Geodetic Survey.*

The zenith telescope of the International Geodetic Association latitude service, used by the writer at Gaithersburg, Md., 1899–1900, is described in the "Anleitung zum Gebrauche des Zenitteleskops auf den Internationalen Breitenstationen, von Th. Albrecht," and also in Appendix No. 5, Coast and Geodetic Survey Report 1900.

The working part of the micrometer screw is limited to 30 revolutions, but the screw can be used between -2 and $+32$ revolutions. When the instrument is set telescope west, a star at western elongation will move over the field in the direction of increasing readings of the screw and at eastern elongation in the direction of decreasing readings of the screw, and vice versa for telescope east. For telescope west, pointing north, the level scales increase toward eye end, and vice versa for telescope east.

The observations to determine the mean value of one revolution of the micrometer screw, and its errors, were made on δ Urs. Min., 51 Cephei, α Urs. Min., and λ Urs. Min., near their elongations. The instrument was set so that the star at elongation would transit over the micrometer thread set at the middle reading, or 15 revolutions, as nearly as practicable. This was accomplished by computing from the approximately known value of one revolution, the time it would take the star to move over 17 revolutions, and with the thread set at -2 or $+32$ revolutions the star was bisected at the time of 17 revolutions before elongation. There was then time to set and clamp the levels before the star would reach the thread set at 0 or 30 revolutions. On α Urs. Min. and λ Urs. Min. transits of the star over the thread set at $0^R.0$, $0^R.2$, $0^R.4$, $0^R.6$, $0^R.8$, $1^R.0$, to 30^R or in reverse order, were observed. The levels were read at the beginning of each revolution.

The times of transit were corrected for changes of level, as follows:

$$\text{Correction} = l = \pm\left\{\frac{n_0+s_0}{2}-\frac{n+s}{2}\right\}\frac{d}{15\cos\delta}\left.\frac{W}{E}\right\}\text{Elong. Tel. W.}\left.\frac{E}{W}\right\}\text{ Elong. Tel. E.}$$

where n and s are the readings of the north and south ends of the level bubble, $\frac{n_0+s_0}{2}$ a selected state of the level to which the observations are to be reduced, and d is the value of one division of the level in seconds of arc.

The chronometer time of elongation was computed as follows:

$T_e = \alpha \pm t_e - \triangle T \left.\begin{matrix} W \\ E \end{matrix}\right\}$ Elongation where $t_e = \cos\delta \tan\varphi$ the hour angle of the star at elongation, counted from upper culmination.

If now T is the chronometer time of any observation and z the corresponding zenith distance of the star and z_e the zenith distance of the star at elongation, then for each observation $z - z_e = 15 \cos\delta \left(T - T_e - \frac{15^2}{6} \sin^2 1'' \, (T - T_e)^3 \right)$

Except in notation, this is the formula given in the "Anleitung" above mentioned. Instead of dealing with the quantities $z - z_e$ in arc as set forth in the "Anleitung," which would have involved a great deal of labor, the computation was arranged as stated below and the method of obtaining the progressive and periodic errors given in the "Anleitung" was practically carried out. By progressive errors is here meant the actual errors at any readings of the screw from the mean value of the screw, the word progressive referring to the progressive readings of the screw as 1^R, 2^R, etc., and not to a uniformly increasing or decreasing error for the whole screw. The progressive errors are deduced for the initial readings of each revolntion only, as 1^R, 2^R, etc., and are assumed to change uniformly between these readings. In the example given it will be noticed that such errors obtained from a single set of observations are largely affected by errors of observation and that a large number of sets are required to give a good determination of the progressive errors. This will be seen by comparing the results from the single set with the mean results of eighteen sets, in Table II. Both the progressive and periodic errors as deduced here are to be added to the micrometer readings, and with the micrometer readings so corrected the mean value of one revolution of the screw is to be used.

The term $\frac{15^2}{6} \sin^2 1'' \, (T - T_e)^3 = C$ is tabulated on page 7 of the "Anleitung," and also on page 366, Appendix No. 7 of Coast and Geodetic Survey Report 1897–98. This term was applied directly to the times of observation, plus before and minus after elongation, thus reducing the observed times of transits to what they would have been had the star moved in a straight line instead of a curve. (See Table I of the example given below.) The times thus reduced are affected by both the progressive and periodic errors of the screw. By taking the means of these reduced times corresponding to $-0^R.4$, $-0^R.2$, $0^R.0$, $+0^R.2$, $+0^R.4$, for each revolution of the screw there was obtained a set of times corresponding to the micrometer readings 1^R, 2^R, to 29^R, all free of periodic errors. (See Table II.)

Let T be any of these times, and M the corresponding micrometer reading, and let T_0 be the mean of all the times, and M_0 or 15^R the corresponding mean of all the micrometer readings and R_s the mean value of one revolution of the screw in time seconds of the star, then for each of these times,

$$(M - M_0) R_s = T - T_0 \text{ for increasing readings of screw.}$$

$$(M - M_0) R_s = T_0 - T \text{ for decreasing readings of screw.}$$

$M - M_0$ and $T - T_0$ or $T_0 - T$ will be negative in all equations where $M < M_0$ and positive in all equations where $M > M_0$. Taking the sum of the negative equations from the sum of positive equations, and letting the signs $d\Sigma$ indicate the difference of these sums, then

$$d\Sigma\,(M - M_0)\,R_s = d\Sigma\,(T - T_0) \text{ increasing readings}$$

$$d\Sigma\,(M - M_0)\,R_s = d\Sigma\,(T_0 - T) \text{ decreasing readings.}$$

Substituting the value of R_s in all the equations, and putting p for the residual or progressive errors,

$$p = (T - T_0) - (M - M_0)\,R_s$$

or

$$p = (T_0 - T) - (M - M_0)\,R_s.$$

The reduced times in Table I were now freed from the effect of the progressive errors by subtracting p from these times if the observations were made with increasing readings of the screw and by adding p to the times if the observations were made with decreasing readings of the screw, the values of p applied to the times corresponding to $0^R.2$, $0^R.4$, $0^R.6$, $0^R.8$ being interpolated. By taking the successive differences of the times, freed from progressive errors, corresponding to micrometer readings $0^R.0 - 0^R.2$, $0^R.2 - 0^R.4$, $0^R.4 - 0^R.6$, $0^R.6 - 0^R.8$, $0^R.8 - 0^R.0$, for the 30 revolutions, Table III was formed, from which the periodic error was computed by the method given by Prof. T. W. Wright, in his treatise on the "Adjustment of Observations," article 194.

The progressive and periodic errors in time seconds of the star were reduced to terms of R by simply dividing by the value of R_s. Finally, the mean value of one revolution of the screw in arc is,

$$R = R_s\ 15 \cos.\delta - \text{corr. for refraction} + \text{corr. for rate.}$$

The values of R_s and p from the times in Table II may be computed by the method of least squares, as follows:

Let R_1 be an assumed value of one revolution of the micrometer screw in time seconds of the star, and put $R_s = R_1 + y$, then,

$$(M - M_0)\,(R_1 + y) = T - T_0$$

or

$$(M - M_0)\,(R_1 + y) = T_0 - T$$

and

$$(M - M_0)y = T - T_0 - (M - M_0)\,R_1$$

or

$$(M - M_0)y = T_0 - T - (M - M_0)\,R_1$$

Put the second member of these equations $= n$ then the normal equation will be

$$\Sigma\,(M - M_0)^2 y = \Sigma\,(M - M_0)\,n.$$

Substituting the value of y in all the equations, and putting p for the residual or progressive errors,

$$p = n - (M - M_0)\,y. \quad \text{(See IV.)}$$

In the example given below R_s and p have been computed by both methods. The least square method adds considerable work where a large number of sets are to be reduced and as the difference of the results obtained by the two methods is insignificant compared with the difference of results from different sets, it is scarcely worth while to use the least square method.

Example of observations and computation of progressive and periodic errors of a micrometer screw and mean value of one revolution by foregoing methods.

Gaithersburg, Md. Dec. 14, 1900. Obsr. E. S.
λ Urs. Min. W. Elong. Telescope E.
Temperature at beginning $-5^\circ\cdot0$; at ending $-6^\circ\cdot3$.
Very light wind, NE. A fine night.
The levels were read at each revolution, but only recorded when a change was noted.

M.	Level I. *s.*	Level I. *n.*	Level II. *s*	Level II. *n.*	$\frac{n-s}{4}$*	$-\frac{n_0-s_0}{4}+\frac{n-s}{4}$	Corr. *l.*	
R.	d.	d.	d.	d.	d.	d.	s.	
30	9·5	32·9	58·9	82·1	45·85	0·00	0·0	$d = 0''\cdot91.$
20	9·5	32·9	58·9	82·2	45·88	+0·03	+0·1	
18	9·4	32·9	58·9	82·2	45·85	0·00	0·0	$\frac{d}{15 \cos \delta} = 3^s.41.$
11	9·4	33·0	58·8	82·2	45·85	0·00	0·0	
7	9·4	33·0	58·7	82·3	45·85	0·00	0·0	$\frac{n_0 - s_0}{4} = 45^d\cdot85.$
5	9·3	33·0	58·7	82·3	45·82	−0·03	−0·1	
2	9·3	33·0	58·6	82·3	45·80	−0·05	−0·2	
0	9·3	33·9	58·6	82·3	45·85	0·00	0·0	

Sidereal time of W. Elongation,		$1^h\ 16^m\ 46^s\cdot5$
	$-\Delta T$	$+\ 1\ \cdot3$
Chronometer time of W. Elongation,		$1\ 16\ 47\ \cdot8$

TABLE I.—*Times of observation corrected for changes of level and the term* $\frac{15^2}{6} \sin^2 1''$ $(T - T_e)$ *and freed from effect of progressive error.*

M.	Times by chronometer.	Times from elong.	Corrections. *C.*	Corrections. *l.*	Reduced times.	*p.*	Reduced times + *p.*
R.	h. m. s.	m.	s.	s.	h. m. s.	s.	h. m. s.
30·0	0 39 03·0	37·7	+10·1	0·0	0 39 13·1	+1·18	0 39 14·28
·8	33·0	37·2	9·7	....	42·7	1·18	43·88
·6	40 04·3	36·7	9·4	....	40 13·7	1·18	40 14·88
·4	34·9	36·2	9·0	....	43·9	1·18	45·08
·2	41 05·9	35·7	8·7	....	41 14·6	1·18	41 15·78
29·0	35·5	35·2	8·3	....	43·8	1·18	44·98
·8	42 06·7	34·7	8·0	....	42 14·7	1·06	42 15·76
·6	36·6	34·2	7·6	....	44·2	0·95	45·15
·4	43 09·3	33·6	7·2	....	43 16·5	0·84	43 17·34
·2	39·2	33·1	+ 6·9	....	46·1	+0·73	46·83

* The mean of the two levels.

TABLE I.—*Times of observation corrected for changes of level and the term* $\frac{15^2}{6} \sin^2 1''$ $(T - T_e)$ *and freed from effect of progressive error*—Continued.

M.	Times by chronometer.			Times from elong.	Corrections.		Reduced times.			*p.*	Reduced times + *p*.		
					C.	*l.*							
R.	h.	m.	s.	m.	s.	s.	h.	m.	s.	s.	h.	m.	s.
28·0		44	09·3	32·6	+6·6	....		44	15·9	+0·62		44	16·52
·8			39·5	32·1	6·3	....			45·8	0·63			46·43
·6		45	09·9	31·6	6·0	....		45	15·9	0·64		45	16·54
·4			40·9	31·1	5·8	....			46·7	0·65			47·35
·2		46	11·2	30·6	5·5	....		46	16·7	0·66		46	17·36
27·0			41·3	30·1	5·2	....			46·5	0·66			47·16
·8		47	13·4	29·6	4·9	....		47	18·3	0·66		47	18·96
·6			43·4	29·1	4·6	....			48·0	0·65			48·65
·4		48	14·1	28·6	4·4	....		48	18·5	0·64		48	19·14
·2			45·3	28·0	4·2	....			49·5	0·63			50·13
26·0		49	13·9	27·6	4·0	....		49	17·9	0·62		49	18·52
·8			44·9	27·0	3·7	....			48·6	0·50			49·10
·6		50	14·6	26·6	3·5	....		50	18·1	0·38		50	18·48
·4			45·8	26·0	3·3	....			49·1	0·26			49·36
·2		51	17·1	25·5	3·2	....		51	20·3	0·15		51	20·45
25·0			47·1	25·0	3·0	....			50·1	0·04			50·14
·8		52	18·1	24·5	2·8	....		52	20·9	0·11		52	21·01
·6			48·7	24·0	2·6	....			51·3	0·18			51·48
·4		53	19·5	23·5	2·4	....		53	21·9	0·24		53	22·14
·2			47·8	23·0	2·3	....			50·1	0·30			50·40
24·0		54	19·0	22·5	2·2	....		54	21·2	0·36		54	21·56
·8			49·2	22·0	2·0	....			51·2	0·46			51·66
·6		55	20·0	21·4	1·9	....		55	21·9	0·55		55	22·45
·4			50·7	20·9	1·8	....			52·5	0·64			53·14
·2		56	21·3	20·4	1·6	....		56	22·9	0·73		56	23·63
23·0			50·0	19·9	1·5	....			51·5	0·82			52·32
·8		57	21·0	19·4	1·4	....		57	22·4	0·70		57	23·10
·6			49·6	19·0	1·3	....			50·9	0·58			51·48
·4		58	22·1	18·4	1·2	....		58	23·3	0·46		58	23·76
·2			51·9	17·9	1·1	....			53·0	0·34			53·34
22·0		59	22·5	17·4	1·0	....		59	23·5	0·23		59	23·73
·8			54·1	16·9	0·9	....			55·0	+0·08			55·08
·6	1	00	23·8	16·4	0·8	....	1	00	24·6	−0·07	1	00	24·53
·4			54·4	15·9	0·8	....			55·2	0·21			54·99
·2		01	25·5	15·4	0·7	....		01	26·2	0·35		01	25·85
21·0			54·7	14·9	0·6	....			55·3	0·49			54·81
·8		02	25·5	14·4	0·5	....		02	26.0	0·49		02	25·51
·6			56·0	13·9	0·5	....			56·5	0·50			56·00
·4		03	25·8	13·4	0·4	....		03	26·2	0·50		03	25·70
·2			56·3	12·9	0·4	....			56·7	0·51			56·19
20·0		04	25·6	12·4	0·3	+0·1		04	26·0	0·51		04	25·49
·8			58·1	11·8	0·3	0·1			58·5	0·52			57·98
·6		05	27·8	11·3	0·2	0·1		05	28·1	0·53		05	27·57
·4			57·7	10·8	0·2	0·1			58·0	0·54			57·46
·2		06	28·6	10·3	0·2	0·1		06	28·9	0·55		06	28·35
19·0			57·4	9·8	0·2	0·1			57·7	0·57			57·13
·8		07	27·3	9·3	0·1	0·1		07	27·5	0·65		07	26·85
·6			59·7	8·8	0·1	0·1			59·9	0·73			59·17
·4		08	29·9	8·3	0·1	0·1		08	30·1	0·81		08	29·29
·2			59·4	7·8	0·1	+0·1			59·6	0·88			58·72
18·0		09	28·7	7·3	0·1	0·0		09	28·8	0·95		09	27·85
·8		10	00·8	6·8	+0·1	....		10	00·9	0·98			59·92
·6			30·7	....	....	....			30·7	1·01		10	29·69
·4		11	01·3	....	....	....		11	01·3	1·04		11	00·26
·2			30·7	....	....	....			30·7	1·07			29·63
17·0		12	02·0	....	....	....		12	02·0	1·09		12	00·91
·8			31·2	....	....	....			31·2	−1·05			30·15

TABLE I.—*Times of observation corrected for changes of level and the term* $\frac{15^2}{6}$ *sin² 1″ (T—T$_e$) and freed from effect of progressive error*—Continued.

M.	Times by chronometer.			Times from elong.	Corrections.		Reduced times.			*p.*	Reduced times + *p.*		
					C.	*l.*							
R.	h.	m.	s.	m.	s.	s.	h.	m.	s.	s.	h.	m.	s.
17·6		13	01·8	...	...	...		13	01·8	−1·01		13	00·79
·4			31·6	...	...	...			31·6	0·97			30·63
·2		14	02·5	...	...	...		14	02·5	0·94		14	01·56
16·0			33·1	...	...	...			33·1	0·91			32·19
·8		15	02·4	...	...	...		15	02·4	0·78		15	01·62
·6			32·7	...	...	...			32·7	0·65			32·05
·4		16	04·3	...	...	...		16	04·3	0·52		16	03·78
·2			32·1	...	...	...			32·1	0·39			31·71
15·0		17	03·1	...	...	...		17	03·1	0·27		17	02·83
·8			32·8	...	...	...			32·8	0·28			32·52
·6		18	03·0	...	...	...		18	03·0	0·29		18	02·71
·4			33·7	...	...	...			38·7	0·30			33·40
·2		19	03·8	...	...	...		19	03·8	0·31		19	03·49
14·0			34·8	...	...	...			34·8	0·32			34·48
·8		20	04·8	...	...	...		20	04·8	0·47		20	04·33
·6			34·7	...	...	...			34·7	0·62			34·08
·4		21	06·1	...	...	...		21	06·1	0·76		21	05·34
·2			35·6	...	...	...			35·6	0·90			34·70
13·0		22	05·7	...	...	...		22	05·7	1·04		22	04·66
·8			36·6	...	...	...			36·6	0·90			35·70
·6		23	07·6	...	...	...		23	07·6	0·76		23	06·84
·4			36·9	6·8	−0·1	...			36·8	0·62			36·18
·2		24	07·2	7·2	0·1	...		24	07·1	0·47		24	06·63
12·0			37·6	7·8	0·1	...			37·5	0·32			37·18
·8		25	06·7	8·3	0·1	...		25	06·6	−0·13		25	06·47
·6			36·3	8·8	0·1	...			36·2	+0·06			36·26
·4		26	07·4	9·3	0·1	...		26	07·3	0·24		26	07·54
·2			36·4	9·8	0·1	...			36·2	0·42			36·62
11·0		27	07·0	10·3	0·2	...		27	06·8	0·60		27	07·40
·8			37·8	10·8	0·2	...			37·6	0·35			37·95
·6		28	08·1	11·3	0·2	...		28	07·9	+0·10		28	08·00
·4			39·6	11·8	0·3	...			39·3	−0·14			39·16
·2		29	09·2	12·4	0·3	...		29	08·9	0·38		29	08·52
10·0			40·9	12·9	0·4	...			40·5	0·62			39·88
·8		30	10·3	13·4	0·4	...		30	09·9	0·52		30	09·38
·6			40·0	13·9	0·5	...			39·5	0·42			39·08
·4		31	12·2	14·4	0·5	...		31	11·7	0·32		31	11·38
·2			40·9	14·9	0·6	...			40·3	0·22			40·08
9·0		32	10·4	15·4	0·7	...		32	09·7	−0·12		32	09·58
·8			40·0	15·9	0·8	...			39·2	+0·22			39·42
·6		33	11·7	16·4	0·8	...		33	10·9	0·55		33	11·45
·4			41·3	16·9	0·9	...			40·4	0·88			41·28
·2		34	11·4	17·4	1·0	...		34	10·4	1·21		34	11·61
8·0			39·0	17·9	1·1	...			37·9	1·54			39·44
·8		35	12·0	18·4	1·2	...		35	10·8	1·34		35	12·14
·6			41·5	18·9	1·3	...			40·2	1·14			41·34
·4		36	13·4	19·4	1·4	...		36	12·0	0·94		36	12·94
·2			42·2	19·9	1·5	...			40·7	0·74			41·44
7·0		37	14·6	20·4	1·6	...		37	13·0	0·54		37	13·54
·8			44·1	20·9	1·8	...			42·3	0·32			42·62
·6		38	14·8	21·5	1·9	...		38	12·9	+0·10		38	13·00
·4			45·7	22·0	2·0	...			43·7	−0·12			43·58
·2		39	15·1	22·5	2·2	...		39	12·9	0·34		39	12·56
6·0			47·9	23·0	2·3	...			45·6	0·56			45·04
·8		40	16·9	23·5	2·4	...		40	14·5	0·49		40	14·01
·6			48·5	24·0	2·6	...			45·9	0·43			45·47
·4		41	17·8	24·5	2·8	...		41	15·0	0·37		41	14·63
·2			47·8	25·0	−3·0	...			44·8	−0·31			44·49

TABLE I.—*Times of observation corrected for changes of level and the term* $\frac{15^2}{6} \sin^2 1'' (T - T_e)$ *and freed from effect of progressive error*—Continued.

M.	Times by chronometer.			Times from elong.	Corrections.		Reduced times.			*p.*	Reduced times + *p*.		
					C.	*l.*							
R.	h.	m.	s.	m.	s.	s.	h.	m.	s.	s.	h.	m.	s.
5.0		42	18.4	25.5	−3.2	−0.1		42	15.1	−0.25		42	14.85
.8			48.9	26.0	3.3	0.1			45.5	0.39			45.11
.6		43	20.5	26.5	3.5	0.1		43	16.9	0.53		43	16.37
.4			51.4	27.1	3.7	0.1			47.6	0.67			46.93
.2		44	20.2	27.5	4.0	0.1		44	16.1	0.80		44	15.30
4.0			51.0	28.1	4.2	0.1			46.7	0.93			45.77
.8		45	23.1	28.6	4.4	0.1		45	18.6	0.55		45	18.05
.6			52.6	29.1	4.6	0.1			47.9	−0.17			47.73
.4		46	21.9	29.6	4.9	0.1		46	16.9	+0.21		46	17.11
.2			52.1	30.1	5.2	0.1			46.8	0.59			47.39
3.0		47	21.4	30.6	5.5	0.1		47	15.8	0.97		47	16.77
.8			52.8	31.1	5.8	0.1			46.9	0.82			47.72
.6		48	23.3	31.6	6.0	0.1		48	17.2	0.67		48	17.87
.4			55.3	32.1	6.3	0.1			48.9	0.52			49.42
.2		49	25.6	32.6	6.6	0.1		49	18.9	0.37		49	19.27
2.0			55.2	33.1	6.9	0.2			48.1	0.23			48.33
.8		50	26.4	33.6	7.2	0.2		50	19.0	0.30		50	19.30
.6			56.4	34.1	7.6	0.2			48.6	0.37			48.97
.4		51	27.0	34.7	8.0	0.2		51	18.8	0.43		51	19.23
.2			58.2	35.2	8.3	0.2			49.7	0.49			50.19
1.0		52	28.2	35.7	8.7	0.2		52	19.3	0.55		52	19.88
.8		53	00.0	36.2	9.0	0.1			50.9	0.55			51.45
.6			28.9	36.7	9.4	0.1		53	19.4	0.55		53	19.95
.4			59.6	37.2	9.8	−0.1			49.7	0.55			50.25
.2		54	33.0	37.7	10.2	0.0		54	22.8	0.55		54	23.35
0.0		55	03.2	38.3	−10.7	0.0			52.5	+0.55			53.05

TABLE II.—*Computation of R_s and p — without least squares.*

M	$M-M_0$	T			T_0-T		$(M-M_0)\,R_s$		p	p	p mean of 18 sets.
R		h	m	s	m	s	m	s	s	R	R
29	+14	0	41	44.24	+35	18.554	+35	17.377	+1.177	+0.007 8	+0.005 9
28	13		44	16.04	32	46.754	32	46.136	+0.618	+0.004 1	+0.005 9
27	12		46	47.24	30	15.554	30	14.894	+0.660	+0.004 4	+0.001 5
26	11		49	18.52	27	44.274	27	43.653	+0.621	+0.004 1	+0.003 3
25	10		51	50.34	25	12.454	25	12.412	+0.042	+0.000 3	+0.003 7
24	9		54	21.26	22	41.534	22	41.170	+0.364	+0.002 4	+0.002 3
23	8		56	52.04	20	10.754	20	09.930	+0.824	+0.005 5	+0.000 1
22	7		59	23.88	17	38.914	17	38.688	+0.226	+0.001 5	−0.002 3
21	6	1	01	55.84	15	06.954	15	07.447	−0.493	−0.003 3	−0.002 4
20	5		04	27.10	12	35.694	12	36.206	−0.512	−0.003 4	−0.003 2
19	4		06	58.40	10	04.394	10	04.965	−0.571	−0.003 8	−0.005 5
18	3		09	30.02	7	32.774	7	33.724	−0.950	−0.006 3	−0.004 4
17	2		12	01.40	5	01.394	5	02.482	−1.088	−0.007 2	−0.003 8
16	+ 1		14	32.46	+ 2	30.334	+ 2	31.241	−0.907	−0.006 0	−0.004 2
15	0		17	03.06	− 0	00.266	0	00.000	−0.266	−0.001 8	−0.000 7
14	− 1		19	34.36	2	31.566	− 2	31.241	−0.325	−0.002 2	−0.002 6
13	2		22	06.32	5	03.526	5	02.482	−1.044	−0.006 9	−0.002 5
12	3		24	36.84	7	34.046	7	33.724	−0.322	−0.002 1	−0.002 0
11	4		27	07.16	10	04.366	10	04.965	+0.599	+0.004 0	−0.001 9
10	5		29	39.62	12	36.826	12	36.206	−0.620	−0.004 1	−0.007 0
9	6		32	10.36	15	07.566	15	07.447	−0.119	−0.000 7	−0.002 6
8	7		34	39.94	17	37.146	17	38.688	+1.542	+0.010 2	−0.001 8
7	8		37	12.18	20	09.386	20	09.930	+0.544	+0.003 6	+0.001 4
6	9		39	44.52	22	41.726	22	41.170	−0.556	−0.003 7	+0.001 1
5	10		42	15.46	25	12.666	25	12.412	−0.254	−0.001 7	+0.001 2
4	11		44	47.38	27	44.586	27	43.653	−0.933	−0.006 2	+0.002 4
3	12		47	16.72	30	13.926	30	14.894	+0.968	+0.006 4	+0.005 3
2	13		49	48.70	32	45.906	32	46.136	+0.230	+0.001 5	+0.005 1
1	−14		52	19.62	−35	16.826	−35	17.377	+0.551	+0.003 7	+0.007 7

$T_0 = 1^h\ 17^m\ 02^s.794$ | + 15880.336
— 15880.330

R_s	=	$151^s.241\ 2$
δ	=	$+ 88°\ 59'\ 38''.09$
R_s 15 cos δ	=	$39''.833\ 2$
Corr. for Ref.	=	− .028 2
Corr. for Rate	=	+ .003 0
R	=	39 .808 0

TABLE III.—*Computation of periodic error.*

M	R R 0·0–0·2	R R 0·2–0·4	R R 0·4–0·6	R R 0·6–0·8	R R 0·8–0·0
R R	s	s	s	s	s
0– 1	29·70	33·10	30·30	28·50	31·57
1– 2	29·69	30·96	30·26	29·67	30·97
2– 3	29·06	29·85	31·55	30·15	30·95
3– 4	29·38	30·28	29·38	29·68	32·28
4– 5	30·47	28·37	30·56	31·26	30·26
5– 6	30·36	29·86	29·16	31·46	28·97
6– 7	32·48	28·98	30·58	30·38	29·08
7– 8	32·10	28·50	31·60	29·20	32·70
8– 9	27·83	30·33	29·83	32·03	29·84
9–10	29·50	28·70	32·30	29·70	29·50
10–11	31·36	29·36	31·16	30·05	30·55
11–12	30·78	29·08	31·28	29·79	29·29
12–13	30·55	30·45	29·34	31·14	31·04
13–14	29·96	29·36	31·26	29·75	29·85
14–15	30·99	30·09	30·69	30·19	29·69
15–16	31·12	27·93	31·73	30·43	29·43
16–17	30·63	30·93	29·84	30·64	29·24
17–18	31·18	29·37	30·57	29·77	32·07
18–19	29·13	29·43	30·12	32·32	29·72
19–20	28·78	30·89	29·89	29·59	32·49
20–21	29·30	30·49	29·70	30·49	30·70
21–22	28·96	30·86	30·46	29·45	31·35
22–23	30·39	29·58	32·28	28·38	30·78
23–24	28·69	30·49	30·69	30·79	30·10
24–25	31·16	28·26	30·66	30·47	30·87
25–26	29·69	31·09	30·88	29·38	30·58
26–27	28·39	30·99	30·49	29·69	31·80
27–28	29·80	30·01	30·81	30·11	29·91
28–29	29·69	29·49	32·19	29·39	30·78
29–30	29·20	30·70	30·20	31·00	29·60
Mean..	30·0107	29.9260	30·6587	30.1617	30·5320

M	*Mean*	l	l
R R	s	s	R
0·0–0·2	30·010 7	−0·247 1	−0·001 6
0·2–0·4	29·926 0	−0·331 8	−0·002 2
0·4–0·6	30·658 7	+0·400 9	+0·002 6
0·6–0·8	30·161 7	−0·096 1	−0·000 6
0·8–0·0	30·532 0	+0·274 2	+0·001 8
Mean ...	30·2578	0·0000	

Mean of 18 sets.

$$\begin{aligned}
&\overset{l}{\text{R}}\\
-0{\cdot}000\,1 &= x + y_1 \cos 0^\circ + z_1 \sin 0^\circ + y_2 \cos 0^\circ + z_2 \sin 0^\circ\\
-0{\cdot}001\,2 &= x + y_1 \cos 72^\circ + z_1 \sin 72^\circ + y_2 \cos 144^\circ + z_2 \sin 144^\circ\\
+0{\cdot}000\,2 &= x + y_1 \cos 144^\circ + z_1 \sin 144^\circ + y_2 \cos 288^\circ + z_2 \sin 288^\circ\\
-0{\cdot}000\,3 &= x + y_1 \cos 216^\circ + z_1 \sin 216^\circ + y_2 \cos 432^\circ + z_2 \sin 432^\circ\\
+0{\cdot}001\,4 &= x + y_1 \cos 288^\circ + z_1 \sin 288^\circ + y_2 \cos 576^\circ + z_2 \sin 576^\circ
\end{aligned}$$

$$y_1 = +0{\cdot}000\,02 \qquad y_2 = 0.000\,12$$

$$z_1 = -0{\cdot}000\,87 \qquad z_2 = 0{\cdot}000\,80$$

$$^*f(\varphi) = +0{\cdot}000\,2 \cos \varphi - 0{\cdot}000\,87 \sin \varphi$$
$$- 0{\cdot}000\,12 \cos 2\varphi - 0{\cdot}000\,80 \sin 2\varphi$$

* See Prof. T. W. Wright's Treatise on the Adjustment of Observations, Article 194.

TABLE IV.—*Computation of R_s and p by method of least squares.*

M	$M-M_0$	$(M-M_0)R_1$		$T_0-T^*-(M-M_0)R_1=n$	$(M-M_0)y$	$n-(M-M_0)y=p$	p
R.		m.	s.	s.	s.	s.	R.
29	+14	+35	17·50	+1·054	+0·032	+1·022	+0·006 8
28	13	32	46·25	+0·504	0·030	+0·474	+0·003 1
27	12	30	15·00	+0·554	0·028	+0·526	+0·003 5
26	11	27	43 75	+0·524	0·025	+0·499	+0·003 3
25	10	25	12·50	—0·046	0·023	—0·069	—0·000 5
24	9	22	41·25	+0·284	0·021	+0·263	+0·001 7
23	8	20	10·00	+0·754	0·018	+0·736	+0·004 9
22	7	17	38·75	+0·164	0·016	+0·148	+0·001 0
21	6	15	07·50	—0·546	0·014	—0·562	—0·003 7
20	5	12	36·25	—0·556	0·012	—0·568	—0·003 8
19	4	10	05·00	—0·606	0·009	—0·615	—0·004 1
18	3	7	33·75	—0·976	0·007	—0·983	—0·006 5
17	2	5	02·50	—1·106	0·005	—1·111	—0·007 4
16	+ 1	+ 2	31·25	—0·916	+0·002	—0·918	—0·006 1
15	0	0	00·00	—0·266	0·000	—0·266	—0·001 8
14	— 1	— 2	31·25	—0·316	—0·002	—0·318	—0·002 1
13	2	5	02 50	—1·026	0·005	—1·021	—0·006 8
12	3	7	33·75	—0·296	0·007	—0·289	—0·001 9
11	4	10	05·00	+0·634	0·009	+0·643	+0·004 3
10	5	12	36·25	—0·576	0·012	—0·564	—0·003 7
9	6	15	07·50	—0·066	0·014	—0·052	—0·000 3
8	7	17	38·75	+1·604	0·016	+1·620	+0·010 7
7	8	20	10·00	+0·614	0·018	+0·632	+0·004 2
6	9	22	41·25	—0·476	0·021	—0·455	—0·003 0
5	10	25	12·50	—0·166	0·023	—0·143	—0·000 9
4	11	27	43·75	—0·836	0·025	—0·811	—0·005 4
3	12	30	15·00	+1·074	0·028	+1·102	+0·007 3
2	13	32	46·25	+0·344	0·030	+0·374	+0·002 5
1	—14	—35	17·50	+0·674	—0·032	+0·706	+0·004 7

R_1	=	151^s·25
2 030 y	=	4^s·660
y	=	.0 ·002 3
R_s	=	151·252 3
δ	=	88° 59′ 38″·09
R_s 15 cos δ	=	39″·836 7
Corr. for Ref.	=	— ·028 2
Corr. for Rate	=	+ ·003 0
R	=	39″·811 5

* For value of $T_0 - T$ see Table II.

ALPHABETICAL INDEX.

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