DEPARTMENT OF COMMERCE AND LABOR

REPORT OF THE SUPERINTENDENT

OF THE

COAST AND GEODETIC SURVEY

SHOWING

THE PROGRESS OF THE WORK

FROM

JULY 1, 1906, TO JUNE 30, 1907

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

National Oceanic and Atmospheric Administration

Annual Report of the Superintendent of the Coast Survey

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DEPARTMENT OF COMMERCE AND LABOR

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COAST AND GEODETIC SURVEY

LETTER OF TRANSMITTAL.

DEPARTMENT OF COMMERCE AND LABOR,
OFFICE OF THE SECRETARY,
Washington, September 17, 1907.

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 submitted 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, 1907. It is accompanied by maps illustrating the general advance in the operations of the Survey up to that date.

Respectfully, OSCAR S. STRAUS,
Secretary.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

LETTER OF SUBMITTAL.

DEPARTMENT OF COMMERCE AND LABOR,
COAST AND GEODETIC SURVEY,
Washington, September 17, 1907.

SIR: In conformity with law and with the regulations of the Department of Commerce and Labor, I have the honor to submit herewith, for transmission to Congress, the Annual Report of progress in the Coast and Geodetic Survey for the fiscal year ended June 30, 1907. It is accompanied by maps illustrating the general advance in the field work of the Survey up to that date.

Respectfully, O. H. TITTMANN,
Superintendent.

To Hon. OSCAR S. STRAUS,
Secretary of Commerce and Labor.

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THE WORK OF THE YEAR.

The most unusual feature of the work of the year was the investigation of the effect of the San Francisco earthquake of April, 1906, on the triangulation covering the region in the vicinity of the great "fault" which shows on the surface of the earth from Point Arena to Monterey Bay, a distance of more than 320 kilometers (200 miles). Fortunately, this region had been covered by triangulation of a high degree of precision in the progress of the work intrusted by law to the Coast and Geodetic Survey, and there are numerous points within the region whose coordinates were determined by this triangulation. There was reason to believe that the relative positions of many of these points had been changed by a measurable amount, and it was decided to repeat as much of the triangulation as proved to be necessary to determine what changes had occurred. Astronomic azimuths were determined and many of the triangulation stations were reoccupied and the horizontal angles were remeasured in order to compute new geographic positions of points within the region. The direct comparison of the coordinates obtained in the old and in the new work shows the movement of any point selected in latitude, in longitude, and in azimuth, referred to adjacent points.

The work extends from the region of no disturbance on the east southward to Monterey Bay and northward to Point Arena. The investigation was completed before the end of the year, and the amount of displacement determined agrees in a general way with the measurements made by the California Earthquake Commission at certain places on roads and along fences where such measurements were possible. One of the international observatories for the determination of latitude is located at Ukiah, 30 miles east of Point Arena, and the observations there show that at this point there was no movement in latitude or it was too small to be measured. Leveling operations were also undertaken and completed in the vicinity of San Francisco to ascertain whether any movement affecting the Survey bench marks could be detected as a result of the earthquake.

A full discussion of the results obtained in this investigation has been made and is published as Appendix 3 to this report.

The conclusions reached in this investigation may be stated as follows:

During an earthquake in 1868, or about that time, about 1 000 square miles of the earth's crust in the region immediately north of San Francisco were permanently displaced to the northward about 1.6 meters (5.2 feet), and the indications are that this whole area moved as a block without distortion or rotation.

During the earthquake of April 18, 1906, earth movements took place as follows: Points on opposite sides of the "fault" moved in opposite directions—those to the eastward of the fault in a southerly direction and those to the westward in a northerly direction. The displacements of all points were approximately parallel to the fault. The displacements on both sides of the fault decrease in amount as the distance from the fault increases. Points on the western side of the fault were displaced, on an average, about twice as much as corresponding points at equal distances on the eastern side.

A small area, including portions of San Francisco, both sides of the Golden Gate, and Sausalito, 1½ miles north of the Golden Gate, where bench marks had been established and tide observations were in progress, was investigated, and the general conclusion was reached from both leveling and tide observations that within the region examined there occurred no general change of elevation of sufficient magnitude to be detected with certainty. In this connection it is interesting to know that certain displacements were developed many years ago by results of triangulation obtained at different dates, and that Prof. George Davidson, then an officer of the Survey, advanced the theory that earth movements had occurred as the result of an earthquake; but at that time there was not sufficient evidence to sustain his theory.

Portions of the work involved in opening and remonumenting the boundary line between the United States and Canada, along the forty-ninth parallel, west of the Rocky Mountains, had been completed and others were being continued at the date of my last annual report. Good progress was made, and the work is almost completed. The final inspection of the completed portion of the line and the placing of numbers on the monuments is in progress under the joint direction of the commissioners.

The examination of the boundary between the United States and Canada, north of the State of Vermont, was completed and the work of opening and remonumenting the line is in progress under the joint direction of commissioners representing the United States and Great Britain. This work was completed for 50 miles of the line during the year.

Satisfactory progress was made in the demarcation of the Alaska-Canada boundary in southeastern Alaska and the work of locating the line, opening the vista along the line, and erecting monuments was being continued at the date of this report. A point on the one hundred and forty-first meridian of west longitude was ascertained, on the Alaska boundary near the Yukon River, as provided in the convention between the United States and Great Britain (signed April 21, 1906), by commissioners representing the two Governments, and the work of tracing and marking the boundary is in progress under the joint direction of the commissioners.

The Fifteenth General Conference of the International Geodetic Association was held at Budapest, Hungary, September 20 to 28, 1906. The Superintendent and another officer of the Coast and Geodetic Survey attended its sessions, representing the United States as delegates. The convention under which this international association exists was formally renewed for a period of ten years and other business of importance was transacted.

Work at the latitude observatories at Gaithersburg, Md., and at Ukiah, Cal., maintained by the International Geodetic Association under my direction, was continued during the year.

An officer of the Survey continued on duty as a member of the Mississippi River Commission, as required by law, and devoted as much of his time as necessary to the work of the Commission. This officer has been appointed by the Secretary of War as a member of the board to examine and report on a 14-foot channel in the Mississippi River from St. Louis to its mouth.

As provided by law, an officer of the Survey was detailed to cooperate with the Maryland State Board of Shell Fish Commissioners in making a survey of and locating the natural oyster beds, bars, and rocks in the waters within the State of Maryland. During the year the work of the Coast and Geodetic Survey representative was completed for the waters of Anne Arundel County and a report and maps were prepared and published. The work is being continued in other waters of the State.

In response to a request from the Naval Board, Jamestown Exposition, several special surveys and hydrographic examinations were made in Hampton Roads and vicinity, and a special anchorage chart was prepared and published showing the anchorages selected for the vessels of United States and foreign navies visiting the Exposition.

The triangulation along the ninety-eighth meridian was extended in Minnesota from the vicinity of Fergus Falls to the Stephen Base. One base line was measured in Minnesota in connection with this triangulation. The primary triangulation along the Pacific coast in Oregon and Washington was completed and the necessary connections of the Tertiary triangulation along the coast with the primary work in the interior were undertaken and two such connections were made. The triangulation of the City of New York by the corporation under the direction of the Coast and Geodetic Survey made satisfactory progress during the fiscal year.

Astronomic observations to determine latitude, longitude, or azimuth were made in Alabama, Florida, Georgia, Kansas, Minnesota, Nebraska, North Carolina, North Dakota, Oklahoma, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, and Virginia.

The standard levels were extended in California, Idaho, Montana, Nevada, Ohio, and Utah.

Hydrographic examinations were made to safeguard navigation in localities where they were necessary along the coasts of Maine, Massachusetts, Rhode Island, and New York. East Penobscot Bay, Eggemoggin Reach, and Jericho Bay on the coast of Maine and certain channels in the vicinity of Key West, Fla., were examined with the long wire drag. This drag, which is described in my Annual Report for 1905, has proved to be an important advance in the work of safeguarding vessels of all classes, as it detects all dangers to navigation above the depth at which the drag is used. Hydrographic work was done on the inside of the entrance to Chesapeake Bay and along the Virginia shore, between New Point Light and Back River Light, off the entrance to York River. The offshore hydrographic work was continued and practically completed to the eastward of Vieques Island, Porto Rico, and in that vicinity, and the offshore hydrography off the north coast of the island of Porto Rico was extended westward from Cape San Juan.

The topographic resurvey of the shores of the Potomac River was completed, topographic work was continued along the shores of Chesapeake Bay, and a survey was made of Fishermans Island, Quarantine Station, as requested by the Treasury Department.

The magnetic survey of the country was continued by making observations in Alabama, Alaska, California, Colorado, Connecticut, District of Columbia, Florida, Idaho, Indian Territory, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nebraska, Nevada, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Philippine Islands, Porto Rico, Rhode Island, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, and Wyoming. Continuous observations were obtained at magnetic observatories maintained at Cheltenham, Md.; Baldwin, Kans.; Sitka, Alaska; Honolulu, Hawaii; and Vieques, P. R. Magnetic observations were made in the Atlantic and Pacific oceans on board the vessels of the Survey on their voyages to and from their fields of work. On one voyage from Norfolk to Seattle via Cape Horn a very valuable series of observations was made both on land and at sea.

Self-registering tide gauges were maintained at the following stations: Fort Hamilton, N. Y.; Philadelphia, Pa.; Baltimore, Md.; Fernandina, Fla.; Weeks, La.; Galveston, Tex.; San Diego, Cal.; Presidio, Cal.; Seattle, Wash.; Honolulu, Hawaii; and Manila and Iloilo, P. I.

The tide indicators at Fort Hamilton, N. Y.; Reedy Island, Delaware River, Delaware; and Alcatraz Island, San Francisco Bay, California, have been continued, and the electric tide indicators in the rooms of the Maritime Association of New York and in the Bourse Building in Philadelphia have given satisfaction.

The information necessary for the revision of the United States Coast Pilot, Atlantic Coast, Part VI, was collected in the field.

ALASKA.

In Alaska, surveys, including triangulation, topography, and hydrography, were made in the following localities, viz, Khaz Bay and adjacent waters; Ketchikan; Warren Cove; Latouche Passage and Dries Bay, Prince William Sound; Alitak Bay and Sitkinak Strait; St. Paul Harbor, Kodiak Island; Anchorage Bay, opposite the Semidi Islands; Usnika Passage; Port Chatham; and Iliamna Bay.

The demand for surveys in Alaska is pressing, and during the year one of the surveying vessels was transferred from the Atlantic to the Pacific coast as an addition to the force engaged in extending the surveys along the Alaskan coast.

Information was collected in the field for a revised edition of the Alaska Coast Pilot, Part 1, and for a publication to cover the coast from Yakutat Bay to Kodiak Island.

Reference has already been made to the demarkation of the Alaska Boundary and to the work at the magnetic observatory at Sitka.

PHILIPPINE ISLANDS.

Rapid progress in the important work of charting the waters of the Archipelago was made during the year. The surveying parties were kept in the field almost continuously, and advantage was taken of the varying weather conditions in different localities to secure a large amount of work.

The results of the field work were promptly made available in the form of drawings for charts and transmitted to Washington for review and publication.

Some details of the work accomplished may be stated as follows:

West coast of Luzon.—Offshore hydrographic work was done between Balingasay Point and Caiman Point, and between Guai Point and Capones Islands, this completing the general survey of the west coast of Luzon from Calili Point to the vicinity of Laguimanoc Bay, except for a portion about 5 miles in length south of the Frailes Islands.

The triangulation was extended southward between Luzon, Mindoro, and Marinduque, and from the vicinity of Manila to Caballo Island at the entrance to Manila Bay.

Verde Island Passage.—The hydrographic survey of this passage was completed.

South and east coast of Luzon.—A reported danger to navigation at the entrance to Port Gubat was located, and work was done to complete the survey of Port Sula.

East coast of Luzon.—One party made a general survey of the coast from Maqueda Channel to San Miguel Bay, and an important and valuable harbor of refuge in typhoons was discovered in the Lamit Islands. Another party completed the survey westward from San Miguel Bay to Jesus Point, and still another made surveys between Alabat Island and the west coast of Polillo Island. Extensive changes in the general coast as shown on existing charts will result from this work. Another valuable harbor of refuge in typhoons in Polillo Island was surveyed, and a survey was made of Port Lampon and Burdens Bay, the latter giving access to the coal deposits on Polillo Island. A dangerous shoal off Cabugao, south coast of Cantanduanes Island, was located and surveyed.

North and east coasts of Samar.—The survey of this coast was extended from Laoang to the Balicuatro Islands, where it joins the work already completed in this region. Surveys were made in Matarinao Bay, between Bacan Islands and Alugon Bay and from Paninihian Point to Matarinao Bay except for a space of 5 miles a short distance south of Llorente. The surveys of all harbors suitable for commerce or refuge on the north and east coasts of Samar have been completed.

Guimaras Straits, east coast of Panay, and north coast of Negros.—The survey was extended from Tomonton Point, Negros and Banate, Panay, northward to Rogalumbi Island, and the triangulation, to a connection with the Zapatos Islands and Jintotolo Light, and east to Don Islands.

South and west coasts of Panay.—The hydrography of these shores from Olon to San Jose de Buena Vista was completed. Triangulation was also done on the west coast, and the topographic work was extended to Bugan River.

West coast of Leyte.—The triangulation was extended from Bulalagui Point, Cebu, to Limasana Island, south of Leyte. The topographic work was completed south to Hindang, and the Comote and Quatro Islands were surveyed. The hydrography was completed from Donajon Banks to Palompon and the general survey from Bacacay Point to Liloan Bay.

North coast of Mindanao.—A survey was made in Iligan Bay, which connects the work previously done in the vicinity of Iligan with Polo Point, and covers the location and development of Iligan Reef.

South coast of Mindanao.—The survey of this coast was resumed in the vicinity of Zamboanga, and the triangulation was extended to the head of Sibuguey Bay; the topographic work was done between Masingloc Anchorage and Buluan Island, and the hydrography was completed to the parallel of Baguilibid Point, within 10 miles of the east coast of the bay.

The survey of the Gulf of Davao was continued and much progress was made.

Tide observations were made in connection with all hydrographic work, and continuous observations were obtained at Manila and at Iloilo. As much as possible of the work of preparing the results for the use of mariners and others is done at the suboffice at Manila in order to aid in its prompt publication by chart and otherwise. Twenty-two drawings for charts were prepared and forwarded to Washington for printing. Eight of these were for new charts, 9 were drawings for new editions, and 5 were drawings with extensive corrections. Eleven notices to mariners and a new edition of section III of the Sailing Directions were prepared and published.

Details of field operations are given in Appendix 1.

OFFICE WORK.

In the Office the current work was kept up to date, and satisfactory progress was made in the various branches of the work, including computation, plotting, and discussion of results of field work and the preparation of the data for publication by chart or otherwise. Constant proof of the usefulness of the work of the Bureau is afforded by the continued increase in the number of requests for data from the archives of the Survey. All such data suitable for publication are being prepared as rapidly as possible for distribution in printed form.

The computation of heights from the leveling observations and the reduction of astronomic observations were made as the records were received, and this work is practically up to date.

The computation necessary to reduce the measurement of base lines made during this and the preceding fiscal year was completed, and the results of this work are published as Appendix 4 to this report.

An investigation of the figure of the earth, based on existing geodetic work in the United States, was completed, and a report on the subject was presented to the International Geodetic Association by the delegates from the United States to the Fifteenth General Conference of the Association at Budapest, Hungary, in September, 1906.

The results of magnetic observations made on land and at sea during the year have been revised and prepared for publication as Appendix 5 to this report. Good progress has been made in the reduction of the records of the magnetic observatories in the endeavor to prepare for early publication the results for the three years 1902–4. The reduction of the vertical intensity observations made at Cheltenham during certain specified hours in 1902–3 was finished, and the results have been transmitted to the German Government, thus completing the data called for in cooperation with the German Antarctic Expedition of 1902–3. In response to requests from magneticians abroad, data have been furnished from time to time to be used in special investigations of terrestrial magnetism and allied phenomena. The compilation of earthquake data obtained from the seismographs at Honolulu, Cheltenham, and Vieques has been completed to the end of 1906. New tables, showing the secular change of the magnetic declination, and a new isogonic chart of the United States, for 1905, were prepared and published as Appendix No. 4 of my report for 1906. A revision of this chart, based on the observations made by this Bureau and the Department of Terrestrial Magnetism of the Carnegie Institution during the past fiscal year, has been completed, and progress has been made in the preparation of isoclinic and isodynamic charts for January 1, 1905.

Tide Tables containing the predicted tides for numerous ports on the coast of the United States and in foreign countries for the year 1908 were prepared for publication. Copies of the predicted tides for Astoria, Oreg., and Sitka, Alaska, were furnished in advance of publication to the Canadian government in response to a request from the authorities, and similar information relating to Wellington and Auckland, New Zealand, was furnished to the New Zealand authorities upon request.

Twenty drawings for charts were completed for reproduction by photolithography, 12 of these being for new charts.

Five new copper plates were engraved, 8 were etched, 65 were extensively corrected, and minor corrections were made on 793.

One hundred and twenty-two thousand charts were printed for sale and distribution.

Details of Office operations are given in Appendix 2.

The Annual Report of the Survey to Congress for 1906 was prepared for printing and sent to the printer on September 1, 1906, and it was available for distribution on December 1, 1906. The results of the magnetic observations made during the year were published as an appendix to the report with an isogonic chart of the United States showing the conditions existing on January 1, 1905.

The amount appropriated for the Coast and Geodetic Survey for the fiscal year 1907 (June 30, 1906) was $848 915 (exclusive of the appropriation for printing), of which $210 245 was for manning and equipping the vessels of the Survey, $30 000 for repairs and maintenance of vessels, and $50 000 for Office expenses. The remainder of the appropriation was divided between expenses of parties in the field ($257 900) and salaries of field and office forces ($300 770). In addition to the above sums, the appropriations for marking the United States and Canada boundary and for locating and marking the Alaska boundary, made to be expended by the Secretary of State, are disbursed under my direction as Commissioner by the Disbursing Agent of the Coast and Geodetic Survey as special disbursing officer for the Department of State.

OFFICE OF ASSISTANT IN CHARGE.

ANDREW BRAID, *Assistant in Charge.*

The Assistant in Charge has direct supervision of the work of the divisions of the Office as follows: Computing Division; Division of Terrestrial Magnetism; Tidal Division; Drawing and Engraving Division; Chart Division; Instrument Division; Library and Archives Division. He also has charge of the purchase of supplies and of all other expenditures for Office expenses, the care of the public property at the Office, the distribution of the publications of the Survey issued free, and of the sale of the charts, Coast Pilots, and Tide Tables published by the Survey.

Details of the Office operations are given in Appendix 2.

OFFICE OF INSPECTOR OF HYDROGRAPHY AND TOPOGRAPHY.

J. J. GILBERT, *Inspector.*

The work of the parties in the field was inspected whenever necessary, and numerous short trips were made by the Inspector in connection with the repair and maintenance of the surveying vessels.

The routine work in connection with enlistment of crews for the vessels and the administrative examination of the accounts of the vessels was kept up to date.

COAST PILOT.

The work in the Office included the completion of the proof reading of the Coast Pilot for Porto Rico; the preparation and proof reading of U. S. Coast Pilot, Atlantic Coast, Part VI, third edition; the preparation of five supplements to Coast Pilot volumes, and the correction of Coast Pilot volumes to a specified date, coinciding with the date of issue whenever practicable.

THE VESSELS AND THEIR WORK.

THE STEAMER BACHE.

At the beginning of the year this vessel was at Baltimore completing repairs and outfitting for the next season's work. She left Baltimore on July 19 and reached Rockland on the 24th. Special hydrographic examinations were made at Eggemoggin Reach and East Penobscot Bay, Maine, and in the vicinity of Portland, Me., and Boston, Mass.

Magnetic observations were made on land and at sea during the season. The vessel sailed for Baltimore on November 10 and reached there on the 17th. Repairs were made and the vessel sailed for Porto Rico on January 21 and reached San Juan on February 3.

During the season hydrographic work was done off the south coast of Vieques Island and off the north and east coasts of the island of Porto Rico. Magnetic observations were made on land and at sea. The vessel sailed for Baltimore on May 30 and reached there on June 6. Repairs were in progress on June 30.

THE STEAMER EXPLORER.

On July 1 repairs were being made to the ship at Baltimore. She sailed on July 23 and reached Newport, R. I., on the 27th. The work of the season included hydrographic work in Narragansett Bay, Vineyard Sound, Nantucket Sound, and Long Island Sound, and magnetic observations on land and at sea. Field work closed December 11, and the vessel reached Baltimore on the 15th. Repairs were made, and the vessel sailed February 19 for Seattle, Wash., via the Straits of Magellan.

Magnetic observations were made at sea en route and at various ports where the vessel stopped. On June 30 the ship was at sea off the coast of Mexico, north of Magdalena Bay, Lower California.

THE STEAMER ENDEAVOR.

On July 1 this vessel was at Baltimore having repairs made. She sailed on October 12 and reached Fort Monroe on the 13th. Hydrographic work was done in the lower portion of Chesapeake Bay until April 19, when the work closed and the vessel reached Washington on the 20th. The vessel was put out of commission, and remained in this condition during the remainder of the year.

THE STEAMER HYDROGRAPHER.

This vessel was prepared for work and sailed from Baltimore on July 10 to collect information for a new edition of the Coast Pilot of Chesapeake Bay and tributaries. This work was continued until October 12, when the vessel returned to Baltimore and was put out of commission at Curtis Bay on October 16.

The vessel was taken to Baltimore on December 4, and sailed for Hampton Roads, Virginia, on the 28th. She reached there on the 31st, and was engaged on special hydrographic work in connection with the Jamestown Exposition until March 7, when she sailed for Baltimore. She sailed on April 29 to collect data for a revised edition of the Coast Pilot of the Gulf of Mexico, and was engaged on this work at the close of the fiscal year.

THE SCHOONER MATCHLESS.

At the beginning of the year this vessel was at Norfolk having repairs made. She sailed on July 16, and was engaged on hydrographic work in Chesapeake Bay in the vicinity of York and Back rivers and in Mobjack Bay until April 30, when the vessel went to Baltimore to have repairs made. She sailed from Baltimore on June 10, and was at work in Pocomoke Sound during the remainder of the year.

THE STEAMER GEDNEY.

On July 1 this vessel was at Sitka, Alaska, preparing for work, and during the season made surveys of Khaz Bay, Slocum and Ford Arms, and the adjacent waters. The work in this vicinity was completed on October 7, and the vessel proceeded to Sitka, where the *Cosmos* and launch *No. 117* were hauled out of the water. On the 12th the vessel sailed for Ketchikan and reached there on the 15th. A survey was made of Ketchikan, and on October 31 the vessel sailed for Seattle, and reached there on November 6. The vessel was put out of commission on November 20 and repairs were made during the winter. She was put in commission again on May 13, and sailed for Alaska on the 30th. Several places were visited to obtain information for the revision of the Coast Pilot, and the vessel reached Sitka on June 10. The launches were put in order and the vessel proceeded to Davidson Inlet, where she was at work at the close of the year.

THE STEAMER M'ARTHUR.

At the beginning of the year this vessel was engaged in extending the triangulation from the Barren Islands to the Chiswell Islands, Alaska. Hydrographic and topographic work was done in the vicinity of Port Chatham, and work for the season closed on October 16, when the ship sailed for Seattle. She reached that port on October 30, and on December 4 was placed out of commission. Repairs were made and the vessel was placed in commission on April 10, and a survey was made of Swiftsure Bank at the entrance to Juan de Fuca Strait between April 17 and 26. The vessel then returned to Seattle, and on May 22 sailed for Alaska. A survey of Iliamna Bay was begun, and this work was in progress at the close of the year.

THE STEAMER PATTERSON.

This vessel was at work on July 1 in the vicinity of Kodiak Island, Alaska, and the survey of this region was continued until October 27, when the ship sailed for Seattle. She reached her destination on November 6 and was placed out of commission on December 15. Repairs were made and the ship was placed in commission on May 1, and sailed for Kodiak Island on the 26th, and was at work in that vicinity at the close of the year.

THE STEAMER TAKU.

On July 1 the *Taku* was at work making a survey of Latouche Passage, Prince William Sound. The work was completed and on October 1 the vessel was laid up at Orca, Alaska, and the party sailed for Seattle. On June 1 the vessel was placed in commission and on June 11 proceeded to the vicinity of Knights Island, Prince William Sound, where she was at work at the close of the year.

Repairs were made to the vessel by the crew before leaving Orca.

The steamers *Pathfinder*, *Fathomer*, *Marinduque*, *Research*, and *Romblon* were at work during the year in the Philippine Islands, and the account of their work is given in connection with the report of progress in the survey of the Islands.

OFFICE OF INSPECTOR OF GEODETIC WORK.

J. F. HAYFORD, *Inspector*.

The duties of the Inspector were performed at the Office in Washington, where the records of parties at work in the field were examined as they were received from the field, and an effective supervision over the work was maintained in this way.

The most important event of the year was the completion of the primary triangulation northward along the Pacific coast to a connection with the Puget Sound triangulation in the vicinity of Tacoma.

The United States Standard Datum can now be extended from central California through this triangulation to the work along the Columbia River and Puget Sound, and through a connection at Semiahmoo Bay to the forty-ninth parallel triangulation and along this international boundary to Montana.

This primary work has been connected with the coast triangulation at two places in Oregon and other connections are in progress.

The work just completed was done in a region where it was formerly supposed that the progress would be slow and the cost excessive, but the work was done with remarkable rapidity and at a very small cost, comparatively.

A field party completed the measurement of a series of six primary base lines in the States of Texas, Oregon, Washington, South Dakota, and Minnesota. These base measurements mark a new epoch in the history of this class of work. The cost per kilometer was 25 per cent less than the cost of similar work previously done by the Survey, and demonstrated that base measurements of the required degree of accuracy can be made rapidly and economically in daylight with invar tapes. By the use of these tapes the cost of base measurement can be still further reduced.

OFFICE OF THE INSPECTOR OF MAGNETIC WORK.

L. A. BAUER, *Inspector*, July 1 to August 31.[a]
R. L. FARIS, *Inspector*, September 7 to June 30.

The instructions for magnetic work in the field were prepared, and the information required by the various field parties was furnished by the Inspector.

The activity of the Survey in magnetic work may be summarized as follows:

OBSERVATORY WORK.

The magnetic observatories at Cheltenham, Md., Baldwin, Kans., Honolulu, Hawaii, Sitka, Alaska, and Vieques, P. R., were kept in continuous operation, and observations were obtained with a self-registering magnetograph and a seismograph at each observatory, except at Baldwin, Kans., where there was no seismograph. The

[a] Resigned August 31, 1906.

facilities of the observatory at Cheltenham for standardizing magnetic instruments were used during the year by the Department of Research in Terrestrial Magnetism of the Carnegie Institution of Washington; by the United States Weather Bureau; by Doctor Angenheister, of the Samoan (German) Observatory. A record of nearly 100 earthquakes was made by the seismograph at the Honolulu Observatory. At Sitka a comparison was made between the observatory instruments and those of Capt. R. Amundsen, used in his magnetic work in North America. New buildings were erected for the Porto Rico Observatory, and the instruments were moved from their old location to these new buildings.

MAGNETIC WORK ON LAND.

The magnetic declination, dip, and intensity were determined at 287 stations distributed over 38 States and Territories, including Porto Rico and the Philippine Islands, as summarized in the following table:

State or Territory.	Localities.	Stations.	Old localities reoccupied.	Declinations observed.	Dips observed.	Intensities observed.
Alabama	3	3	2	3	3	3
Alaska	9	10	2	11	4	5
California	10	10	2	10	10	10
Colorado	21	21	2	21	21	21
Connecticut	1	1	0	1	1	1
District of Columbia	1	1	1	1	1	1
Florida	1	1	0	1	1	1
Hawaii	1	1	1	1	1	1
Idaho	8	8	1	8	8	8
Indiana	5	5	1	5	5	5
Indian Territory	1	1	0	1	1	1
Kansas	5	5	4	9	8	9
Maine	2	2	2	3	3	3
Maryland	2	3	2	7	6	7
Massachusetts	3	3	2	3	3	3
Michigan	3	3	1	3	3	3
Minnesota	2	2	1	2	2	2
Missouri	2	2	2	2	2	2
Montana	28	30	6	30	30	30
Nebraska	4	4	2	4	4	4
Nevada	2	2	1	2	2	2
New York	2	2	1	2	2	2
North Carolina	9	10	9	10	10	11
North Dakota	17	18	3	18	18	18
Ohio	5	5	4	5	5	5
Oklahoma	2	2	1	2	2	2
Oregon	28	28	3	28	28	28
Pennsylvania	2	3	2	3	3	2
Porto Rico	2	10	2	10	3	3
Philippines	3	3	0	3	3	3
Rhode Island	1	1	1	1	1	1
South Dakota	22	23	4	23	23	23
Tennessee	3	4	1	5	5	5
Texas	2	2	0	2	2	2
Utah	11	11	1	11	11	11
Virginia	11	11	6	11	10	11
Washington	4	4	2	4	4	4
Wyoming	19	19	2	19	19	19
Foreign countries	12	13	5	13	13	13
Total	269	287	83	300	282	288

MAGNETIC WORK AT SEA.

The observations made on shipboard are summarized in the following table:

Vessel.	Region.	Results from swings.			Observations on three headings.		
		Declination.	Dip.	Intensity.	Declination.	Dip.	Intensity.
Explorer	Atlantic	19	18	18	52	33	33
Bache	do	18	18	18	2	2	2
Explorer	Pacific	19	19	19	67	49	49
Patterson	do	6	9	9	0	0	0
Pathfinder	Philippines	5	0	0	0	0	0
Marinduque	do	4	0	0	7	0	0
Total		71	64	64	128	84	84

A very important series of observations was made on board the *Explorer* while on her way from Baltimore, Md., to San Diego, Cal., by way of the Straits of Magellan. The observations obtained in the equatorial regions of the Pacific Ocean are especially valuable as contributions to the knowledge of the magnetic elements in this locality.

The steamer *Bache*, on her way to Porto Rico and return, followed courses inside and outside the usual route in order to make observations in regions where no observations had been made. More observations were obtained at sea than during any previous year.

OFFICE OF DISBURSING AGENT.

SCOTT NESBIT, *Disbursing Agent.*

The Disbursing Office of the Coast and Geodetic Survey has charge of all of the appropriations made for that service and, in addition, the appropriations made to the State Department for the survey and marking of the boundary between the United States and Canada and of the boundary between Alaska and Canada. The extremely wide field of work covered by these appropriations compel payments to be made in all parts of the United States proper and in the most remote regions of the possessions under the jurisdiction of the United States, especially in Alaska, Porto Rico, Hawaii, and the Philippine Islands. The services of more than 70 bonded chiefs of party are required to make these payments at the remote points occupied by the working parties of this Survey, both on land and sea. All of the public funds used by these officers are advanced from the central Disbursing Office of the Survey, and the resulting bookkeeping and auditing are done in that office. Necessarily a very extensive line of correspondence results, as, in addition to all pay and salaries, the manning, equipping, outfitting, and repairing of the vessels of the Survey, the purchase and sale of clothing and small stores, the system of allotments made by seamen and other employees, and the entire expense of the field work of the service, which is both extensive and varied, and the survey and marking of the two boundary lines mentioned, are financed entirely from the central Disbursing Office. The above-mentioned chiefs of party are bonded in the sums of from $2,000 to $10,000 each, and while acting as chiefs of party these officers receive from time to time such advances of public funds from the Disbursing Agent as are approved by the Superintendent and 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 made to him, and on the other hand receiving credit for all proper expenditures made by him, when presented on regularly supported vouchers after such accounts have been audited in the office of the Disbursing Agent, found to be correct, and approved by the Superintendent of the Survey. All of these accounts, after they have received the administrative examination required by law in the office of the Superintendent of the Coast and Geodetic Survey, are, with their supporting vouchers, sent through the Department of Commerce and Labor to the Auditor for the State and other Departments for examination and audit by him. This system has met the needs of this Survey and results, in the main, in economy and good order in its expenditures. A very large proportion of the appropriations named is now being expended in the survey of the most remote waters of Alaska and the Philippine Islands, and, in the survey and marking of the boundary between Alaska and Canada, far in the interior of that territory. An itemized statement of receipts and expenditures is submitted to Congress each year, as required by law, and is printed as a Congressional document.

OFFICE OF EDITOR OF PUBLICATIONS.

The Annual Report of the Superintendent (pp. 1–230) covering the progress of the work of the Survey during the fiscal year 1906 was completed and sent to the Public Printer through the Secretary of Commerce and Labor on September 1, and the last proof was read and returned to the Printer on October 22. Copies of the Report were received for distribution on December 1, 1906.

The annual statement covering the work of the year was prepared and transmitted to the Secretary of Commerce and Labor. Numerous assignments to temporary duty were completed.

The publications of the Coast and Geodetic Survey are given in the following list:

Report of the Superintendent of the Coast and Geodetic Survey, showing the progress of the work from July 1, 1905, to June 30, 1906, 230 pages, with the following appendices published as separates:

No. 3. Results of Magnetic Observations made by the Coast and Geodetic Survey between July 1, 1905 and June 30, 1906. Reprint, 106 pp.

No. 4. Distribution of the Magnetic Declination in the United States for January 1, 1905, with Isogonic Chart and Secular Change Tables. Reprint, 16 pp.

Tide Tables for the year 1907, 594 pp.

Tide Tables for the Atlantic Coast of the United States, including Canada and the West Indies, for the year 1907. Reprint from Tide Tables 1907, 175 pp.

Tide Tables for the Pacific Coast of the United States, together with a number of foreign ports in the Pacific Ocean. Reprint from Tide Tables for 1907, 206 pp.

United States Coast Pilot. Atlantic Coast, Part VI. Chesapeake Bay and Tributaries. Third edition, 192 pp.

United States Coast Pilot. West Indies, Porto Rico, first edition, 114 pp.

United States Coast Pilot, Atlantic Coast, Part VII. From Chesapeake Bay Entrance to Key West. Third edition, 221 pp.

Survey of Oyster Bars, Anne Arundel County, Maryland. Descriptions of Boundaries and Landmarks, and Report of Work of United States Coast and Geodetic Survey in Co-operation with Maryland Shell Fish Commission. 106 pp.

Notices to Mariners, Nos. 349–351.

The publications named below were prepared and published in Manila, P. I., and issued from the suboffice at that place as follows:

- General Instructions for Coast Surveys in the Philippine Islands. Published at Manila, P. I., in 1906, 92 pp.
- Philippine Islands Sailing Directions, Section II, Southwest and South Coasts of Luzon and Adjacent Islands. Third edition, 1906, 69 pp.
- Philippine Islands Sailing Directions, Section III, Panay, Negros, Cebu, and Adjacent Islands. Third edition, 1906, 109 pp.
- Philippine Islands Sailing Directions, Sections VI and VII, Mindoro Strait, Palawan Island, and Sulu Sea and Archipelago. Second edition, 1906, 230 pp.
- Philippine Islands Notices to Mariners, Nos. 5 to 10 of 1906 and Nos. 1 to 5 of 1907.

APPENDIX 1

REPORT 1907

DETAILS OF FIELD OPERATIONS

CONTENTS.

DETAILS OF FIELD OPERATIONS.

UNITED STATES.

CALIFORNIA.

[B. A. BAIRD.]

The tide gauge at the Presidio of San Francisco was connected by leveling with various bench marks in San Francisco and with those across the bay at Sausalito. This work involved 29 kilometers of leveling, and 26 old bench marks were recovered and used.

The elevations of these bench marks were determined before the earthquake of April, 1906, and these elevations were determined for the purpose of measuring any movement which remains as the effect of the earthquake. The results of this work are given in Appendix 3 of this Report, which treats of the earth movements.

MINNESOTA.

[WILLIAM BOWIE.]

SUMMARY OF RESULTS.—Astronomic observations: 2 azimuths determined. Triangulation: 25 stations occupied.

The triangulation in Minnesota in the vicinity of the ninety-eighth meridian was continued by Assistant Bowie from July 13 to October 13. A signal-building party was organized, and rapid progress was made in the erection of signals, so that there was no delay on this account. Observations were made to determine the horizontal and vertical angles at 25 triangulation stations, and the work was extended over a lineal distance of 146 miles, or from the vicinity of Fergus Falls to Stephen. Observations to determine an azimuth were made at two triangulation stations during the season. Signals were erected at all triangulation stations northward to the boundary line between the United States and Canada.

FLORIDA, GEORGIA, AND SOUTH CAROLINA.

[WILLIAM BOWIE; J. S. HILL.]

The determination of the differences of longitude between the places named in the following list was assigned to Assistants Bowie and Hill, in charge of cooperating parties: Key West and Miami, Fla.; Miami and Jupiter, Fla.; Jupiter and Sebastian, Fla.; Sebastian and Daytona, Fla.; Daytona and Fernandina, Fla.; Fernandina, Fla., and

Atlanta, Ga.; Fernandina, Fla., and Darien, Ga.; Darien, Ga., and Allendale, S. C.; Allendale, S. C., and Doraville, Ga.; Doraville and Atlanta, Ga.

The work began on February 4 and was completed on June 4. The determinations of the differences of longitude were made by the telegraphic method, and transit micrometers were used in making observations.

The observers occupied the stations in succession, the same observer always having the forward station and the outfit of the rear station being shipped to the second station in advance in each case.

INDIANA, MARYLAND, NEW YORK, AND OHIO.

[J. E. Burbank.]

The work at the magnetic observatory at Cheltenham, Md., was continued without interruption during the year. A continuous record of the relative force of the three elements of terrestrial magnetism was obtained. On the 1st and 15th of each month until February, in accordance with an international programme, one of the magnetographs was made to record at a rapid rate for a period of two hours. Observations were made once each week to determine the absolute value of the magnetic forces.

The seismograph was kept in operation during the year and a record of all earth tremors was obtained. The wireless telegraph receiving apparatus continued work in a satisfactory manner and was used in receiving time signals.

In January and February an observer from the Weather Bureau visited the observatory, studied the methods of work, and standardized a set of instruments belonging to the Weather Bureau. In May Mr. Burbank visited the Weather Bureau Observatory at Mount Weather to make additional comparisons between the instruments used at the two observatories. The facilities for standardizing magnetic instruments were also used by members of Department of Research in Terrestrial Magnetism of the Carnegie Institution of Washington.

In June observations of the three elements of terrestrial magnetism were made at the stations named below under the direction of Mr. Burbank by observers detailed to work under his direction: In *Indiana*, at Brookville, Connersville, Newcastle, Richmond, and Winchester; in *New York*, at Auburn and Ithaca; and in *Ohio*, at Cincinnati and Marietta.

ALABAMA, DISTRICT OF COLUMBIA, FLORIDA, GEORGIA, INDIAN TERRITORY, KANSAS, MINNESOTA, NEBRASKA, NORTH CAROLINA, NORTH DAKOTA, OKLAHOMA, SOUTH CAROLINA, SOUTH DAKOTA, TENNESSEE, TEXAS, AND VIRGINIA.

[W. H. Burger.]

Summary of results.—Astronomic observations: 24 azimuths determined and 30 latitudes determined. Magnetic observations: 30 stations occupied.

On July 1 Assistant Burger was engaged in making astronomic and magnetic observations, and this work was continued during the fiscal year. Observations to determine an azimuth were made at 2 stations in Alabama, 1 in Georgia, 3 in Kansas, 1 in Minnesota, 3 in Nebraska, 1 in North Carolina, 3 in South Dakota, 3 in Tennessee, 3 in Texas, and 4 in Virginia. Latitude was determined at 2 stations in Alabama, 1 in Florida, 3 in Kansas, 2 in Minnesota, 3 in Nebraska, 1 in North Carolina, 1 in North Dakota, 1 in Oklahoma, 1 in South Carolina, 4 in South Dakota, 4 in Tennessee, 3 in Texas, and 4 in Virginia.

Advantage was taken of the presence of the observer in the various localities mentioned to have magnetic observations made at 24 stations distributed as follows: 3 in Alabama, 1 in Florida, 1 in Indian Territory, 4 in Kansas, 2 in Minnesota, 3 in Nebraska, 1 in North Carolina, 1 in North Dakota, 2 in Oklahoma, 4 in South Dakota, 3 in Tennessee, 2 in Texas, and 3 in Virginia.

The observations were made to supply astronomic data along the ninety-eighth meridian and in certain other regions where additional astronomic observations were needed for the proper discussion of the triangulation in those regions.

The work was arranged in such order as would insure the most favorable weather conditions and the least amount of travel consistent with this requirement.

Many of the observation stations were triangulation points on mountains, and considerable delay in this portion of the work resulted from difficulties of transportation and from unfavorable weather and the difficulty of using long lines in determining an azimuth at such stations. At nearly all the stations on mountains it was necessary to clear the lines used in determining azimuth, at both ends.

Whenever it was necessary, the latitude station was connected with the triangulation, and in some cases additional stations were established and marked in making this connection.

In response to a request from the Superintendent of Public Buildings and Grounds at Washington, the elevation of certain bench marks on the Washington Monument were redetermined from other bench marks in the vicinity to form a portion of the record bearing on the stability of the structure.

CALIFORNIA, COLORADO, KANSAS, MISSOURI, MONTANA, NEBRASKA, SOUTH DAKOTA, UTAH, AND WYOMING.

[S. A. DEEL.]

STATIONS OCCUPIED.—*California*: Barstow, Stockton, and Ukiah. *Colorado*: Aspen, Boulder, Buena Vista, Canon City, Cortez, Craig, Delta, Fort Collins, Glenwood Springs, Greeley, Hahns Peak, Meeker, Pagosa Springs, Red Cliff, Rico, Steamboat Springs, Sulphur Springs, and Toponas. *Missouri*: Chillicothe and Kansas City. *Montana*: Birney. *Nebraska*: Chadron. *South Dakota*: Belle Fourche and Custer. *Utah*: Beaver, Dragon, Green River, Junction, Kanah, Manti, Modena, Panguitch, Parowan, Richfield, and St. George. *Wyoming*: Arvada and Sundance.

The work at the magnetic observatory at Baldwin, Kans., was continued during the year under the direction of Magnetic Observers W. B. Keeling (July 1 to August 24) and S. A. Deel (August 25 to June 30).

A practically continuous record of the relative force of the three elements of terrestrial magnetism was obtained. Observations were made at least once every week to determine the absolute value of the magnetic elements. Meteorological observations were continued during the year. In addition to the work at the observatory, magnetic observations were made at the stations named above by observers detailed to work under Mr. Deel's direction. On June 30 this work was in progress in Missouri.

MASSACHUSETTS, RHODE ISLAND, AND VIRGINIA.

[W. C. DIBRELL, Commanding, Steamer *Explorer*.]

SUMMARY OF RESULTS.—Hydrography: 20 square miles of area covered; 1 056 miles of lines sounded; 45 849 soundings made; 7 tide stations occupied, and 4 hydrographic sheets completed. Magnetic observations: 15 stations occupied on land and 123 stations occupied at sea.

Hydrographic work along the coast of Massachusetts and Rhode Island was assigned to Assistant Dibrell, and he sailed from Baltimore on July 23.

Magnetic observations were made on board the vessel in Hampton Roads, once en route to Newport, and in Narragansett Bay off the city.

A hydrographic examination was made of the shoal area in Narragansett Bay just north of Dyer Island, and the rock on which the barge *Ohio*, drawing 14 feet, struck in 1905, was found and its position determined.

A hydrographic resurvey was made of the Middle Ground in Vineyard Sound and of L'Hommedieu and Hedge Fence shoals in Nantucket Sound. Hydrographic work was also done on Orion Shoal in the approach to Nantucket Sound. The progress of the work was greatly delayed by unfavorable weather. Magnetic observations were made on shore at Vineyard Haven and on board the vessel outside the harbor.

On December 3 the vessel sailed for Baltimore and en route made examinations of Intrepid Rock in Fishers Island Sound, and of a small rock in Hart Island Roads. An unsuccessful search was made for a rock reported to be off Peacock Point near Oyster Bay, N. Y. Magnetic observations were made on shore at Stonington, Conn., on board the vessel in Fishers Island Sound, and near Falkner Island and each day while the vessel was at sea en route to Baltimore, including observations in Lynnhaven Roads at the entrance to Chesapeake Bay and on shore in Baltimore. The vessel reached Baltimore on December 15, and the magnetic work was completed by making observations on shore.

The steamer *Explorer* sailed from Baltimore on February 20, and on June 30 was off the coast of Mexico north of Magdalena Bay, Lower California, en route to Seattle, Wash., under orders to proceed to Alaska and take part in survey of the coast of that Territory. Advantage was taken of the ship's voyage to secure magnetic observations in the regions traversed, and those secured in the equatorial regions of the Pacific Ocean are especially valuable. The vessel proceeded from Callao to Panama by way of Chatham Island, Galapagos Islands, and magnetic observations were made on shore and at sea off the island.

WASHINGTON.

[E. F. DICKINS, Commanding, Steamer *McArthur*.]

SUMMARY OF RESULTS.—17 square miles of area covered; 66 miles of lines sounded, and 310 soundings made.

In response to a request from the Light-House Board a hydrographic examination of Swiftsure Bank, at the entrance to Juan de Fuca Strait, was made by Assistant Dickins, commanding the Steamer *McArthur*.

The work began on April 17 and was completed on the 27th. An examination was also made in the vicinity of Duncan Rock.

CALIFORNIA AND TEXAS.

[W. B. FAIRFIELD.]

SUMMARY OF RESULTS.—*Texas:* 1 station occupied. *California:* 20 stations occupied and 32 geographic positions determined.

The determination of the geographic position of Sabine Bank Light-house in the Gulf of Mexico was in progress on July 1, and Assistant Fairfield was at Sabine Pass Light-house on that date. The observations were finished the following day and on July 6 all the work in this vicinity was completed.

The reoccupation of certain triangulation stations in California for the purpose of determining whether their relative positions were affected by the San Francisco earthquake of April, 1906, was assigned to Assistant Fairfield, and he reached Tomales Bay on August 11. Some preliminary work had been done before his arrival and five stations had been recovered. Three additional stations in the old triangulation were recovered, and some new stations were established. Horizontal angles were measured at these stations, and the work was completed on November 20, after great delay on account of fog and strong winds.

The party was then moved to Redwood, Cal., and five triangulation stations in the vicinity of Pulgas Base Line were recovered and two new ones were established.

Horizontal angles were measured at three of the primary triangulation stations, all of which were on mountains, and serious delay resulted from rain, fog, and snow and the impassable condition of the roads at certain times.

The work was completed and the party was disbanded on May 31.

DISTRICT OF COLUMBIA.

[O. W. FERGUSON.]

In response to a request from the Director of the Bureau of Standards, Assistant Ferguson was directed to make a topographic survey of the grounds of the Bureau and of the land in its immediate vicinity with sufficient detail for a map of the grounds on a large scale (40 ft. = 1 inch).

The area was divided into squares with sides equal to 100 feet by using a theodolite, and the corners were marked. The elevations of these marks were determined by leveling, and they were then used in the topographic survey with a plane table. The contour interval was fixed at 5 feet, and all topographic details were located.

The work began on May 1 and was in progress at the close of the fiscal year. It was temporarily suspended from May 26 to June 5.

CANADA, IDAHO, MONTANA, NORTH CAROLINA, NORTH DAKOTA, SOUTH DAKOTA, TENNESSEE, VIRGINIA, AND WASHINGTON.

[J. A. FLEMING.]

STATIONS OCCUPIED.—*Canada:* Gateway. *Idaho:* Bonners Ferry, Challis, Grangeville, Harrison, Lewiston, Pierce, St. Anthony, and Salmon. *Montana:* Avery, Big Sandy, Big Timber, Billings, Browning, Chouteau, Deer Lodge, Divide, Fort Benton, Glendive, Great Falls, Havre, Jennings, Judith, Kalispell, Missoula, Neihart, Ovando, Poplar, Red Lodge, Ronan, Shelby, Sweet Grass, Tokna, Wisdom, and Zortman. *North Dakota:* Ashley, Crosby, Dickinson, Fargo, Fayette, Garrison, Haley, Kenmare, Linton, Medora, Napoleon, New England, Portal, Schafer, White Earth, and Williston. *South Dakota:*

Bixby, Chance, Creston, Harding, Highmore, Interior, Murdo, Pierre, Presho, Rapid City, Reva, Roscoe, Seim, Selby, Stearns, and Vale. *Tennessee:* Knoxville. *Virginia:* Boydton, Bristol, Cape Henry, Charlottesville, King George, Little Creek Inlet, and Princess Anne. *Washington:* Colville and Spokane.

The extension of the magnetic work in various localities as stated above was assigned to Magnetic Observer Fleming, and three observers were ordered to work under his direction. The work was in progress on July 1 and was completed on October 29.

Observations to determine the three elements of terrestrial magnetism were made at the stations named above by the observers assigned to the party. Most of the stations were marked in a permanent manner with stone monuments and the others were marked with such material as could be conveniently obtained. Observations had been made previously at several of the stations.

VIRGINIA.

[S. FORNEY.]

SUMMARY OF RESULTS.—106 square miles of area covered; 51 miles of shore line of rivers surveyed; 67 miles of shore line of creeks surveyed; 24 miles of shore line of ponds surveyed; 247 miles of roads surveyed, and 4 topographic sheets completed.

The topographic resurvey of the south shore of the Potomac River was completed by Assistant Forney from Nomini Cliffs to Smiths Point, at the mouth of the river. This includes a survey of a portion of the shore line of Yeocomico and Coan rivers.

The survey was extended inland to the high land overlooking the river, and included the location of contours, roads, creeks, and all other topographic features. In the vicinity of Nomini Cliff the land reaches an elevation of 190 feet above mean high water, the highest point within the area surveyed.

The banks of the rivers are being eroded, and many of the old triangulation stations have disappeared. The position of the shore line on Gwynns Island and at the southern entrance to Milford Haven has changed very much, and both banks of the Piankatank River between its mouth and Stove Point have receded.

DISTRICT OF COLUMBIA, MINNESOTA, AND VIRGINIA.

[O. B. FRENCH.]

SUMMARY OF RESULTS.—Base measurement: 1 base line measured. Topography: 18 square miles of area covered; 37 miles of general coast line surveyed; 36 miles of shore line of creeks surveyed; 134 miles of roads and railroads surveyed, and 2 topographic sheets completed. Triangulation: 20 square miles of area covered; 4 stations occupied, and 31 geographic positions determined.

On July 1 base measurement was in progress in Minnesota under the direction of Assistant French. The work at the Royalton base line of the triangulation along the ninety-eighth meridian was completed on July 11, and the party was disbanded on that date.

At Royalton all the tapes used in measuring the base lines during the season were standardized on a 50-meter comparator, whose length was determined with the iced bar.

A discussion of the work of the season and the results of the measurement of the base lines is published in appendix 4.

In November and December (November 22 to December 17) topographic work was done in the vicinity of Hampton Roads, Virginia, to be used in the construction of an anchorage chart as requested by the Naval Board on the Jamestown Exposition. In connection with this work observations were made at four triangulation stations, and the geographic positions of numerous prominent objects, visible from Hampton Roads, were determined. The work in the vicinity of the exposition grounds covers the region from Tanners and Masons creeks to Sewall Point. A survey was also made of the water front from Newport News shipbuilding yard to the town of Hampton and extended inland to include the location of all streets and roads within the area shown on the published chart.

In response to a request from the Superintendent of Public Buildings and Grounds in the District of Columbia, the position of a point near the Potomac River, on the prolongation of the line between the center of the dome of the Capitol and the Washington Monument, was determined and marked, and a survey was made of the area between the Washington Monument, B street south, and the Potomac River. In connection with this work the geographic positions of a number of objects were determined.

FLORIDA, MAINE, AND VIRGINIA.

[N. H. HECK.]

The examination of channels and harbors with the long wire sweep was continued by a party under charge of Aid Heck. The work began in East Penobscot Bay at Great Spruce Head on August 3 and was extended to Devils Head in Eggemoggin Reach by October 4. After that date work with the sweep was begun in Jericho Bay and was continued until November 6, when the work was stopped for the winter. Forty-two square miles of area were covered with the sweep and this involved passing over a linear distance of 423 miles. In Eggemoggin Reach the sweep was passed over all the area outside of the 6-fathom (36 feet) curve, and 15 reefs not indicated on the charts were discovered within the area investigated. In Jericho Bay two additional uncharted reefs were discovered. Three chartered power boats were used in operating the sweep.

In December Mr. Heck was assigned to the command of the steamer *Hydrographer* under orders to do special work in Hampton Roads, Virginia, in connection with the Jamestown Exposition.

Hydrographic work was done to establish the 4 and 5 fathom curves between Old Point Comfort and Newport News Bar and to develop the anchorage in the vicinity of Newport News Middle Ground. An area of 2½ square miles was covered by soundings, involving 112 miles of lines sounded and 6 621 soundings. Three ranges were determined on the north shore of Hampton Roads and one on Old Point Comfort. Two marks were placed on each range in the water on Hampton Bar and one on shore on each range. The positions of the marks were determined by triangulation. The positions of three electric railways in the vicinity of Willoughby Spit were determined and 5 miles of their lines were located.

The work in the vicinity of Hampton Roads was completed between January 2 and February 21.

From March 10 to June 4 examinations were made with the long wire sweep of certain selected areas in the vicinity of Key West, Fla. The examinations were made for the purpose of ascertaining whether better or deeper channels exist through the reefs in this vicinity and to determine what dangers to navigation exist above certain selected depths. Thirteen square miles of area were covered with the sweep, which involved passing over a linear distance of 139 miles. In certain regions the drag was set at a depth of 35 feet and in others at 30 feet.

Nine reefs were discovered with a less depth than that shown on the chart. The work closed on June 4 on account of unfavorable weather and health conditions.

OREGON AND WASHINGTON.

[J. S. HILL.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth measured. Reconnaissance: 1 400 square miles of area covered and 19 triangulation stations selected. Triangulation: 4 700 square miles of area covered, 24 stations occupied, and 30 geographic positions determined.

The completion of the primary triangulation in Oregon and Washington and the connection of this work with the triangulation in the immediate vicinity of the coast was in progress on July 1 under the direction of Assistant Hill. This work began in June and the statistics given above cover the work of the season, which ended on November 17.

The primary work was connected with the triangulation in the immediate vicinity of the coast at Coos Bay, Oregon, and a reconnaissance was made for a similar connection at Port Orford and at Cape Sebastian.

Extensive forest fires caused serious delay in the work, the party being detained at one station for more than three weeks waiting for the smoke to clear away.

CALIFORNIA, MICHIGAN, NEVADA, OHIO, OREGON, PENNSYLVANIA, AND WASHINGTON.

[W. M. HILL.]

STATIONS OCCUPIED.—*California:* Alturas, Bartle, Bieber, Madeline, Montgomery, Susanville, and Yreka. *Michigan:* Detroit, Monroe, Mount Clemens, and Port Huron. *Nevada:* Amos, McDermitt, and Winnemucca. *Ohio:* Cleveland, Toledo, and Youngstown. *Oregon:* Alba, Andrews, Bly, Burns, Canyon City, Condon, Denio, Diamond, Heffner, Fort Klamath, Klamath Falls, Lakeview, Mitchell, Moro, Paisley, Paulina, Pendleton, Plush, Prineville, Rosland, Shaniko, Silver Lake, Sisters, The Dalles, Three Mile Creek, Tygh Valley, and Umatilla. *Pennsylvania:* Allegheny and Harrisburg. *Washington:* Stevenson.

Magnetic work was in progress in Oregon on July 1 and was continued until October 15, when the last observations were made and the observer started to Washington.

During this period observations were made in California, Nevada, Oregon, and Washington, at the stations named above, to determine the three elements of terrestrial magnetism. Most of the travel was away from the railroads and the work was greatly delayed in consequence. Field work was resumed on June 5 and continued during the remainder of the fiscal year. Stations were occupied in Michigan, Ohio, and Pennsylvania, as stated above. These stations were marked by stone posts. The work was in progress in Michigan at the close of the year.

COLORADO AND WYOMING.

[W. B. KEELING.]

STATIONS OCCUPIED.—*Colorado:* Holyoke and Wray. *Wyoming:* Basin, Buffalo, Cheyenne, Cody, Douglas, Lander, Lovell, Mayoworth, Meeteetse, Myersville, Pacific, Powder River, Sheridan, Shoshone, Thermopolis, Valley, and Worland.

The magnetic survey of the country was extended by observations at the stations named above to determine the three elements of terrestrial magnetism. These observations were made under the direction of Mr. Keeling by an observer who was detailed to report to him for that purpose. The work was in progress on July 1 and was completed on September 13.

VIRGINIA.

[J. B. MILLER, Commanding, Steamer *Hydrographer*.]

SUMMARY OF RESULTS.—Hydrography: 167 square miles of area covered, 2 593 miles of lines sounded, 93 447 soundings made, 6 tide stations occupied, and 4 hydrographic sheets completed. Topography: 1 square mile of area covered. Triangulation: 6 stations occupied.

In response to a request from the Secretary of the Treasury, a topographic survey was made (September 10 to 15) of Fishermans Island, at the entrance to Chesapeake Bay, where a national quarantine station is located. Several old triangulation stations were used, and two new stations were established on the island. Four men and a boat were furnished by the steamer *Hydrographer* for this work, which was completed on September 15.

On October 25 Assistant Miller, commanding the steamer *Hydrographer*, began hydrographic work in Chesapeake Bay at the south end.

The work continued until April 15, and during this time a hydrographic survey was made of the eastern part of Horseshoe Shoal, off Old Point Comfort; of Plum Tree Bar, off Back River; of the tail of Horseshoe Shoal; of the long narrow Middle Ground Shoal; and of the ship channel leading to Baltimore.

Lines of soundings were made at intervals of 200 meters and these were crossed with a similar set of lines.

There was a great deal of stormy weather during the season, and the signals erected in the water were carried away almost immediately.

A hydrographic survey was also made of Willoughby Bay and approaches, and the positions of six beacons, established in connection with the anchorage for naval vessels off the Jamestown Exposition, were determined. The work closed on April 15, as stated above, and the vessel proceeded to Washington.

IDAHO, OHIO, AND PENNSYLVANIA.

[E. H. PAGENHART.]

SUMMARY OF RESULTS.—313 kilometers of line completed and 124 bench marks established.

The extension of the standard levels was in progress in Idaho on July 1, and this work was continued by Aid Pagenhart until August 7 and after that date by Aid H. M. Roy.

The work completed by Mr. Pagenhart extends from the vicinity of Pocatello to Humphrey, along the Oregon Short Line Railway. Three of the bench marks established by the railway company were used as permanent bench marks in this line.

The distance leveled was 201 kilometers and 58 permanent bench marks were established. The line was leveled once in each direction and numerous temporary bench marks were used to compare the results from the two measures. When the required degree of accuracy was not obtained between adjacent bench marks by leveling between them, as stated above, the work was repeated until the discrepancy was reduced to the allowable limit.

In September and October leveling in Ohio and Pennsylvania was done to eliminate discrepancies in certain railroad levels which it was desirable to use in adjusting the level net of the United States. These levels were extended along the Baltimore and Ohio Railway between Greenwich and Sullivan, Ohio (17 kilometers); between Ellwood City and Monaco, Pa. (23 kilometers), over the Baltimore and Ohio, Pennsylvania, and Erie railways; and between Alliance and Youngstown, Ohio (72 kilometers), over the Baltimore and Ohio and the Pennsylvania railways.

CALIFORNIA.

[J. F. PRATT.]

In response to a request from the Navy Department, the preparation of a speed-trial course in the vicinity of Goleta, on Santa Barbara Channel, was in progress on July 1, and the work was completed on the 19th.

A suitable range, 1 nautical mile in length, was selected and marked by erecting front and rear beacons at each end. These range beacons were connected with the coast triangulation and the distance between them along the trial course was determined in this way. Substantial structures, securely anchored to concrete foundations, were erected and they will last many years. Assistance was rendered Commander H. T. Mayo, U. S. Navy, Light-House Inspector of the Twelfth district, at his request, in selecting the proper positions for the buoys to mark the trial course and in determining their positions.

A portion of the work involved in the investigation of the effect of the San Francisco earthquake of April 18, 1906, upon the triangulation in California was assigned to Assistant Pratt, and he began this work on August 4.

All the necessary preparations, involving the recovery of old stations, the posting of heliotropers, etc., were made, and the observing party reached the first station on September 21. The work was continued, whenever the weather and other conditions permitted, during the remaining portion of the fiscal year. Observations were made to determine the horizontal angles at five primary stations, and an azimuth was measured at one station. The weather was exceptionally unfavorable and caused serious delay at all stations, to secure suitable conditions for observations over the long lines included in the work.

Heliotropes by day and signal lights at night were used at the stations observed upon, but long delays at all the stations resulted from cloudy weather and fog at night.

MAINE, MASSACHUSETTS, AND VIRGINIA.

[H. P. RITTER.]

In response to requests from the Navy Department, additional work was done on the Provincetown, Mass., speed-trial course. Two new ranges were established, the necessary surveys were made, and new range beacons were designed and erected. The distance between the ends is a nautical mile, and each range was marked by a front and a rear beacon.

An investigation and survey was also made for the selection of a suitable position for a speed-trial course in the vicinity of Rockland, Me., and a recommendation in regard to the matter was furnished to the Navy Department.

A resurvey of the shore line of Willoughby Bay, Virginia, was made in connection with the issue of an anchorage chart for the Naval Board of the Jamestown Exposition.

A survey was made of the low-water line of Fishermans Island, Virginia, as requested by the Treasury Department, to determine the boundary of the quarantine reservation for the Public Health and Marine-Hospital Service, and the boundary was marked in fourteen places, at the salient points, with iron pipes.

CALIFORNIA.

[A. F. RODGERS.]

The suboffice in San Francisco was continued in charge of Assistant Rodgers, who attended to numerous duties, many of them matters of routine, as the representative of the Superintendent on the Pacific coast.

ALABAMA, FLORIDA, LOUISIANA, MARYLAND, AND VIRGINIA

[JOHN ROSS, Commanding, Steamer *Hydrographer*.]

The collection of data in the field for the revision of United States Coast Pilot, Atlantic Coast, Parts VI and VIII, was assigned to Nautical Expert Ross, and he was engaged on this work in connection with Part VI from July 10 to October 11. During this time the waters of Chesapeake Bay and tributaries were covered, and information was obtained from local pilots, boatmen, and others interested in navigation.

The general location of fish weirs, which at certain seasons of the year form obstructions in navigable waters, was noted. Courses on the sailing lines were checked, and objects that can be used in locating a vessel on the sailing lines were noted. General information in regard to the draft of vessels using these waters and their class was obtained. The work closed and the vessel reached Baltimore on October 11.

On April 25 the vessel sailed from Baltimore to collect information in the Gulf of Mexico for the revision of Part VIII of the Coast Pilot. The ship reached Key West on May 19, and after that date was engaged in visiting the ports along the coasts of Florida, Alabama, and Louisiana until June 30, when the vessel was at New Orleans, La.

CALIFORNIA, MONTANA, NEVADA, AND UTAH.

[H. M. Roy.]

Summary of results.—848 kilometers of lines completed and 214 bench marks established.

The extension of the standard levels was in progress on August 7 under the direction of Aid E. H. Pagenhart, and on that date Aid Roy relieved him as chief of party, and continued the work until October 5, when the line was completed to Butte, Mont. The route followed the Oregon Short Line Railway.

On October 17 leveling work began at Ogden, Utah, and was completed to Salt Lake City on December 8. The weather was very unfavorable, and the progress of the work slower than usual.

The Salt Lake base line of the transcontinental triangulation was connected with this line, thus determining its elevation by precise leveling now continuous to the ocean on both the eastern and western coasts.

The party was transferred to Barstow, Cal., and began work there on December 13. The work continued until May 20, when the line was completed to Las Vegas, Nev.

The route followed the Atchison, Topeka, and Santa Fe Railway to Leastalk, Cal., and then the San Pedro, Los Angeles, and Salt Lake Railway to Las Vegas. North of Daggett, Cal., it was necessary for the party to live in camp, as the country affords nothing except the railroad to facilitate the progress of the work, and the party suffered many hardships.

From Las Vegas the party returned to Butte, Mont., and on May 31 began work on the extension of the lines to Billings, Mont., along the Northern Pacific Railroad. The work continued without interruption until June 30, when it was in progress in the vicinity of Willow Creek, Mont.

CALIFORNIA.

[C. H. Sinclair.]

Summary of results.—Astronomic observations: 1 azimuth measured. Triangulation: 8 stations occupied.

The reoccupation of certain triangulation stations in California for the purpose of determining whether their relative position was disturbed by the earthquake of April, 1906, was assigned to Assistant Sinclair.

Preparations for the work began in San Francisco on July 9. An azimuth station at Santa Cruz and several triangulation stations in the region around Monterey Bay were recovered. Some of these were stations in the primary work, situated on the tops of mountains and the difficulty of reaching them caused delay, so that observations of angles did not begin until August 23.

Horizontal angles were observed at four stations and observations to determine an azimuth were made at one. The work in this region was greatly delayed by fog, and it was not completed until the close of January. The party was then moved to the vicinity of Redwood City to assist in the work already in progress in that region. A great deal of delay was caused by unfavorable weather, and the observations of horizontal angles at the four stations assigned to the party were not completed until April 9.

The instruments were returned to Washington, the outfit was stored at San Francisco, and the observer started to Washington on April 14.

CALIFORNIA.

[EDWIN SMITH.]

SUMMARY OF RESULTS.—27 stations occupied.

A portion of the work necessary to determine the effect of the California earthquake on the triangulation in the disturbed region was assigned to Assistant Smith. He reached San Francisco on July 9 and the work was continued from July 9 to 24 and from September 24 to March 1, the interruption in the work being caused by the necessity of assigning Assistant Smith temporarily to other duty. In July several old triangulation stations were recovered in the vicinity of Tomales Bay and some new ones were selected. Signals were erected at these stations, but no observations were made, as the service of the observer was needed on the Alaska boundary work.

Work in connection with the investigation of the effect of the earthquake was resumed on September 24 in the vicinity of Point Arena. Nine old stations were recovered and one new one was established. Observations of horizontal angles were made at all these stations and the work was completed on October 29.

Similar work was begun after this date in the vicinity of Fort Ross, and 12 old stations were recovered and occupied for the measurement of horizontal angles. This work was completed on December 28 and the party moved to Colma, 8 miles south of San Francisco. Six stations in this vicinity were recovered and two new ones were established. Observations of horizontal angles were finished at six of these stations on February 26, thus completing the work assigned to this party. Serious delay was caused by rain and fogs.

PENNSYLVANIA AND VIRGINIA.

[E. SMITH; WILLIAM BOWIE.]

The determination of the latitude of the Allegheny Observatory at Allegheny, Pa., was assigned to Assistant Smith. The necessary observations were completed between May 2 and 10, and preparations were made for the determination of the longitude of the observatory by the telegraphic method.

On June 14, 15, and 17 observations were made to determine the difference in longitude between Washington, D. C., and the United States Weather Bureau research station at Mount Weather, Va., with Assistant Bowie cooperating at the Washington station.

Signals were exchanged between Washington and the Allegheny observatory on June 8, 14, and 15, and observations were made to determine the difference of longitude between these places, with Mr. Frank Schlessinger as observer at Allegheny.

MARYLAND.

[C. M. SPARROW.]

SUMMARY OF RESULTS.—8 square miles of area covered; 7 miles of shore line surveyed; 23 miles of roads surveyed, and 4 miles of creeks surveyed.

Topographic work along the shores of Chesapeake Bay in the vicinity of Chesapeake Beach, Md., was assigned to Assistant Sparrow. The work began on April 15 and was continued until the end of the fiscal year and was in progress at that time.

Several of the old triangulation stations were recovered and occupied and the topographic work was extended along the shore to a point about 3 miles below the town. The topographic work, including all details and contours, extends inland to the main road along the coast except where it approaches the coast within 1 mile, and in those places the survey covered the territory within 1 mile of the shore line.

CALIFORNIA, FLORIDA, HAWAII, LOUISIANA, MARYLAND, NEW YORK, PENNSYLVANIA, TEXAS, VIRGINIA, AND WASHINGTON.

Self-registering tide gauges were kept in operation during the year at the following places: Presidio and San Diego, Cal.; Fernandina, Fla.; Honolulu, Hawaii; Weeks, La.; Baltimore, Md.; Fort Hamilton, N. Y.; Philadelphia, Pa.; Galveston, Tex.; Colonial Beach, Va., and Seattle, Wash.

MARYLAND AND VIRGINIA.

[W. I. VINAL, Commanding, Schooner *Matchless*.]

SUMMARY OF RESULTS.—170 square miles of area covered; 1 434 miles of lines sounded; 46 704 soundings made; 6 tide stations occupied, and 2 hydrographic sheets completed.

Hydrographic work in Chesapeake Bay was assigned to Assistant Vinal, commanding the schooner *Matchless*. The work began July 16 and was continued during the remainder of the year, except when repairs were made to the vessel between May 2 and June 9. The hydrography was completed from Back River Light-house to Wolf Trap Light-house, and included the entrances to York and Poquosin rivers and Mobjack Bay. A considerable area was also covered by sounding in the vicinity of Saxis, Va., before the close of the fiscal year.

HAWAII.

[WILLIAM F. WALLIS.]

A continuous record of the variations in the earth's magnetic condition was obtained during the year at the magnetic observatory near Honolulu, Hawaii, under the direction of Observer Wallis. Observations were made once each week to determine the absolute value of the three elements of terrestrial magnetism and once each month to determine the scale values.

On the 1st and 15th of each month until February, the magnetograph was made to record at a rapid rate for two hours in accordance with an international programme.

The seismograph was kept in operation during the year. From July 1 to December 31, 50 earthquakes were recorded, and from January 1 to June 30 the number was 47.

Meteorological observations were also made and reported every month to the United States Weather Bureau observer at Honolulu.

MAINE, MARYLAND, MASSACHUSETTS, AND VIRGINIA.

[P. A. WELKER, Commanding, Steamer *Bache*.]

SUMMARY OF RESULTS.—Hydrography: 11 square miles of area covered; 1 057 miles of lines sounded; 22 591 soundings made; 6 tide stations occupied, and 5 hydrographic sheets completed. Magnetic observations: 6 stations occupied on land and 8 stations occupied at sea.

Hydrographic work on the coasts of Maine and Massachusetts was assigned to Assistant Welker, commanding the steamer *Bache*, and, as usual, advantage was taken of the presence of the vessel in various localities to obtain magnetic observations on shore and at sea. The vessel sailed from Baltimore on July 19, and on the following day magnetic observations were made in Hampton Roads, Virginia. The vessel reached Rockland on July 24. Observations were made on shore and on board the vessel, and these observations were repeated in October. Observations were also made at sea near Ram Island, on shore near Salem and at Boston, at sea en route to Baltimore, in Chesapeake Bay, and on shore at Baltimore.

Special examinations were made in East Penobscot Bay and Eggemoggin Reach to define all shoal spots discovered by a party operating a long wire sweep in this region. In addition to this work numerous other areas were examined with channel sweeps and by sounding. These channel sweeps were attached to the vessel and to two launches. The sweeps were set at different depths as required and were constantly used while running lines of soundings at intervals of from 10 to 20 meters apart within the areas under examination. While this work was in progress a careful search was made for a rock supposed to exist just outside the black buoy at the entrance to Casco Passage with 14 feet of water on it, but no such rock was found. An examination was also made near the northeast end of Great Spruce Island, where a shoal had been reported, and less water was found than shown on the chart.

On August 31 the steam yacht *Mohican* was hauled off a shoal east of Saddle Island, near Rockport, Me., and an examination of the shoal showed much less water than indicated on the chart. An examination was also made of a shoal in the vicinity of Rockland, and the vessel proceeded to Portland to examine the area north of House Island in Portland Harbor.

On November 1 the vessel went to Salem, Mass., where a search was made for a reported rock on which the schooner *Cole* had struck in the vicinity of Powers Rock Buoy, and the examination showed that there is no uncharted rock in this locality. The vessel then proceeded to Boston where a survey was made of the shoal in the vicinity of Hospital Shoal Buoy. This completed the hydrographic work for the season, and the vessel sailed for Baltimore and reached there on November 17.

FLORIDA.

[ISAAC WINSTON.]

The recovery of old triangulation stations south of Sebastian, Fla., and the determination of the geographic positions of aids to navigation on the east coast of Florida were assigned to Assistant Winston.

The work began on November 15, 1906, and was continued until April 24, 1907. During this period a search was made for all of the triangulation stations between Sebastian and Barnes Sound, along the lower Indian River, Jupiter Narrows, Hobe Sound, Lake Worth, Key Biscayne Bay and the inland waterway connecting the above, Cards Sound, and Barnes Sound, a distance along the coast of 300 kilometers (188 miles). One hundred and thirty-seven stations were searched for, 49 were recovered and remarked, 73 were determined as lost, and 2 were not found. A preliminary examination was made in the vicinity of 13 stations near the end of the season, and in these cases additional work will be necessary in order to determine whether they can be recovered. A large number of the stations determined as destroyed were not originally marked in a permanent manner.

Eight new stations were established and observations of horizontal angles were made at 31 stations. The geographic positions of the new light-house at Hillsboro Inlet and of numerous prominent objects along the coast and the inland waters were determined, the total number being 60.

Town plans of West Palm Beach and Miami were obtained with notes to show the built-up portions of these places.

MARYLAND AND VIRGINIA.

[F. A. YOUNG.]

SUMMARY OF RESULTS.—38 square miles of area covered; 208 miles of shore line of bays, rivers, and creeks surveyed, 55 miles of roads surveyed, and 4 topographic sheets completed.

Topographic work along the western shores of Chesapeake Bay and tributaries was in progress on July 1, under charge of Assistant Young. The work was continued until April 8, 1907, when the chief of party was assigned to other duty. During this period a survey was made of the following regions: Poquosin River and tributaries and the surrounding country; the shore line of the bay between Poquosin and Back rivers; Back River; Salt Pond and vicinity; the shore line of the bay to Old Point Comfort and beyond to Hampton Creek, including a survey of the creek.

On March 27 the party went to Chesapeake Beach, Md., and continued work in that vicinity until April 8, as stated above.

MARYLAND OYSTER BARS, ETC.

[C. C. YATES.]

SUMMARY OF RESULTS.—Hydrography: 60 square miles of area covered; 624 miles of lines sounded, 35 929 soundings made, 4 tide stations occupied, and 9 hydrographic sheets completed. Triangulation: 150 square miles of area covered; 88 stations occupied, and 67 geographic positions determined.

Under authority conferred by law a successful cooperation was maintained during the year between the Coast and Geodetic Survey and the Maryland Shell Fish Commission in surveying and marking the natural oyster beds, bars, and rocks in the waters within the State of Maryland. Assistant Yates was designated to represent the Coast and Geodetic Survey on this work. The necessary preparations were made and field work began on August 10, 1906, and continued during the remainder of the fiscal year. During this period the triangulation in Anne Arundel County was extended, so as to form the base of the survey of the oyster lands within and adjacent to the county, and the corners of all the oyster bars officially established were connected with adjacent triangulation stations, and the geographic positions of these corners were determined.

Descriptions of the boundaries of the oyster bars were prepared, showing the location on charts made for the purpose and giving the geographic location of the corners in the boundaries of each bar, with distances and directions to the adjacent triangulation stations, so that the position of the corners can be recovered, even when the marks have been destroyed by chance or otherwise. The work undertaken by the representative of the Survey was completed in Anne Arundel County, and a report embodying the descriptions of the boundaries of the oyster bars, and containing descriptions of all triangulation stations used in locating these boundaries, was prepared. Special charts covering the region mentioned and showing the location of the bars were also prepared. The work was in progress in another portion of the State at the close of the fiscal year.

ALASKA.

[R. B. DERICKSON, Commanding, Steamer *Taku*.]

SUMMARY OF RESULTS.—Hydrography: 55 square miles of area covered; 368 miles of lines sounded; 5 121 soundings made; 1 tide station occupied, and 1 hydrographic sheet completed. Topography: 78 square miles of area covered; 84 miles of general coast line surveyed, and 1 topographic sheet completed. Triangulation: 78 square miles of area covered; 4 stations occupied, and 10 geographic positions determined.

On July 1 the survey of Latouche Passage, Prince William Sound, was in progress under the direction of Assistant Derickson, and the work was continued until September 30. The survey of Latouche Passage and adjacent waters was completed.

An unusual amount of rain during the season caused serious delay in the progress of the work. The party returned to Seattle, Wash., on October 23. Work was resumed in Prince William Sound on July 11, in the vicinity of Dries Bay, Knights Island, and was in progress on June 30.

[E. F. DICKINS, Commanding, Steamer *Gedney*.]

SUMMARY OF RESULTS.—Astronomic observations: 3 azimuths determined. Base measurement: 2 base lines measured. Hydrography: 30 square miles of area covered; 411 miles of lines sounded; 8 810 soundings made, and 3 tide stations occupied. Topography: 127 square miles of area covered; 238 miles of shore line surveyed; 15 miles of shore line of creeks and lakes surveyed, and 4 topographic sheets completed. Triangulation: 172 square miles of area covered and 69 stations occupied.

On July 1 the *Gedney* was at Sitka, where the ship's launches were left at the end of the previous season. Repairs were made and on the 13th the vessel proceeded to Khaz Bay. The survey of the bay and adjacent waters began immediately and was continued whenever the weather and other conditions permitted until October 6, when the work in this vicinity closed for the season. On August 18 the launch *Cosmos* struck a sunken rock, which made a large hole in her bottom. At low tide a temporary patch was put on and the launch towed to a convenient place where she could be put on the beach and repaired. After a delay of one week to complete this work the survey of the waters was resumed in this vicinity and completed on October 6, when the vessel returned to Sitka and the launches were hauled out of the water and housed for the winter. On the 13th the vessel proceeded to Ketchikan and a survey of the town and vicinity was completed on October 31. The vessel started immediately to Seattle and reached there on November 5.

In May preparations were made to resume work in Alaska, and on the 25th magnetic observations were made at Port Orchard, and on the 30th the vessel sailed for Alaska. Magnetic observations were made at sea on the way to Alaska, and various stops were made to enable Nautical Expert H. C. Graves, who was on board, to collect data for a revised edition of the Coast Pilot of the waters in southeast Alaska. The vessel reached Warren Cove on June 26 and began work immediately. The survey in this vicinity was in progress on June 30.

[H. M. W. EDMONDS.]

The work at the Sitka magnetic observatory was continued during the year. A record of the variations in the relative value of the three elements of terrestrial magnetism was obtained with self-registering instruments, and the international programme of running the magnetograph at high speed for a specified time on the 1st and 15th of each month was carried out until February. The seismograph was kept in operation and meteorological observations were made every day.

Observations were made at least once every week to determine the absolute value of the magnetic forces. Time signals were received over the cable and observations to determine the local time were not made, except when the cable time service was interrupted.

Various instruments were compared with those at the observatory, notably those used by Capt. R. Amundsen in making observations in the region around the north magnetic pole, in British Columbia.

[H. C. GRAVES.]

The collection of information for a revised edition of United States Coast Pilot, Pacific Coast of Alaska, Part I, and for the preparation of a publication to cover the coast from Yakutat Bay to Kodiak, was assigned to Nautical Expert Graves.

Information was collected in Seattle May 10 to 29, and on the 30th he sailed for Alaska on the steamer *Gedney*. On the voyage to Sitka, Ketchikan, Juneau, Khaz Bay, and other places were visited. Commercial steamers were used after reaching Sitka and a voyage was made through the principal passages of southeast Alaska. In June Dundas Bay was visited, and special courtesy was extended to the observer by Mr. R. B. Bell, superintendent of the Northwestern Fisheries Company, who gave him the use of the company's tug and pilot for a trip through Lisiansky Strait and into all the bays along the coast between Cape Bingham and Khaz Bay and through Icy Passage. The work was in progress on June 30.

[W. C. HODGKINS, Commanding, Steamer *Patterson*.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth and 1 latitude determined. Base measurement: 2 base lines measured. Hydrography: 106 square miles area covered; 200* miles lines sounded; 3 906* soundings made; 6 tide stations occupied, and 4 hydrographic sheets completed. Magnetic observations: 3 stations occupied on land and 2 stations at sea. Topography: 217 miles of general coast line surveyed and 6 topographic sheets completed. Triangulation: 985 square miles area covered; 29 stations occupied, and 46 geographic positions determined.

On July 1 the steamer *Patterson* was at work in Alitak Bay at the southern end of Kodiak Island, and the survey of this region was continued until October 27. Considerable progress was made in the survey of Alitak Bay and Sitkinak Strait, and surveys were made of St. Paul Harbor, Kodiak Island, and of Anchorage Bay, on the shore of the mainland opposite the Semidi Islands. In doing this work parties were located on shore in camps, and the work was continued during the absence of the ship when trips were made for coal and other supplies. The work in Alitak Bay is not connected with other work in Alaska, and it was necessary to determine the position of a station by making astronomic observations. A suitable place was selected and the necessary astronomic

* Incomplete.

observations were made while the other survey work was in progress. An observer was stationed at Kodiak to make observations at the astronomic station previously established at that place, and three round trips were made between the two stations to determine the difference of longitude by carrying chronometers and making comparisons after each trip with the chronometers left at the stations.

A base line was measured on Tugidak Island, and from this line the triangulation was extended.

Early in October the vessel was severely injured by drifting on a shoal in a violent storm after two anchor chains had broken. At first the ship could not be controlled under a full head of steam, but she was taken from the shoal in a short time without serious injury. After losing two of the three anchors on board it was necessary to close work as soon as possible, and the vessel proceeded to Kodiak and sailed for Seattle on October 27.

On May 26 the *Patterson* sailed from Seattle to resume work in Alaska, and reached Kodiak on June 4. Magnetic observations were made on land before starting and at the end of the voyage and at sea during the voyage. A self-registering tide gauge was established at Kodiak, and buoys were placed so as to mark two reefs in the approach to the town. A base line was measured and the survey of Usinka Passage begun without delay. The survey of the region in the vicinity of Kodiak was in progress at the close of the fiscal year.

[H. W. RHODES, Commanding, Steamer *McArthur*.]

SUMMARY OF RESULTS.—Astronomic observations: 3 azimuths and 2 latitudes determined. Base measurement: 2 base lines measured. Hydrography: 412 square miles of area covered; 443 miles of lines sounded; 10 140 soundings made; 4 tide stations occupied, and 3 hydrographic sheets completed. Magnetic observations: 1 station occupied. Topography: 23 square miles of area covered; 38 miles of general coast line surveyed, and 2 topographic sheets completed. Triangulation: 620 square miles of area covered; 60 stations occupied, and 62 geographic positions determined.

On July 1 the party on board the steamer *McArthur* was at Port Chatham at work on the triangulation from Barren Islands to Chiswell Islands. A base line was measured, and a self-registering tide gauge was established. A party was placed on shore to make observations for latitude and azimuth and to make tide observations. The triangulation was completed on October 3.

Two lines of soundings were made between Port Chatham and the Chiswell Islands, and one between Port Chatham and Seldovia Harbor.

The topographic and hydrographic work in Port Chatham was completed on October 14. The vessel sailed for Seattle on October 16, and reached there on the 30th.

The vessel returned to Seldovia on June 2 and the survey of Iliamna Bay was begun on the 6th and was in progress at the close of the fiscal year.

OUTLYING TERRITORY.

PHILIPPINE ISLANDS.

[J. E. McGRATH.]

The survey of the coasts of the Philippine Islands was continued under the direction of Assistant McGrath, who represented the Superintendent in all matters requiring action without delay.

As Director of Coast Surveys in the Philippine Islands he made plans for field operations and issued instructions for field work at the suboffice in Manila. The observations made in the field were computed, and drawings for charts of the regions surveyed were prepared for transmission to Washington for review and publication. Sailing Directions and Notices to Mariners were prepared and published. He was aided in this work by such advice and instructions issued from Washington as became necessary.

The work was done under the same general plan of the division of expenses in force during the previous year. The National Government paid the salaries and subsistence of its technical corps detailed for duty in the Philippines, including several experts in the suboffice, furnished the instrumental equipment, paid the expenses of one large surveying steamer and for the supplies for two other surveying steamers, paid the expense of chart publication, the traveling expenses of officers to and from the Philippine Islands, and the hire of launches. The Philippine government paid the operating expenses of two surveying steamers, paid for the crew and repairs of two other surveying steamers (not including pay of officers), the party expenses of several surveying parties on shore, the salaries of the office force, and for office supplies obtained in Manila, and furnished office accommodations and printing.

There was a free exchange of information and good offices between the Survey and the various military and civil bureaus having common aims, and a gratifying interest was shown in responding to all requests for information. Special mention is made of the courtesies extended to the Survey by the Chief Engineer of the Philippines Division, the Chief of the Military Information Division, the Bureau of Navigation, and its Light-House and Port Works divisions, the Bureau of Public Works, and the Bureau of Customs. The Army was supplied with all available information required by each of the numerous parties recently employed on the military survey of the region in the vicinity of Manila and by those at work in Samar and Mindanao. The Bureau of Public Lands and the Bureau of Forestry were furnished with very complete data for the work undertaken by those bureaus, and much assistance was rendered to the managers of the scheme of railroad developments in the Archipelago.

THE SURVEY STEAMERS.

The *Pathfinder* has been steadily at work except from December 1 to February 8, when she was sent to Hongkong for the installation of new masts.

The *Research* was absent from the working grounds only five weeks, which was the time required for the semiannual repairs.

The *Fathomer* was at Manila from October 24 to December 5 and from May 9 to June 8. This steamer has not required any extensive repairs and has been most satisfactory as a working vessel.

The *Romblon* was at Manila from October 27 to December 6 and from March 30 to May 10 outfitting and having repairs made.

The *Marinduque* was at Manila from November 3 to December 12 and was repaired and examined. She returned to Manila on April 12 with a very moderate list of repairs, but one shaft was found to be in such condition that the vessel was pronounced unfit for work in any but sheltered waters. A new shaft was ordered, the other repairs were made, and the vessel sailed on May 22.

The repairs to the *Fathomer*, *Marinduque*, and *Romblon* were made at Manila, and the *Research* was repaired at Iloilo.

OFFICE WORK.

Twenty-two drawings for charts were completed and forwarded to Washington to be printed. Eight of these were for new charts, nine were complete drawings for new editions, and five were drawings with extensive corrections for new editions.

The following publications were prepared, verified, and published: Notices to Mariners, Nos. 7 to 10, 1906; Notices to Mariners, Nos. 1 to 7, 1907; Sailing Directions, Section 111, Panay, Negros, Cebu, and adjacent islands, 1906 (third edition).

There was an increase of 36 per cent in the number of charts sold during the year as compared with the previous year.

FIELD WORK.

[J. B. BOUTELLE, Commanding, Steamer *Research*.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth determined. Base measurement: 1 base line measured. Hydrography: 394 square miles of area covered; 2 448 miles of lines sounded; 44 462 soundings made; 2 tide stations established, and 1 hydrographic sheet completed. Topography: 182 square miles of area covered, 198 miles of coast line surveyed; 53 miles of rivers and creeks surveyed; 58 miles of roads surveyed, and 6 topographic sheets completed. Triangulation: 1 057 square miles of area covered; 59 stations occupied, and 117 geographic positions determined.

The work began on the north coast of Negros and on the northeast coast of Panay on July 15. The triangulation was extended from the vicinity of Banate, Panay, to Ilacaon Island on the Negros side and to Ananayan and Tugubanhan islands on the Panay side. Topography and hydrography were done within the same limits. About November 15 work was begun on the coast of Panay, which was protected from the heavy seas existing along the coast of Negros at that time. The triangulation and topography were extended as far north as the western point of Bagucay Bay before December 31.

The work was continued without interruption until February 22, when the vessel was taken to Iloilo to have repairs made. During this period a base line was measured and an azimuth was determined on the south end of Concepcion Island. The topographic work was completed to Rogalumbi Island, and the hydrographic work to a line between Point Malpal and Culebra Island.

The vessel was repaired, and in March (19th to 25th) some triangulation was done in Guimaras Straits and along the coast of Panay northward to the Gigantes Islands. On April 14 work was resumed on the north coast of Negros and was in progress on June 30. The triangulation was completed to the Bocaboc and Don islands, and the topography was extended eastward from Sicaba to Bito Point. A considerable amount of hydrographic work was completed around the large shoal north of Cadiz and Sagay and along the east coast of Panay.

[H. C. DENSON, Commanding, Steamer *Marinduque*.]

SUMMARY OF RESULTS.—Astronomic observations: 3 azimuths observed. Base measurement: 3 base lines measured. Hydrography: 1 948 square miles of area covered; 3 560 miles of lines sounded; 71 830 soundings made; 3 tide stations occupied, and 7 hydrographic sheets completed. Magnetic observations: 11 stations at sea occupied. Topography: 365 square miles of area covered; 303 miles of coast line surveyed; 13 miles of rivers surveyed; 17 miles of roads surveyed, and 11 topographic sheets completed. Triangulation: 6 279 square miles of area covered and 65 stations occupied.

The survey along the east coast of Luzon in the vicinity of Atimonan was begun by Assistant Denson, commanding the steamer *Marinduque*, on April 28, 1906, and was continued during the remainder of the fiscal year, as stated in the Annual Report for 1906, but no statistics were available when that report was printed. The figures given above include all work done after the date mentioned.

A base line was measured and an azimuth was determined in the vicinity of Atimonan.

On May 6, 1906, the vessel proceeded to Port Lampon, and a survey in this vicinity was completed on May 27. On May 28 work began in Polillo Harbor, on the east coast of Polillo Island, and a survey of the harbor was completed. A survey was made of Hook Bay, and work was continued in Burdens Bay and vicinity until July 20, when enough work had been done to develop a deep-water channel into the bay. The weather had become very unfavorable and the ship returned to Atimonan and resumed work in that vicinity.

On July 22 the launch *Covadonga* was found in a disabled condition and was towed to a safe anchorage, and the vessel then proceeded to Legaspi for coal, leaving a party at work on shore. When about 2 miles from the anchorage at that place, the coastguard cutter *Rover* was sighted off Sula flying the distress signal. The engines were found to be disabled and the cutter was towed to Legaspi.

The triangulation was completed from Atimonan to Infanta and the islands of Alabat, Cabalete, Balesin, and Polillo were connected with the mainland. A survey was made in the vicinity of Mauban and of Cabalete and Alabat islands. The work closed for the season on October 25 and the vessel sailed next day for Catanduanes Island. A shoal off Cabagao was located and developed by sounding on the 29th, and the ship started to Manila the following day. The work was delayed by unfavorable weather, ten typhoons being recorded by the party during the season.

On December 13 the vessel sailed from Manila for the west coast of Leyte, and magnetic observations were made during the voyage. Tide gauges were established at

Polompon and Baybay, and the survey began on December 18. The work of the season is stated under the following headings:

A topographic survey was made of the Cuatro and Camote islands, along 2 miles of the shore line south of Hindang and in Liloan Bay.

The hydrographic work with a small boat covered the inshore soundings around the Cuatro and Camote islands and along the shore for a distance of 1½ miles south of Hindang and along the northern edge of Danajon Banks. The banks are exposed to northeast winds and the water was too rough on them for work with a small boat. The work with the ship extended from the boat work to a distance of about 3 miles offshore to a depth of from 150 to 200 fathoms with lines one-third of a mile apart, and outside this limit to a depth of 400 fathoms with lines 2 miles apart. An examination was made of a shoal off Hindang which had been previously surveyed.

The triangulation extends from Limasana Island off the south point of Leyte to Bulalaqui Point, the northern point of Cebu, and connects the astronomic stations at Ormoc and Maasin.

The vessel sailed from Manila in May and on May 23 began work between Verde and Mindoro islands. The work was continued until June 18, and during this time the topographic work was extended along the north coast of Mindoro from Port Galera to Bagalayag Point. Hydrographic work done in South Pass, Verde Island Passage, from the eastern end of Verde Island to the eastern end of Maricaban Island, and in Verde Island Passage from Bagalayag Point and Cape Santiago to the eastern end of Maricaban Island.

[O. W. FERGUSON.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth measured. Base measurement: 2 base lines measured. Triangulation: 15 stations occupied.

Triangulation and base measurement work was in progress in the vicinity of Calapan, Mindoro, on July 1, under the direction of Assistant Ferguson. The measurement of the base line near Calapan was completed and observations were made at the six triangulation stations in the base net. Observations to determine an azimuth were made and two triangulation stations used in the hydrographic survey in this vicinity were occupied. The party returned to Manila on September 1. Between October 8 and December 13 the triangulation along the central valley of Luzon was extended from the vicinity of Manila to Caballo Island at the entrance to Manila Bay. In this work observations were made at seven stations. On December 28 the party left Manila for Lingayen for the purpose of remeasuring the base line near that place. This work was completed and observations were made at four triangulation stations in the vicinity of the base line. The party returned to Manila on January 22.

[E. B. LATHAM.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth determined. Hydrography: 235 square miles of area covered; 1 796 miles of lines sounded; 42 764 soundings made, 8 tide stations occupied, and 7 hydrographic sheets completed. Topography: 52 square miles of area covered; 35 miles of coast line surveyed, 10 miles of creeks surveyed; 61 miles of roads surveyed, and 2 topographic sheets completed. Triangulation: 1 234 square miles of area covered; 32 stations occupied, and 60 geographic positions determined.

The survey of the shores of Iligan Bay on the north coast of Mindanao was assigned to Assistant Latham. On July 1 the party was at Oroquieta ready to begin work, and the work was continued until December 1. The triangulation covers Iligan Bay south of Oroquieta on the west side and of Initao on the east side.

The topographic survey of the western shore of the bay was completed from Polo Point, north of Oroquieta, to Loculon, and the hydrographic work was completed over Iligan Reef and along the western shore of the bay from Polo Point to Balecaocao Point.

On January 22 hydrographic work was begun on the coast of Panay and was continued until May 27. During this period the inshore hydrography was completed along the south and west coast of Panay from Oton to Dalipe Point.

[H. D. KING, Commanding, Steamer *Romblon*.]

SUMMARY OF RESULTS.—Hydrography: 263 square miles of area covered; 1 225 miles of lines sounded; 35 003 soundings made; 5 tide stations established, and 5 hydrographic sheets completed. Topography: 18 square miles of area covered; 109 miles of general coast line surveyed; 11 miles of reef lines surveyed; 10 miles of rivers surveyed, and 3 topographic sheets completed. Triangulation: 878 square miles of area covered; 18 stations occupied, and 19 geographic positions determined.

Hydrographic work on the west coast of Luzon was in progress on February 1, when Assistant King took command, in the vicinity of the Capones Islands. The work was continued until February 26, when it was completed to Botalon Point. A reference to this work is made under the head of L. H. Westdahl, the former commander of the vessel, and the statistics of the work accomplished to February 26 are given in the statement under that head.

On March 4 the survey of the coast was begun at Talin Point on the west coast of Luzon and was completed to Cape Santiago on March 30.

The vessel was repaired at Manila and then proceeded to the east coast of Luzon. On May 13 and 14 a reported rock off Port Gubat was located and a hydrographic survey was made in its vicinity. On the 14th the vessel reached Port Sula and supplementary work began in this locality. This work was finished on the 17th and the vessel proceeded to Mercedes at the entrance to San Miguel Bay. The survey of this bay began immediately and was practically completed before June 30. A topographic survey of the Calaguas group of islands was also made. A well-sheltered anchorage with soft mud bottom was found behind Canuit Island and Assistant King reports that he considers it a safe anchorage in typhoons. Lines of soundings were made across the bay at intervals of about 550 meters for the offshore work and at intervals of 300 meters, perpendiculars to the shore, for the inshore work. Assistant King's report contains an interesting description of the hydrographic features of regions surveyed and information which is valuable as Coast Pilot data.

[J. W. MAUPIN.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth measured. Base measurement: 1 base line measured. Topography: 114 square miles of area covered; 90 miles of general coast line surveyed; 109 miles of shore line of rivers surveyed; 158 miles of roads surveyed, and 6 topographic sheets completed. Triangulation: 520 square miles of area covered, 33 stations occupied, and 91 geographic positions determined.

Triangulation and topographic work on the west coast of Panay began on January 5 under the direction of Assistant Maupin and the work was continued until May 24.

During this period the triangulation was extended from San Jose to Ibajay and the topography from San Jose to Bugan River. A topographic survey was also made of Batbatan Island.

[W. E. PARKER, Commanding, Steamer *Fathomer*.]

SUMMARY OF RESULTS.—Hydrography: 100 square miles of area covered; 432 miles of lines sounded; 10 398 soundings made; 2 tide stations occupied, and 2 hydrographic sheets completed. Magnetic observations: 3 stations occupied on land and 4 stations occupied at sea. Topography: 60 square miles of area covered; 69 miles of coast line surveyed, and 2 topographic sheets completed. Triangulation: 480 square miles of area covered; 10 stations occupied, and 13 geographic positions determined.

On March 23 the survey of the south coast of Mindanao was in progress by the party on the steamer *Fathomer*, under the command of Assistant D. B. Wainwright. He was succeeded in command by Assistant Parker on that date and the work was continued until May 2. During this period the triangulation was extended to the head of Sibuguey Bay and down the east shore to a point about opposite Port Banga. The topographic work covers the shore from Point Vitali to Buluan Island, and the hydrographic work extends from the south side of Tunganan Bay to Bagolibud Point. After the close of the work in Sibuguey Bay a search was made for an unchartered shoal reported in Basilan Strait, southwest of San Mateo, and it was shown that no shoal exists at the place reported.

Repairs were made to the vessel at Manila, and on June 16 she sailed for Catanduanes Island to make a survey of the east coast of the island. A survey of Port Anajao was begun immediately, as it offers the only safe anchorage in this vicinity during typhoons, and enough work was done to make it safe to enter the port in bad weather. It was found necessary to extend the triangulation from the work previously done on Maqueda Channel, across the north end of the island, and then down the east coast. This work was in progress at the close of the fiscal year.

[C. G. QUILLIAN, June 28 to September 6; J. W. MAUPIN, September 7 to November 28.]

SUMMARY OF RESULTS.—Hydrography: 95 square miles of area covered; 768 miles of lines sounded; 21 872 soundings made; 1 current station occupied, 3 tide stations occupied, and 2 hydrographic sheets completed. Topography: 23 square miles of area covered; 33 miles of coast line surveyed; 23 miles of creeks surveyed; 25 miles of roads surveyed, and 2 topographic sheets completed. Triangulation: 90 square miles of area covered; 9 stations occupied, and 13 geographic positions determined.

The survey of the north coast of Samar, west of Laoang, was in progress on July 1, under the direction of Assistant Quillian, until September 7, and after that date, under the direction of Assistant Maupin. The work was continued until November 24 and the survey along the coast was completed from Livas Point to Bobon. The weather became so unfavorable that the work was suspended at Bobon and the party returned to Manila.

[D. B. WAINWRIGHT, Commanding, Steamer *Fathomer*.]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth determined. Base measurement: 1 base line measured. Hydrography: 1 265 square miles of area covered; 3 840 miles of lines sounded; 49 172 soundings made; 6 tide stations occupied, and 13 hydrographic sheets completed. Magnetic observations: 1 station occupied (at sea). Topography: 556 square miles of area surveyed; 252 miles of general shore line surveyed, and 9 topographic sheets completed. Triangulation: 1 404 square miles of area covered; 69 stations occupied, and 101 geographic positions determined.

On July 1 the survey of the east coast of Luzon, between Lohuy Island and San Miguel Bay, was in progress, as stated in the report for the previous fiscal year. The work began on May 9, and the statistics given above include the work after that date, as no statistics were available when the previous report was sent to the printer. The work was continued until October 16, and during this period the survey was completed between the points named, a distance of 50 miles. The topographic survey was confined to the shore line of the coast and of the islands close inshore. The hydrographic work with the steamer began in not less than 10 fathoms of water, as near the shore as it was safe to go, and extended seaward to a depth of 30 to 35 fathoms, on a line about 6 miles outside the islands along the shore. Repairs were made to the ship at Manila, and work on the south coast of Mindanao was begun on December 10 and continued until March 23, when Assistant Wainwright was detached from the command of the vessel. During this period the survey of the coast was extended from Sacol Island, northeast of Zamboanga, to the Tigbaon Islands, at the entrance to Sibuguey Bay, a distance of 68 miles. The coast is heavily wooded in this region, and it was necessary to use signals placed on shoals offshore, and to measure a base line on a coral reef, which was only available at a low stage of the tide. The topographic work was rendered difficult by the rocky bluffs with deep water at their bases, by the coral reefs, and by the growth of mangrove extending from the shore over the waters, so that the plane table could not be used outside of them at more than half tide.

The inshore hydrography presented no unusual features. Nearly all the area sounded by the steamer was in depths of less than 100 fathoms, and this work was completed nearly to Port Banga.

[F. WESTDAHL, Commanding, Steamer *Pathfinder*.]

SUMMARY OF RESULTS.—Hydrography: 238 square miles of area covered, 1 546 miles of lines sounded, 45 397 soundings made, 5 tide stations occupied, and 7 hydrographic sheets completed. Topography: 48 square miles of area covered, 192 miles of coast line surveyed, 221 miles of reefs and rivers surveyed, 32 miles of creeks surveyed, 16 miles of roads surveyed, and 6 topographic sheets completed. Triangulation: 237 square miles of area covered, 33 stations occupied, and 120 geographic positions determined.

The survey of Gumay Bay, on the east coast of Samar, was in progress on July 1, and work in this region was continued until August 7. During this time the survey of the bay was completed and the work was extended northward to Benay Island.

An examination was made of a shoal off Macati Island and of a reef off Taig Point, and on August 10 work began in Port Libas and was continued along this coast until November 16. A survey was made of Port Libas, Port Borongan, and Matarinao Bay and along the coast between Port Libas and Matarinao Bay, except for a short space south of Llorente, where the topography and hydrography were not completed.

[F. WESTDAHL, February 18 to March 24; D. B. WAINWRIGHT, March 25 to June 30, Commanding, Steamer *Pathfinder*.]

SUMMARY OF RESULTS.—Astronomic observations: 3 latitudes and 4 longitudes (chronometric) determined. Hydrography: 359 square miles of area covered, 1 325 miles of lines sounded, 24 252 soundings made, 2 tide stations occupied, and 7 hydrographic sheets completed. Magnetic observations: 2 stations occupied on land and 5 stations occupied at sea. Topography: 37 square miles of area covered, 117 miles of general coast line surveyed, 34 miles of shore line of rivers surveyed, 3 miles of shore line of ponds surveyed, 3 miles of roads surveyed, and 8 topographic sheets completed. Triangulation: 1 435 square miles of area covered, 30 stations occupied, and 54 geographic positions determined.

The survey of the Gulf of Davao, on the south coast of Mindanao, was continued northward from the point to which it was completed during the previous season, near the north end of Samal Island, and was extended around the head of the gulf and down the east coast to a point nearly opposite the south end of Samal Island. The triangulation, hydrography, and topography were completed within these limits. It was difficult to extend the triangulation along the channel east of Samal Island on account of the heavy growth of timber on the shores, and quadrilaterals could not always be used, as it would have involved a very large amount of work to clear the lines. The hydrographic work with the launch extended to the 100-fathom curve, and outside that line the ship was used while making soundings. After the work noted above was completed the survey on the west shore of the gulf was extended south to a point opposite the south end of Samal Island, thus completing the survey of the Gulf of Davao north of the south end of Samal Island.

[L. H. WESTDAHL, Commanding, Steamer *Romblon.*]

SUMMARY OF RESULTS.—Astronomic observations: 1 azimuth determined. Base measurement: 1 base line measured. Hydrography: 785 square miles of area covered, 3 085 miles of lines sounded, 81 558 soundings made, 4 tide stations occupied, 2 current stations occupied, and 9 hydrographic sheets completed. Topography: 26 square miles of area covered, 119 miles of general coast line surveyed, 5 miles of shore line of rivers surveyed, 2 miles of shore line of creeks surveyed, 12 miles of roads surveyed, and 8 topographic sheets completed. Triangulation: 1 097 square miles of area covered and 20 stations occupied.

On July 1 the survey of the east coast of Luzon, between Daet and Dagdap Point, including the islands offshore and the passage inside Canimo Island to San Miguel Bay, was in progress under the direction of Assistant Westdahl, commanding the steamer *Romblon.*

The statistics given above cover the whole season from May 22 to October 24, 1906, as no statistics were available when the previous report was compiled. The survey of the coast, including triangulation, topography, and hydrography, was extended along the coast from the vicinity of Canimo Island to Point Jesus, which is about 15 miles west of Port Mambulao, a distance of 50 miles. The work closed on October 24 and the vessel returned to Manila for repairs.

On December 6 the vessel proceeded to Cape Bolinao and began work on the inshore hydrography south of that point to Dasol Bay. A self-registering tide gauge was established in Bolinao Harbor and the sounding work began as soon as the signals were erected. A whaleboat was used while working inside the 25-fathom curve; outside this line the ship was used. In December the work was completed to Agno Bay, and a tide gauge was established in the bay east of Caiman Point. The hydrographic survey was extended south to Dasol Bay in January, and on the 19th the vessel proceeded to Botolan Point. The work was continued between this point and Capones Islands until February 1, when Assistant Westdahl was relieved of the command on the expiration of his term of service in the Philippine Islands.

The work was continued until February 26, with Assistant H. D. King in command of the vessel, and the statistics of the work during this period are included in the summary given above. The hydrography along the coast was completed to Caloguaguin Bay, or from Capones Islands to Botolan Point.

PORTO RICO.

[W. B. KEELING.]

The work at the magnetic observatory at Vieques, P. R., was continued during the fiscal year without interruption, except for a short period, when it became necessary to transfer the instrument to the new building, which was constructed under the direction of Magnetic Observer Keeling. The building formerly occupied as an observatory was required for other use, and the construction of suitable observatory buildings on leased ground was authorized. An examination was made of five available locations and observations were made to test their relative merits, with the result of locating the new buildings one-third of a mile from Vieques, on an estate known as the "Cofi." The buildings were completed and the instruments were transferred early in April.

A continuous record of the relative force of the three elements of terrestrial magnetism was obtained except for the period April 4 to 10, when the transfer of the instrument was made. The record on the seismograph was also continuous, except for a short period in March and April, when the instruments were moved. Observations were made twice every week to determine the absolute value of the magnetic elements, and observations were made at intervals of ten days to determine the local time. On the 1st and 15th of each month until February the magnetograph was made to record at a rapid rate for two hours.

[P. A. WELKER, Commanding, Steamer *Bache*.]

SUMMARY OF RESULTS.—Hydrography: 255 square miles of area covered; 1 648 miles of lines sounded; 28 340 soundings made; 1 tide station occupied, and 7 hydrographic sheets completed. Magnetic observations: 1 station occupied on land, and 12 stations occupied at sea.

Hydrographic work in Porto Rico was assigned to Assistant Welker, commanding the steamer *Bache*, and magnetic observations were made while the vessel was en route to and from the working ground. The first observations were made in Hampton Roads, and a special route was followed from Diamond Shoal Light-ship to San Juan in order to make magnetic observations in specified localities, and the set of observations was completed by observing on board and on shore in Fajardo Roads, Porto Rico. In returning to Baltimore a prescribed route was again followed, and a similar set of observations was secured. The hydrographic work during the season included surveys off the south and east coasts of the island of Vieques and off the north and east coast of the island of Porto Rico. Work was carried on in different localities to take advantage of weather conditions, and in this way very little time was lost as the result of unfavorable weather.

A special examination of the region where a shoal had been reported off the east coast of the island of Porto Rico was made under most favorable conditions, when the location of all the shoals within a radius of several miles could be clearly distinguished by the light-green color of the water in their vicinity, but no indication of the existence of an uncharted shoal was seen or was found by sounding.

The work completed on the north coast of Porto Rico extends from Cape San Juan to the entrance to San Juan Harbor, but this does not include the inshore work, which consists of a strip one-half to one mile wide along the coast where work was impracticable at the time without unreasonable expense and delay, on account of the usual rough condition of the sea.

The work along the north coast extends seaward about 10 nautical miles. Within the area surveyed a dangerous shoal was located and defined. The work closed on May 27 and the vessel reached Baltimore on June 6.

SPECIAL DUTY.

NEW YORK.

[A. T. Mosman.]

The trigonometric survey of Greater New York was continued by the city authorities under the direction of Assistant Mosman.

During the year the triangulation was completed in the Borough of Richmond. Forty stations were occupied and 48 geographic positions were determined. A reconnaissance was then made of a portion of the Borough of Queens, covering 99 square miles, and in this area 62 points were selected as triangulation stations.

The field work was suspended during the greater portion of the year on account of lack of funds for field expenses.

MISSISSIPPI RIVER COMMISSION.

[H. P. Ritter.]

Assistant Ritter continued on duty as a member of the Mississippi River Commission and performed the duties required of a member of the Commission. He also served as a member of the board to examine and report on a 14-foot channel in the Mississippi River from St. Louis to the Gulf of Mexico.

UNITED STATES AND CANADA BOUNDARY.

[O. H. Tittmann.]

The work of remarking this boundary west of the Rocky Mountains was continued during the year, under direction of the joint commission in which Messrs. O. H. Tittmann and C. D. Walcott represent the United States and Mr. W. F. King took part as Commissioner for Great Britain. Observations were made at the triangulation stations necessary to perfect a connection with the triangulation along the Pacific coast in the United States, and the work of opening and monumenting the line was continued.

In October Messrs. O. B. French and C. A. Bigger, representatives of the Commissioners, were sent to Portal, N. Dak., to mark the boundary between Portal and North Portal in Canada. A boundary monument was recovered on each side of the town, and the line was reproduced and marked for the use of the custom-house officers.

In June representatives of the Commissioners, Messrs. C. H. Sinclair and N. Ogilvie, began the work of numbering the monuments for final inspection and acceptance by the Commissioners. This work was in progress at the close of the fiscal year.

The work of opening and remonumenting the boundary between the United States and Canada along the northern border of Vermont was begun under the supervision of Mr. O. H. Tittmann and Mr. W. F. King, Commissioners of the United States and Great Britain, respectively. This work began in the vicinity of Beecher Falls, Vt., on August 1 and was continued until November 13. During this period 30 miles of the boundary westward from Beecher Falls was practically completed. A vista 30 feet wide was cut through the forest, the old monuments were reset in concrete bases, and the new monuments are intervisible wherever it was possible to accomplish this. Large-scale maps of the country in the immediate vicinity of the boundary were made and the topographic survey was extended to a distance of about 1 mile on each side of the boundary. Monuments were established on each side of the principal houses intersected by the boundary and marks were made on all houses found to be on the line, to indicate the position of the boundary. Work was resumed on this portion of the boundary on May 8 and was in progress on June 30. During this time the work, as outlined above, was completed over 20 miles of the line.

The work was in charge of Assistant J. B. Baylor and Mr. G. C. Rainboth, D. L. S., the representatives in the field of the United States and British commissioners, respectively.

ALASKA BOUNDARY.

[O. H. TITTMANN.]

The demarcation of the boundary between Alaska and Canada along the one hundred and forty-first meridian of west longitude was undertaken, as provided in the convention between the United States and Great Britain (signed April 21, 1906), by Mr. O. H. Tittmann, the Commissioner representing the United States, and Mr. W. F. King, the Commissioner representing Great Britain.

The Commissioners sent astronomers to the boundary where it crosses the Yukon River, who proceeded to "ascertain by the telegraphic method a convenient point on the one hundred and forty-first meridian of west longitude" by establishing such a point from determinations of the proper difference of longitude from stations in each country whose longitude was already known from independent determinations by the telegraphic method made by observers representing the countries concerned. Mr. Edwin Smith was the United States astronomer who took part in this work, and he reports that the officers on duty at the Army post at Fort Egbert, Alaska, rendered every possible assistance in facilitating the work. Assistant Smith reached Fort Egbert on August 12, and the work was completed on August 29.

In the spring, the Commissioners sent parties to the one hundred and forty-first meridian to begin tracing and marking the boundary. Messrs. G. C. Baldwin and F. A. McDiarmid, representing the Commissioners of the United States and Great Britain, respectively, reached the boundary at Yukon River on April 20, determined the position of a "north and south line" passing through the point whose position had been fixed as noted above, and then began tracing this line to the southward. Nine miles of the boundary had been traced on June 30, and the work was in progress on that date. On June 13 the work of opening a vista along the boundary and erecting monuments to mark the line was begun, and this work was in progress on June 30, under the direction of Thomas Riggs, jr.

In southeastern Alaska, several parties were at work on the demarcation of the boundary at the close of the previous report. In the vicinity of the Chilkat River, Mr. D. W. Eaton extended the triangulation to the boundary and determined the position of two points on the line. One monument was placed in position on each side of the Chilkat River. A plane table survey was made of the valley from the boundary to a point 2 miles below. Phototopographic camera stations were occupied and negatives were obtained covering about 100 square miles of territory, of which no topographic survey had previously been made. The boundary line between peaks S 6000 and S 6850, a distance of 30 kilometers, was traced and a profile was prepared. A vista along a portion of the line was cleared in the Chilkat Valley on both sides of the river.

Mr. O. M. Leland extended the triangulation of the previous season to Chilkoot Pass, and beyond, and determined the position of peaks S 6500 and S 6000. Monuments were placed in position on each side of Chilkoot Pass to mark the line at that place. On June 30 work was in progress in the vicinity of Lynn Canal and the triangulation was being extended up the Katzehin River.

Mr. Fremont Morse extended the triangulation from a base line on Dry Bay up the Alsek River to the boundary and from the same base to Disenchantment Bay via Yakutat Bay. The positions of the following boundary peaks were determined: S 12430, S 9500, Mount Fairweather, S 5800, S 7500, S 6825, S 8600, S 8900, S 8000, S 10000 (Mount Seattle), S 16400 (Mount Herbert), S 12400, S 15617 (Mount Vancouver), S 14700 (Mount Cook), S 17978 (Mount St. Elias).

The boundary line between Mount Cook and S 5800, a distance of 86 miles, was located. Numerous camera stations were occupied and negatives were made in the phototopographic survey of the region in the vicinity of the triangulation.

On June 30 work was in progress in the vicinity of Glacier Bay.

INTERNATIONAL GEODETIC ASSOCIATION.

[O. H. TITTMANN; J. F. HAYFORD.]

The duty of representing the United States as delegates to the Fifteenth General Conference of the International Geodetic Association, at Budapest, Hungary, was performed by O. H. Tittmann, Superintendent, and J. F. Hayford, Inspector of Geodetic Work, Coast and Geodetic Survey. The conference was in session from September 20 to 28, inclusive.

The delegates presented a report which gave an account of an investigation of the figure of the earth, based on the trigonometric and astronomic work done in the United States.

The Conference voted to continue the latitude service unaltered, at least until the next meeting of the Association, and a formal vote was taken to record the action of the adhering Governments in prolonging the convention of 1895 for a new period of ten years.

The Conference met at Budapest upon the invitation of the Imperial Government of Austria-Hungary and numerous courtesies were extended to the delegates by officers of the Government and the city.

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APPENDIX 2

REPORT 1907

DETAILS OF OFFICE OPERATIONS

CONTENTS.

DETAILS OF OFFICE OPERATIONS.

OFFICE OF THE ASSISTANT IN CHARGE.

ANDREW BRAID, *Assistant in Charge.*

The Assistant in Charge of the Office has direct supervision over the work of the divisions named below.

The Miscellaneous Section is a part of the immediate office of the Assistant in Charge.

COMPUTING DIVISION.

The current work of this Division has been kept up to date. The demand for information of various kinds has continued as great as during the preceding year, but has not shown any increase. The close attention paid to the systemization of the methods and the increased use of computing machines have resulted in increasing the output in all classes of computation with consequent reduction in cost. The computations of the precise leveling work and of the astronomic observations have been made as the field work progressed. Good progress was made in the reduction of the triangulation in California north of Monterey Bay to the United States Standard Datum, and the office computation of the six primary base lines measured in the summer of 1906 was completed. A large group of triangulation in the vicinity of St. Croix River, Maine, was computed.

An unusually large number of astronomic determinations of latitude, longitude, and azimuth were made in the field during the year with consequent increase in this class of computations.

The average effective force of the Division during the year numbered 12 computers, not including the Chief.

DIVISION OF TERRESTRIAL MAGNETISM.

The preparation of the results of the magnetic observations on land and at sea during the previous fiscal year was completed for publication in the Annual Report for that year, and the computation of the observations made during the current year were made as the work progressed.

The compilation of earthquake data recorded by seismographs at Cheltenham, Md., Vieques, P. R., and Honolulu, Hawaii, was completed to the end of the year 1906, and the results were furnished to the International Seismological Association and to others interested in this subject.

The routine work of the Division was kept up to date, and information was prepared in response to numerous requests received during the year.

A report on the "Distribution of the Magnetic Declination in the United States for January 1, 1905, with Isogonic Chart and Secular Change tables," was prepared for publication, and considerable progress was made in the preparation of a publication on the "Distribution of the Magnetic Elements in the United States for January 1, 1905." Good progress was made in the reduction of the work at the magnetic observatories previous to 1905, and the observations of vertical intensity made by eye readings at the Cheltenham observatory on certain specified days in 1902 and 1903 in cooperation with the German Antarctic Expedition were reduced, and the results were transmitted to the German Government. Information was furnished to several magneticians in foreign countries to aid them in making special investigations.

TIDAL DIVISION.

Harmonic analyses were completed for three stations with a combined length of 1 year and 7 months. Nonharmonic reductions were made for 65 stations with a combined length of 14 years and 4 months. Tide notes were prepared for 680 stations on 167 charts and 52 original hydrographic sheets. Tidal information was furnished to field parties and to individuals in response to 330 requests for information, involving the preparation of 670 descriptions of bench marks, tidal data for 544 stations, and current data for 40 stations. Tabulations of high and low water and of hourly heights of the sea were made for 27 years and 7 months of self-registering tide-gauge records from 117 stations, and mean sea level was computed for 20 stations from records with a combined length of nearly 27 years.

There were received, examined, and registered in this Division an aggregate of 16 years of records from self-registering tide gauges at 29 stations, together with 4 years and 4 months of records from staff gauges, and from sources outside the Survey 9 years and 10 months of records at 14 stations.

Current observations at 1 000 stations were reduced and the results entered on cards in order to make them easily accessible. The Tide Tables for 1908 were prepared and the proof for the Tide Tables for 1907 and 1908 was read during the year. The tide predictions for Wellington and Auckland, New Zealand, for the year 1908 were furnished in response to a request from the Secretary of the Marine Department.

DRAWING AND ENGRAVING DIVISION.

The Division is divided into five sections: The Drawing, the Engraving, the Printing, the Photographing, and the Electrotyping sections. Each section does the work indicated by its title, and the combined result is shown on the charts published and issued by the Survey.

Drawing Section.

During the year the following drawings for new charts were completed:

Chart No.	
——.	Maryland Shell Fish Commission Maps, Nos. 1-4.
400*a*.	Anchorage Chart, Hampton Roads.
412.	Chickahominy River, Virginia.
559.	Lower Cedar Point to Mattawoman Creek.
4200.	Philippine Islands.
5530.	San Francisco Bay.
6380.	Washington Sound.
8150.	Dixon Entrance to Chatham Strait.
8241.	Bay of Pillars and Washington Bay.
8262.	Bays and Harbors in Southwestern Alaska.
8502.	Icy Strait to Semidi Islands.
8515.	Prince William Sound, Western Entrance.
8522.	Latouche Passage.
8821.	Harbors and Bays in Southwestern Alaska.
8851.	Bays and Anchorages in Southwestern Alaska.
9196.	Anchorages and Harbors in Southwestern Alaska.

A new drawing for a new edition of the chart of Honolulu Harbor, Hawaii, was also completed.

Extensive corrections were made to the drawings for 26 charts in preparing them for the issue of new editions, and four new tracings were completed for charts already published. Corrections were made on 434 charts and 286 proofs were verified; 87 projections (hydrographic or topographic) were constructed on paper and 17 on copper plates; 11 topographic sheets were inked, and 32 hydrographic sheets were plotted and 41 were verified. A large number of miscellaneous drawings and tracings were completed.

The two Filipino students remained attached to the Division and received instructions in drawing during the year.

Engraving Section.

The following original plates were completed:

Chart No.	
282.	Haverstraw to Newburg, Hudson River.
136.	Chesapeake Bay—Sandy Point to Head of Bay.
904.	Virgin Passage and Vieques Sound.
5532.	San Francisco Entrance.
6445.	Seattle Harbor, Washington.

The following original etched plates were completed:

Chart No.	
297.	Cuttyhunk Harbor, Massachusetts.
918.	Yabucoa Harbor, Porto Rico.
932.	Boqueron Bay, Porto Rico.
4106.	Kaunakakai Harbor, Hawaii.
4108.	Hanapepe Bay, Hawaii.
4442.	Port Romblon, Porto Rico.
5339.	Lompoc Landing, California.
5773.	Shelter Cove, California.
8076.	Harbors in Clarence Strait, Alaska.

The following new bassos were completed:

Chart No.	
7.	Cape Ann to Block Island.
8.	Gay Head to Cape Henlopen.
9.	Cape May to Cape Henry.
15.	Straits of Florida.
105.	Penobscot Bay to Kennebec Entrance.
106.	Kennebec Entrance to Saco River.
110.	Cape Cod Bay.
119.	Fire Island Beach to Rockaway Beach.
130.	Hog Island to Cape Henry.
140.	Albemarle Sound, eastern sheet.
188.	Mobile Bay and Entrance.
209.	Aransas Pass, Aransas and Copano Bays.
306.	Frenchmans Bay.
307.	Blue Hill Bay, etc.
311*a*.	Fox Islands Thoroughfare.
312.	St. George River and Muscle Ridge Channel.
314.	Kennebec and Sheepscot Rivers.
315.	Casco Bay.
327.	Richmond Island Harbor.
353.	Narragansett Bay.
398.	York River—Entrance to Kings Creek.
401*a*.	James River—Hampton Roads to Point of Shoals.
447.	St. Simons Sound, etc.
5491.	Monterey Harbor.
5500.	Point Pinos to Bodega Head.
8300.	Lynn Canal and Stephens Passage.

The following plates were corrected for new editions of charts:

Chart No.	
145.	Cape Hatteras to Ocracoke Inlet.
146.	Ocracoke Inlet to Beaufort.
147.	Cove Island to Bogue Inlet.
169.	Newfound, Harbor Key to Boca Grand Key.
170.	Key West to Rebecca Shoal.
204.	Galveston Bay to Oyster Bay.
244.	Salem Harbor and Approaches.
375.	Raritan River, New Jersey.
469.	Key West Harbor.
518.	Calcasieu Pass, Louisiana.
520.	Galveston Entrance.
5525.	Mare Island Strait, California.
6378.	Bellingham Bay, Washington.
6400.	Seacoast and Interior waters of Washington.

New etched plates were completed for the Philippine Islands base map and for the progress sketch of Alaska.

RECAPITULATION.

	Number.		Number.
New plates completed	5	New bassos unfinished	28
New plates unfinished	18	Plates for new editions completed	14
New plates (etched) completed	9	Plates for new editions unfinished	1
New bassos completed	26		

Printing Section.

	Number.		Number.
Impressions for Chart Section from plates	84 365	Impressions for Chart Section from stones	81 349
Impressions for proofs from plates	4 474	Impressions for proofs from stones	4 130
Impressions for standards, from plates	126	Impressions for transfers (Drawing Section) from stones	469
Impressions for transfers (lithograph) from plates	174	Impressions on bond paper from stones	1 248
Impressions on bond paper from plates	911		
Number of impressions from plates	90 050	Number of impressions from stones	87 196
		Total number of impressions	177 246

The following charts were published by printing from stones and sent to the Chart Section for distribution:

NEW CHARTS.

Chart No.		Chart No.	
400.	Anchorage Chart, Hampton Roads.	4461.	East coast of Samar.
412.	Chickahominy River.	4512.	Samales Group.
4200.	Philippine Islands.	4543.	Isabela Channel and Approaches.
4220.	San Bernardino Strait and approaches.	4544.	Siasi and Lapac Islands.
4240.	Manila and Subic bays to Verde Island Passage.	4645.	Masinloc Anchorage to Caldera Bay.
4257.	Anchorages, Batangas and Balayan bays.	4647.	Agusan River Entrance.
4259.	Rapurapu Strait and Calanaga Bay.	4649.	Malalog Bay.
4309.	Balabac Strait.	8150.	Dixon Entrance to Chatham Strait.
4420.	Calbayog to Tacloban.	8241.	Bay of Pillars and Washington Bay.
4460.	Iloilo Strait and part of Guimaras Strait.	8262.	Bays and Harbors in Southwest Alaska.

NEW EDITIONS.

Chart No.		Chart No.	
389.	Potomac River, Piney Point to Lower Cedar Point.	4713.	East Coast of Luzon.
577.	Fernandina to Jacksonville.	4715.	Southeastern Luzon, Masbate and Samar.
904.	Virgin Pass and Vieques Sound.	4718.	Panay, Negros, and Cebu.
920.	Porto Rico.	4719.	Surigao Strait and Leyte.
1000.	Cape Sable to Cape Hatteras.	5052.	San Francisco to Cape Flattery
4109.	Honolulu Harbor.	5339.	Lompoc Landing.
4232.	Manila Harbor and part of Pasig River.	5532.	San Francisco Entrance.
4243.	Manila and Cavite Anchorages.	5533.	San Pablo Bay.
4442.	Port Romblon.	5534.	Suisun Bay.
4449.	Port Palapag and Laoang Bay.	6195.	Grays Harbor.
4619.	Eastern Part of Illana Bay.	6400.	Seacoast and Interior Waters of Washington.
4711.	Northern Part of Luzon.	6446.	Lake Washington.
4712.	West Coast of Luzon.	7000.	Cape Flattery to Dixon Entrance

NEW PRINTS.

Chart No.	
79.	Chesapeake Bay.
260.	Guilford to Blackstone Rocks.
269.	Stamford Harbor to Little Captain Island.
270.	Little Captain Island to Rye Neck.
297.	Cuttyhunk Harbor.
329.	Portsmouth Harbor.
366.	Hempstead Harbor.
369[8].	Hudson River, Fifty-third street to Fort Washington.
390.	Potomac River.
560.	Potomac River, Mattowan Creek to Washington.
1001.	Chesapeake Bay to Jupiter Inlet.
1002.	Straits of Florida and Approaches.
1007.	Gulf of Mexico.
3108 to 3164.	District of Columbia (Nos. 8, 12, 13, 18, 22, 26, 28, 31, 34, 35, 40, 42, 44, 51, 54, 59, 60, 62, 63, 64.)
4458.	Harbors in Cebu and Negros.
5052.	San Francisco to Cape Flattery.
5773.	Shelter Cove.
5832.	Humboldt Bay.
5984.	Coos Bay.
6003.	Umpqua River Entrance.
6195.	Grays Harbor.
6400.	Seacoast and Interior Waters of Washington.
8000.	Dixon Entrance to Cape St. Elias.
8050.	Dixon Entrance to Head of Lynn Canal.
8150.	Dixon Entrance to Chatham Strait.
8283.	Honiah Sound to Chatham Strait.
8519.	Fidalgo Bay and Valdez Arm.
9008.	Dutch Harbor.
9302.	Bering Sea, eastern part.
9307.	Cape Romanzof to St. Michael.

CHARTS REISSUED.

Chart No.	
249.	Buzzards Bay.
263.	Oyster River to Milford.
268.	Sheffield Island to Wescott Cove.
297.	Cuttyhunk Harbor.
316*b*.	Kennebec River, Court-House Point to Augusta.
376.	Delaware and Chesapeake Bays.
517.	Sabine Pass and Lake.
8051.	Portland Canal.
8235.	Gastineau Channel, etc.
8500.	Icy Cape and Semidi Islands.
8860.	Unimak and Akutan Passes.

MISCELLANEOUS PRINTS.

Base Map of the United States.
Base Map of the Philippine Islands.
Conventional symbols.

SUMMARY.

	Number.
New charts	24
New editions of charts	26
New prints of charts	56
Reissues of charts	11
Miscellaneous	3
Total	120

Photographic Section.

	Number.
Charts of which negatives for photolithographs were made	70
Charts for which matrices were made	19
Copper plates etched	10
Glass negatives made	1 022
Paper negatives made	25
Velox prints made	1 734
Bromide prints made	272
Vandyke prints made	142
Blueprints made	1 047
Lantern slides made	55
Matrices made	102
Prints mounted	465
Negatives developed	258

Electrotyping Section.

Kilograms of copper deposited	1 215	Alto plates completed	44
Square decimeters on which deposited	8 961	Basso plates completed	36

CHART DIVISION.

A new edition of the chart catalogue was completed and the proof was read. A new edition of the Table of Depths in the United States, including Alaska, Porto Rico, and the Philippine Islands was prepared. The issue of charts during the year was 3 per cent larger than during the preceding year, and the correspondence in the chart section shows an increase of 7 per cent.

The work necessary in correcting the published charts to date of issue requires a great deal of time and is increasing.

Charts were received as follows from the Drawing and Engraving Division:

	Number.
Prints from plates	83 675
Prints from stone	38 348

In addition to the above, 6 023 copies of special charts Nos. 1, 2, 3, and 4, prepared for the Maryland Shell Fish Commission, and printed by contract, were received for distribution.

Charts were issued as follows:

	Number.		Number.
Sales agents	47 443	Executive Departments	5 280
Sales at the office	2 099	Foreign governments	739
Congressional account	4 148	Miscellaneous	1 246
Hydrographic Office, U. S. Navy	25 668		
Light-House Board	3 751	Total	103 556
Coast and Geodetic Survey Office	5 487		
Coast and Geodetic Survey Suboffice, Manila, P. I	7 695		

All the work in connection with the sale of charts is done in this Division.

All the corrections necessary to keep the charts up to date were indicated in this Division, and a Notice to Mariners was prepared every month, giving information in regard to changes in the location of aids to navigation and all other data in possession of the Bureau important for mariners to know.

The following work was completed: 21 charts reviewed for publication; 173 charts, corrections on office standards verified; 50 charts, corrections on proofs verified; 19 hydrographic sheets examined and verified.

INSTRUMENT DIVISION.

In this Division an account was kept of all instruments and general property owned by the Survey or purchased during the year, except the articles on the inventory of the office at Washington. All necessary repairs were made to the instruments used by the Survey. Minor repairs were made to the office buildings and furniture, and progress was made in constructing a new tide-predicting machine.

The various kinds of acetylene lamps for sale for use on automobiles were examined, and a "9-inch" lamp was selected as being most available for use as a signal lamp in triangulation work. Twelve of these lamps were bought and the necessary changes were made before sending them to the field, where they were successfully used.

A special receiver for wireless telegraph signals was perfected and three sets of the apparatus were constructed. Experiments made with these receivers show that signals sent at sea over distances up to 50 miles can be readily received for comparison of chronometers used in the determination of longitude by the telegraphic method. No special expert knowledge is required to operate the device.

A new gas engine was installed for the electrotyping work, and a cement-lined pit was constructed just outside the engine room, and the exhaust pipe from the engine was led into it. This does away entirely with the noise caused by the exhaust discharge.

Special eye-piece micrometers were designed and made as additions to the theodolites prepared for use in the demarcation of the Alaska Boundary along the one hundred and forty-first meridian. Four transits were fitted with transit micrometers and provided with new electric illuminating lamps, with devices for regulating the illumination to correspond to stars of any magnitude. A 10-inch circle with 10-minute spaces and a vernier reading to minutes were graduated for the Bureau of Standards.

Three duplicates of the spirit level devised and adopted by the Coast and Geodetic Survey, made for the Canadian government by private parties, subject to inspection and approval by the Superintendent, were carefully examined and recommended for approval.

LIBRARY AND ARCHIVES.

The current routine work was kept up to date. The records of observations made in the field were indexed as they were received. Progress was made in the preparation of a complete author and subject catalogue.

The tables show the accessions and issues during the year:

Accessions.

	Purchased.	Donated.	Exchanged.	Total.
Books and pamphlets	125	106	472	704
Serials	4	95	264	363
Maps and charts	0	293	1 836	2 129

Issued for temporary use.

	Number.
Books and pamphlets	1 851
Serials	639
Records	5 241
Original sheets	3 780
Maps and charts	2 073

The following list shows the original records received:

Subject.	Volumes.	Cahiers.	Sheets or rolls.
Astronomy	60	95	21 rolls.
Geodesy	233	171	
Hydrography	549	2	53 sheets.
Hypsometry	118	18	
Log Books	58		
Magnetism		437	348 sheets.
Tides	155	21	203 rolls.
Topography	10	16	49 sheets.
Miscellaneous			38 sheets.
Total	1 241	860	712

Photographic prints	422
Photographic negatives	190

MISCELLANEOUS SECTION.

The publications received were issued without delay and all current work was kept up to date. All purchases under the appropriation for Office expenses were made through this section and this work involved a great deal of correspondence. The mailing list for the "Notices to Mariners" numbers 1 650, and 4 200 copies are distributed to these addresses every month. An index is distributed at the end of each calendar year.

The following publications were received from the Public Printer:

	Number.
Report of the Superintendent of the Coast and Geodetic Survey for 1906	2 000
Appendices to Report for 1906 published as separates	3 030
Catalogue of Charts, 1907	1 050
United States Coast Pilots, Atlantic Coast	4 495
United States Coast Pilots, Porto Rico	1 506
Supplements to Coast Pilots	4 800
Tide Tables, complete	1 100
Tide Tables, Atlantic Coast	1 260
Tide Tables, Pacific Coast	9 000
Geodetic Operations in the United States	250
Survey of Oyster Bars, Anne Arundel County, Md	2 000
Notices to Mariners	54 200

The following publications were received from the suboffice at Manila:

	Number.
Catalogue of Charts, Philippine Islands	25
Sailing Directions, Philippine Islands	447
Supplements to above, Philippine Islands	53
General Instructions for Coast Surveys in Philippine Islands	40
Notices to Mariners, Philippine Islands	557

The following publications were issued by the Office:

	Number.
Annual Reports, 1846–1906	2 737
Appendices to Annual Reports	2 530
Bulletins Nos. 1–40	487
Catalogue of Charts, United States	1 318
Catalogue of Charts, Philippine Islands	12
United States Coast Pilots, Atlantic Coasts	2 391
United States Coast Pilots, Porto Rico	77
United States Coast Pilot, Pacific Coast, Alaska, Part I	145
United States Coast Pilot, Pacific Coast, California, Washington, and Oregon	567
Supplements to Coast Pilots	3 170
Leaflets, Pan American Exposition (Spanish edition)	26

	Number.
United States Magnetic Declination Tables	184
Sailing Directions, Philippine Islands	413
Supplements to Sailing Directions, Philippine Islands	23
Special Publications:	
No. 1	32
No. 3	18
No. 4	45
No. 5	46
No. 6	25
No. 7	33
Tide Tables, complete	953
Tide Tables, Atlantic Coast	1 208
Tide Tables, Pacific Coast	9 297
Administration and Work of the Coast and Geodetic Survey	4
Coast Pilot Notes on Warren Channel	23
Conversion Tables	7
Deep Sea Sounding and Dredging	3
General Instructions for Coast Survey in Philippine Islands, 1906	42
General Instructions for Hydrographic Work	8
Historical sketch, June, 1884	1
Geodetic Operations, United States, 1900–1903	1
Geodetic Operations, United States, 1903–1906	248
Instructions and Memoranda for Descriptive Reports	3
Laws and Regulations, 1887	17
List and Catalogue	165
Regulations for Enlistment, Discharge, etc	1
Salary Tables, 1904	4
Star Factors, A, B, C	1
Survey of Oyster Bars, Anne Arundel County, Md	1 308
Table of Coefficients	5
Table of Factors (in Feet)	6
Table of Factors (in Meters)	1
Table of Heights (in Meters)	5
Tidal Researches, Ferrell	2
Tides and Tidal Action in Harbors	1
Treatise on Projections	24
Work of the Coast and Geodetic Survey	65
Notices to Mariners	52 824
Notice to Mariners, Philippine Islands	351

APPENDIX 3

REPORT 1907

THE EARTH MOVEMENTS IN THE CALIFORNIA EARTHQUAKE OF 1906

By

JOHN F. HAYFORD
Inspector of Geodetic Work; Assistant, Coast and Geodetic Survey
and
A. L. BALDWIN
Computer, Coast and Geodetic Survey

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ILLUSTRATIONS.

THE EARTH MOVEMENTS IN THE CALIFORNIA EARTHQUAKE OF 1906.

By JOHN F. HAYFORD,
Inspector of Geodetic Work; Assistant, Coast and Geodetic Survey,
and
A. L. BALDWIN,
Computer, Coast and Geodetic Survey.

GENERAL STATEMENT.

The Coast and Geodetic Survey has done much triangulation in California to serve as a control or framework for its surveys along the coast and other surveys. The results of all the triangulation south of the latitude of Monterey Bay, together with the primary triangulation to the northward, have already been published.* In 1906 the results of the triangulation in California from the vicinity of Monterey Bay northward, were being prepared for publication. The reports from various sources in regard to the effects of the earthquake of April 18, 1906, indicated that there had been relative displacements of the earth's surface of from 2 meters (7 feet) to 6 meters (20 feet) at various points near the great fault accompanying the earthquake. These were relative displacements of points on opposite sides of the fault and had been reported along all parts of the fault for 185 miles, from the vicinity of Point Arena, in Mendocino County, to the vicinity of San Juan, in San Benito County. The average relative displacement was said to be about 3 meters (10 feet). Displacements of that size would so change the relative positions of points which had been determined by triangulation and so change the lengths and directions of the lines joining them that the triangulation would no longer be of value as a means of control for accurate surveys. The value of the triangulation could be restored only by repeating a sufficient amount of it to determine definitely the extent and character of the absolute displacements. It was therefore decided to repair the old triangulation, damaged by the earthquake, by doing new triangulation.

If the displacements of a permanent character had been limited to a narrow belt close to the fault, only a few triangulation points would have been affected. The available evidence, however, indicated that the movements probably extended back from the fault for many miles on each side, and that the new triangulation necessary for repair purposes must, therefore, cover a wide belt.

* See Appendix 9, of the Report of the Coast and Geodetic Survey for 1904, Triangulation in California, Part I, by A. L. Baldwin, Computer.

The new triangulation to repair the damage was completed in July, 1907. In addition to serving this practical purpose, it has shown the character of the earth movements of 1906, which were found to extend back many miles on each side of the fault. These are very interesting results from a purely scientific point of view. Moreover, there came to light, during the study of the movements of 1906, entirely unexpected evidence of earlier earth movements, probably in 1868, which also affected a large area.

The purpose of this publication is to set forth fully the amount and nature of tnese two great displacements of large portions (at least 4 000 square miles) of the earth's crust and to indicate the degree of certainty in regard to these displacements warranted by the evidence.

Extent of New Triangulation.

The new triangulation in California, done during the interval July 12, 1906, to July 2, 1907, extends continuously northwestward from Mount Toro, in Monterey County, and Santa Ana Mountain, in San Benito County, to Ross Mountain and the vicinity of Fort Ross, in Sonoma County. This new continuous triangulation, as indicated on map 1, extends over an area 270 kilometers (170 miles) long and 80 kilometers (50 miles) wide, at its widest part. It includes the station known as Mocho, about 11½ miles northeast from Mount Hamilton and a station on Mount Diablo, both on the eastern side of the fault and 53 kilometers (33 miles) from it. It also includes the Farallon Light-house on the west side of the fault and 36 kilometers (22 miles) from it. There were in all 51 old triangulation stations which were recovered and their new positions accurately determined by the new triangulation. The stations had been marked upon the ground by stone monuments, by bolts in rock, etc., or by permanent structures, such as the Farallon Light-house, Point Reyes Light-house, and the small dome of Lick Observatory, or were themselves permanent marks, as, for example, Montara Mountain Peak (a sharp peak).

This continuous scheme consists of a chain of primary triangulation comprising the 11 occupied stations, Mount Toro, Gavilan, Santa Cruz Azimuth Station, Loma Prieta, Sierra Morena, Mocho, Mount Tamalpais, Point Reyes Hill, Tomales Bay, Sonoma Mountain, and Ross Mountain; triangulation of the secondary grade of accuracy extending from the stations Mount Tamalpais, Mount Diablo, Rocky Mound, and Red Hill, to the Pulgas Base near the southern end of San Francisco Bay, and triangulation of a tertiary grade of accuracy in three different localities, namely, in the vicinity of Colma west of San Francisco Bay, along Tomales Bay, and in the vicinity of Fort Ross, Sonoma County.

The primary and secondary triangulations are shown on map 1, and the tertiary triangulation on map 2. On these two maps the straight blue lines indicate lines over which observations were taken in the new triangulation. The small red circles indicate stations marked upon the ground, of which the relative positions were fixed by the triangulation. Observations were taken in both directions over each blue line which is unbroken throughout its length. Observations were taken in one direction only, from the solid end toward the broken end, over each blue line which is broken at one end. A station from which no blue line is drawn unbroken was not occupied. The position of such a station was determined by intersections from the occupied stations.

In addition to this continuous triangulation, a detached piece of new triangulation of the secondary grade of accuracy, connecting old triangulation stations, was done in the vicinity of Point Arena. (See map 2.) This makes the total number of old triangulation stations which were recovered and redetermined 61.

In connection with the new triangulation, astronomic determinations of azimuth or true direction, were made by observations on Polaris at the stations Mount Tamalpais, Mocho, and Mount Toro.

Four different observers, each with his own complete outfit and party, were engaged in the new work for an aggregate period of thirty-five months. The observers were all field officers of the Coast and Geodetic Survey, with previous experience in triangulation.

The Old Triangulation.

The old triangulation fixing the positions of the points before the earthquake of April 18, 1906, was done in many years, extending from 1851 to 1899, as a part of the regular work of the Coast and Geodetic Survey and without reference to the possible future use of this triangulation as a means of determining the movements of permanent character due to earthquakes. During the earlier years certain parts of this old triangulation had existed as detached triangulation not connected with other parts. Before 1906, however, all parts of the old triangulation had been connected with each other by triangulation to form one continuous scheme. It was also connected with other triangulation extending to many parts of the United States, including many of the interior States, as well as the Atlantic and Gulf coasts.

In connection with studies of the evidence as to the earth movements set forth in this publication, it is important to note briefly the dates of the old triangulation which serves, in connection with the new triangulation of 1906–7, to determine changes in positions of marked points on the earth's surface.

During the years 1854–1860 primary triangulation was carried from the stations Rocky Mound, Red Hill, and Mount Tamalpais, northward to Ross Mountain, through a primary scheme practically identical with that shown on map 1, except that the station Bodega was occupied in this earlier triangulation, though not in 1906–7.

Tertiary triangulation, following substantially the scheme shown on map 2, was also done in 1856 to 1860, along Tomales Bay, starting with the line Tomales Bay-Bodega, of the primary triangulation referred to in the preceding paragraph. In connection with this work the station Chaparral, of the Fort Ross triangulation, shown on map 2, was also determined.

Primary triangulation was done during the years 1851 to 1854, connecting the group of stations, Mount Diablo, Rocky Mound, Red Hill, with the Pulgas Base, the scheme being somewhat different from that shown on map 1, but equally direct and strong.

During the years 1854, 1855, 1864, and 1866 primary triangulation was done connecting the stations in the vicinity of Rocky Mound, referred to in the preceding paragraph, with stations Gavilan, Santa Cruz, and Point Pinos Light-house, around Monterey Bay. This triangulation, for the greater part of its length, consists of a single chain of triangles, affording, therefore, comparatively few checks upon the results.

This practically completes the statement of triangulation done before 1868 which is concerned in the present investigation. The extent of the triangulation done between 1868 and 1906 is stated separately in the following paragraphs.

Northward of the line Mount Diablo-Mount Tamalpais but one station of the primary scheme shown on map 1 was determined by primary triangulation in the interval 1868–1906, namely, Ross Mountain. It was determined directly from the stations Mount Tamalpais, Mount Diablo, and Mount Helena, of the transcontinental triangulation.*

During the years 1876–1887 primary triangulation was extended southward (by substantially the same scheme as that shown on map 1, except that station Gavilan was omitted) from the line Mount Diablo-Mount Tamalpais to the line Mount Toro-Santa Ana. Some pointings were also taken on Gavilan, Point Pinos Light-house, and other stations in this vicinity, but not from a sufficient number of stations to furnish checked determinations independent of earlier determinations made before 1868.

Secondary triangulation near Point Arena, forming the western extremity of the transcontinental triangulation, was done in the interval 1870–1892, the scheme being substantially the same as that shown on map 2, except that all stations were occupied. The triangulation fixing the initial stations, Fisher and Cold Spring, has been published.†

Tertiary triangulation in the vicinity of Fort Ross was done in 1875–76, following a scheme similar to that shown on map 2, and starting from the line Bodega Head-Ross Mountain, as determined before 1868.

Tertiary triangulation was done during various years from 1851 to 1899, extending from the vicinity of the Pulgas Base northward, spanning San Francisco Bay, to the Golden Gate, and thence southward to the vicinity of Colma, including stations shown on sketch 4, on map 2. The greater portion of this triangulation was done before 1868, but it is impracticable to separate the computations into two parts dealing with triangulation before and triangulation after 1868, respectively.

PERMANENT DISPLACEMENTS PRODUCED BY THE EARTHQUAKES OF 1868 AND 1906.

The following tables (1, 2, and 3) show the permanent displacements of various points as caused by the earthquakes of 1868 and 1906. These permanent displacements were determined by comparisons of the positions of identical points upon the earth's surface as determined by triangulation before and after the earthquakes in question.

While for the sake of brevity in statement these movements are referred to the earthquakes of 1868 and 1906, the evidence furnished by the triangulation simply indicates the fact that the displacements in question took place some time during the two blank intervals within which no triangulation was done fixing the points in question; namely, the interval 1866–1874, including the 1868 earthquake, and the interval 1892 to July, 1906, including the 1906 earthquake. Neither does the triangulation furnish any evidence indicating whether the displacements took place gradually, extending over many months and possibly years, or whether they took place suddenly. The evidence connecting the displacements of 1906 with the particular earthquake and indicating that they were sudden comes from other sources and will be commented upon later in this paper.

The permanent displacements indicated in Tables 1, 2, and 3 must be carefully distinguished from the vibrations of a more or less elastic character which take place during

* See The Transcontinental Triangulation, Special Publication No. 4, pp. 597–608.

† See The Transcontinental Triangulation, Special Publication No. 4, pp. 597–610.

earthquakes. These vibrations die out in a few seconds, minutes, or hours. While they are in progress, a given point on the earth's surface is in continuous motion along a more or less complicated path, which turns upon itself and leaves the point, at the end of the vibration, near the initial position. The displacements indicated in Tables 1, 2, and 3, on the other hand, remain for years, possibly for centuries. They are of a permanent character. The displaced point remains in the new position until another displacement occurs in some later earthquake or possibly slow relief of strain, accompanied by a creeping motion, causes a new permanent displacement. In Tables 1, 2, and 3 the first column gives the name of the station by which it may also be identified on map 1 or on map 2, or both. The second column gives its latitude at the time indicated in the heading. The third column gives the seconds only of the new latitude at the later time indicated in the heading. The fourth and fifth columns have the same significance with reference to the longitude as the second and third have with reference to the latitude of each point. The sixth column gives the north and south component along a meridian of the displacement. A plus sign in this column means that the point moved toward the south. The seventh column shows the east and west component of the motion. A plus sign in this column means that the point moved toward the east. The sixth and seventh columns were computed by converting the changes in latitude and longitude, respectively, into meters.

By combining the values in columns 6 and 7, the direction and amount of the displacement were obtained as shown in columns 8, 9, and 10. In column 8 the direction of displacement is given, reckoned as geodetic azimuths are usually reckoned—clockwise around the whole circumference from south as zero. In this reckoning west is 90°, north 180°, and east 270°. Column 9 gives the amount of displacement in meters and column 10 gives it in feet. Column 11 shows the approximate distance of the point from the fault of 1906, measured approximately at right angles to the fault. In this column E indicates that the point is to the east of the fault and W that it is to the west.

For example: The fifth line of Table 1 indicates that during the earthquake of 1906 the Farallon Light-house moved 0.83 meter north and 1.57 meters west, or, in other words, moved 1.78 meters (5.8 feet) in azimuth 118° or 62° west of north, and that it is 37 kilometers (23 miles) from the fault of 1906 and to the west of it.

In the heading the expression "Before 1868" refers to years within the interval 1851–1866. The expression "After 1868" refers to years within the interval 1874–1891, and "1906–7" refers to dates within the interval July, 1906–July, 1907.

The latitudes and longitudes given in tables are all computed upon the United States Standard Datum and differ somewhat from those now in use on the charts and maps of this region. They are, however, the latitudes and longitudes to which all charts and maps should ultimately conform.

Table 1 shows the displacements which occurred on April 18, 1906. Table 2 shows the displacements which occurred in 1868, and Table 3 shows the total, or combined, displacements in both 1868 and 1906.

For some cases, as, for example, Point Reyes Hill, the separate displacements were not directly determined by the triangulation, but only the combined displacements. In such cases, if probable values could be derived for the separate displacements, indirectly, by inference from surrounding points, they were so derived and placed in the table. In each case such inferred displacements are clearly distinguished in the table from others which were determined directly by measurement, by leaving the third and fifth columns blank and by having the values in the sixth to tenth columns inclosed in parentheses.

All of the displacements given in Tables 1, 2, and 3 are computed upon the assumption that the two stations, Mount Diablo and Mocho, remained unmoved during the earthquake of April 18, 1906. The reasons why this assumption is believed to be true will be set forth fully in a later part of this paper.

In the tables the points are separated into seven groups for convenience of discussion. Each group of points is fixed by a portion of the triangulation which may conveniently be considered as a unit in discussing the magnitude of the possible errors of the triangulation. The discussion of the observed displacements and the degree of certainty in regard to them is given after the tables and deals with each group in succession.

TABLE 1.—*Displacements of 1906.*

Station	Latitude after 1868	Latitude 1906-7	Longitude after 1868	Longitude 1906-7	Southward component of displacement	Eastward component of displacement	Direction of displacement	Amount of displacement		Relation to fault			Degree of certainty
GROUP 1	° ′ ″	″	° ′ ″	″	*Meters*	*Meters*	°	*Meters*	*Feet*	*Km.*	*Miles*	*Dir.*	
Rocky Mound	37 52 57.253	57.262	122 14 30.507	30.515	−0.28	−0.20	145	0.34	1.1	32	20	E	Doubtful
Red Hill	37 33 04.730	04.738	122 05 40.982	40.975	−0.25	+0.17	215	0.30	1.0	19	12	E	Do
Sierra Morena	37 24 38.266	38.305	122 18 28.006	28.054	−1.20	−1.18	136	1.68	5.5	4.3	2.7	W	Certain
Mount Tamalpais	37 55 27.507	27.492	122 35 45.242	45.228	+0.46	+0.34	324	0.58	1.9	6.4	4.0	E	Do
Farallon Light-house	37 41 58.250	58.277	123 00 03.605	03.669	−0.83	−1.57	118	1.78	5.8	37	23	W	Do
Point Reyes Light-house	37 59 45.458	45.572	123 01 20.577	20.618	−0.43	−1.00	113	1.09	3.6	19	12	W	Doubtful
Point Reyes Hill	38 04 48		122 52 01		(−2.96)	(−2.25)	(143)	(3.72)	(12.2)	2.7	1.7	W	Inferred, certain
Tomales Bay	38 10 55		122 56 47		(−3.06)	(−2.41)	(142)	(3.89)	(12.8)	2.1	1.3	W	Do
Bodega	38 18 24		123 00 04		(+1.16)	(+0.89)	(323)	(1.47)	(4.8)	2.0	1.2	E	Inferred, reasonably certain
Ross Mountain	38 30 20.583	20.572	123 07 09.221	09.204	+0.34	+0.41	309	0.53	1.8	7.0	4.3	E	Doubtful
GROUP 3													
Black Ridge 2	37 44 54.214	54.207	122 27 59.502	59.505	+0.22	−0.07	19	0.23	0.7	7.0	4.3	E	Doubtful *
Bonita Point Light-house	37 48 57.447	57.363	122 31 43.569	43.554	+2.59	+0.37	352	2.62	8.6	6.0	3.7	E	Do
San Bruno Mountain	37 41 16.130	16.129	122 26 05.344	05.334	+0.03	+0.24	277	0.25	0.8	5.1	3.2	E	Do
Black Bluff	37 43 10.158	10.149	122 30 12.684	12.672	+0.28	+0.29	313	0.40	1.3	2.5	1.6	E	Do
Road	37 37 57.595	57.665	122 28 28.512	28.559	−2.16	−1.15	152	2.45	8.0	1.5	0.9	W	Do
Flat	37 36 51.991	52.060	122 27 35.197	35.236	−2.13	−0.96	156	2.33	7.7	1.5	0.9	W	Do
False Cattle Hill 2	37 36 50.401	50.460	122 29 40.926	40.967	−1.82	−1.01	151	2.08	6.8	4.1	2.5	W	Do
Montara Mountain Peak	37 33 42.506	42.549	122 28 36.940	36.904	−1.33	+0.88	214	1.59	5.2	6.1	3.8	W	Do
San Pedro Rock	37 35 44.158	44.239	122 31 22.422	22.441	−2.50	−0.47	169	2.54	8.3	7.4	4.6	W	Do
GROUP 4													
Bodega Head	38 18 29		123 03 45		(−3.56)	(−0.52)	(172)	(3.60)	(11.8)	2.2	1.4	W	Inferred, certain
Tomales Point	38 12 46		122 58 14		(−2.81)	(−2.24)	(141)	(3.59)	(11.8)	2.0	1.2	W	Do
Foster	38 08 13		122 54 23		(−3.61)	(−2.83)	(142)	(4.59)	(15.1)	1.9	1.2	W	Do
Smith	38 14 52		122 56 09		(+1.46)	(+0.80)	(331)	(1.66)	(5.4)	2.6	1.6	E	Do
Mershon	38 10 55		122 54 06		(+1.90)	(+0.42)	(348)	(1.95)	(6.4)	1.1	0.7	E	Do
Hans	38 07 58		122 52 02		(+1.94)	(−0.23)	(7)	(1.95)	(6.4)	0.5	0.3	E	Inferred, doubtful
Hammond	38 04 45		122 48 35		(+1.79)	(−1.42)	(38)	(2.28)	(7.5)	1.2	0.7	E	Do

* Though the absolute displacements in Group 3 are all doubtful, only two of the relative displacements are doubtful, namely: Bonita Point Light-house and Montara Mountain Peak.

TABLE I.—*Displacements of 1906*—Continued.

Station	Latitude after 1868	Latitude 1906–7	Longitude after 1868	Longitude 1906–7	Southward component of displacement	Eastward component of displacement	Direction of displacement	Amount of displacement		Relation to fault			Degree of certainty
	° ′ ″	″	° ′ ″	″	*Meters*	*Meters*	°	*Meters*	*Feet*	*Km.*	*Miles*	*Dir.*	
GROUP 5													
Peaked Hill	38 25 53.725	53.704	123 07 04.450	04.405	+0.65	+1.09	301	1.27	4.2	2.0	1.2	E	Reasonably certain
Lancaster	38 37 16.134	16.086	123 18 44.268	44.228	+1.48	+0.97	327	1.77	5.8	2.0	1.2	E	Do
Chaparral	38 29 33.964	33.927	123 10 56.216	56.187	+1.14	+0.70	328	1.34	4.4	1.8	1.1	E	Do
Dixon	38 30 30.735	30.703	123 11 54.496	54.457	+0.99	+0.94	316	1.37	4.5	1.8	1.1	E	Do
Henry Hill	38 32 47.724	47.688	123 14 27.513	27.474	+1.11	+0.94	320	1.46	4.8	1.5	0.9	E	Do
Salt Point	38 34 00.302	00.350	123 19 57.771	57.827	−1.48	−1.36	138	2.01	6.6	3.2	2.0	W	Do
Horseshoe Point	38 36 27.969	28.004	123 22 09.462	09.504	−1.08	−1.02	137	1.48	4.9	2.9	1.8	W	Do
Stockhoff	38 32 56.969	57.016	123 18 11.870	11.913	−1.45	−1.04	144	1.78	5.9	2.6	1.6	W	Certain
Timber Cove	38 31 59.557	59.615	123 16 35.519	35.573	−1.79	−1.31	144	2.22	7.3	1.9	1.2	W	Do
Fort Ross	38 30 46.084	46.152	123 15 12.655	12.711	−2.10	−1.36	147	2.50	8.2	1.9	1.2	W	Do
Pinnacle Rock	38 30 02.982	03.056	123 14 02.956	02.995	−2.28	−0.94	158	2.47	8.1	1.6	1.0	W	Do
Funcke	38 34 34.972	35.029	123 18 07.323	07.386	−1.76	−1.52	139	2.33	7.6	0.4	0.2	W	Do
GROUP 6													
Cold Spring	39 01 21.370		123 31 20.468							13.5	8.4	E	Assumed unmoved
Fisher	39 03 59.721		123 35 11.758							11.2	7.0	E	Do
Dunn	39 00 39.986	39.964	123 38 40.716	40.699	+0.68	+0.41	329	0.79	2.6	3.9	2.4	E	Certain
Clark	38 59 37.744	37.721	123 37 53.842	53.824	+0.71	+0.43	329	0.83	2.7	3.8	2.4	E	Do
Spur	38 59 16.549	16.509	123 40 13.994	13.957	+1.23	+0.89	324	1.52	5.0	0.5	0.3	E	Do
Lane	39 00 34.636	34.590	123 41 35.602	35.580	+1.42	+0.53	340	1.52	5.0	0.2	0.1	E	Do
Shoemake	38 57 58.425	58.527	123 40 57.846	57.883	−3.14	−0.89	164	3.27	10.7	1.5	0.9	W	Do
Point Arena Catholic Church, spire	38 54 45.079	45.162	123 41 36.283	36.315	−2.56	−0.77	163	2.67	8.8	5.7	3.5	W	Do
Point Arena Light-house	38 57 18.722	18.797	123 44 23.887	23.920	−2.31	−0.80	161	2.45	8.0	6.4	4.0	W	Do
Sinclair	38 54 39.582	39.661	123 42 19.095	19.129	−2.44	−0.82	161	2.57	8.4	6.7	4.2	W	Do
High Bluff	38 54 03.866	03.950	123 41 53.305	53.347	−2.59	−1.01	159	2.78	9.1	6.8	4.2	W	Do
Arena	38 55 18.927	19.005	123 43 36.908	36.942	−2.40	−0.82	161	2.54	8.3	7.6	4.7	W	Do
GROUP 7													
Lick Observatory, small dome	37 20 31.511	31.511	121 38 31.707	31.702	0.00	+0.12	270	0.12	0.4	36	22	E	Doubtful
Loma Prieta	37 06 40.912	40.895	121 50 36.423	36.390	+0.52	+0.82	303	0.97	3.2	4.8	3.0	E	Certain
Santa Cruz Light-house	36 57 08.821	08.837	122 01 33.667	33.682	−0.49	−0.37	143	0.62	2.0	19	12	W	Doubtful
Mount Toro	36 31 34.712	34.742	121 36 32.276	32.284	−0.92	−0.20	168	0.95	3.1	32	20	W	Somewhat uncertain
Santa Cruz Azimuth Station	36 58 42		122 03 19		(+0.61)	(−1.78)	(71)	(1.88)	6.2	19	12	W	Inferred, very doubtful
Gavilan	36 45 21		121 31 11		(+1.48)	(+1.62)	(312)	(2.19)	7.2	6.4	4.0	W	Do
Point Pinos Light-house	36 38 01		121 55 59		(+2.86)	(+1.16)	(338)	(3.09)	10.1	39	24	W	Do
Point Pinos Latitude Station	36 37 59		121 55 32		(+2.31)	(+0.24)	(354)	(2.32)	7.6	39	24	W	Do

TABLE 2.—*Permanent displacements in 1868.*

Station	Latitude before 1868	Latitude after 1868	Longitude before 1868	Longitude after 1868	Southward component of displacement	Eastward component of displacement	Direction of displacement	Amount of displacement		Degree of certainty
GROUP 1	° ′ ″	″	° ′ ″	″	*Meters*	*Meters*	°	*Meters*	*Feet*	
Rocky Mound	37 52 57.237	57.253	122 14 30.510	30.507	−0.49	+0.07	188	0.50	1.6	Doubtful
Red Hill	37 33 04.717	04.730	122 05 41.003	40.982	−0.40	+0.52	232	0.65	2.1	Do
Mount Tamalpais	37 55 27.455	27.507	122 35 45.228	45.242	−1.60	−0.34	168	1.64	5.4	Certain
Farallon Light-house	37 41 58.210	58.250	123 00 03.579	03.605	−1.23	−0.64	153	1.39	4.6	Do
Point Reyes Hill	38 04 48.325		122 52 00.801		(−1.51)	(−0.31)	(168)	(1.54)	(5.0)	Inferred, certain
Tomales Bay	38 10 55.456		122 56 46.733		(−1.56)	(−0.22)	(172)	(1.57)	(5.2)	Do
Bodega	38 18 23.680		123 00 03.726		(−1.62)	(−0.11)	(176)	(1.62)	(5.3)	Inferred, reasonably certain
Ross Mountain	38 30 20.528	20.583	123 07 09.223	09.221	−1.70	+0.05	182	1.70	5.6	Reasonably certain
GROUP 4										
Bodega Head	38 18 29.249		123 03 45.417		(−1.62)	(−0.11)	(176)	(1.62)	(5.3)	Inferred, certain
Tomales Point	38 12 45.732		122 58 14.449		(−1.57)	(−0.19)	(173)	(1.58)	(5.2)	Do
Foster	38 08 13.410		122 54 23.271		(−1.54)	(−0.26)	(170)	(1.56)	(5.1)	Do
Smith	38 14 51.518		122 56 08.865		(−1.58)	(−0.17)	(174)	(1.59)	(5.2)	Do
Mershon	38 10 55.295		122 54 06.016		(−1.56)	(−0.22)	(172)	(1.57)	(5.2)	Do
Hans	38 07 58.492		122 52 02.072		(−1.54)	(−0.28)	(170)	(1.57)	(5.2)	Inferred, doubtful
Hammond	38 04 45.046		122 48 34.993		(−1.51)	(−0.31)	(168)	(1.54)	(5.1)	Do
GROUP 5										
Chaparral	38 29 33.905	33.964	123 10 56.207	56.216	−1.82	−0.22	173	1.83	6.0	Reasonably certain
GROUP 7										
Loma Prieta	37 06 40.971	40.912	121 50 36.521	36.423	+1.82	+2.42	307	3.03	9.9	Certain

TABLE 3.—*Combined displacements of 1868 and 1906.*

Station	Latitude before 1868	Latitude 1906–7	Longitude before 1868	Longitude 1906–7	Southward component of displacement	Eastward component of displacement	Direction of displacement	Amount of displacement		Relation to fault			Degree of certainty
	° ′ ″	″	° ′ ″	″	*Meters*	*Meters*	°	*Meters*	*Feet*	*Km.*	*Miles*	*Dir.*	
GROUP 1													
Rocky Mound	37 52 57.237	57.262	122 14 30.510	30.515	−0.77	−0.12	171	0.78	2.6	32	20	E	Doubtful
Red Hill	37 33 04.717	04.738	122 05 41.003	40.975	−0.65	+0.69	227	0.94	3.1	19	12	E	Certain
Mount Tamalpais	37 55 27.455	27.492	122 35 45.228	45.228	−1.14	0.00	180	1.14	3.7	6.4	4.0	E	Do
Farallon Light-house	37 41 58.210	58.277	123 00 03.579	03.669	−2.07	−2.20	133	3.02	9.9	37	23	W	Do
Point Reyes Hill	38 04 48.325	48.470	122 52 00.801	00.906	−4.47	−2.56	150	5.15	16.9	2.7	1.7	W	Do
Tomales Bay	38 10 55.456	55.606	122 56 46.733	46.841	−4.62	−2.63	150	5.32	17.5	2.1	1.3	W	Do
Bodega	38 18 23.680	23.695	123 00 03.726	03.694	−0.46	+0.78	239	0.90	3.0	2.0	1.2	E	Reasonably certain
Ross Mountain	38 30 20.528	20.572	123 07 09.223	09.204	−1.36	+0.46	199	1.43	4.7	7.0	4.3	E	Do
Sonoma Mountain	38 19 24.539	24.579	122 34 27.894	27.891	−1.23	+0.07	183	1.24	4.0	34	21	E	Certain
GROUP 2													
Pulgas East Base	37 28 36.265	36.258	122 08 08.143	08.129	+0.22	+0.34	302	0.41	1.3	12	7	E	Doubtful
Guano Island	37 34 23.655	23.649	122 15 43.475	43.479	+0.18	−0.10	28	0.21	0.7	10	6	E	Do
Pulgas West Base	37 28 48.787	48.764	122 15 15.681	15.673	+0.71	+0.20	344	0.74	2.4	3.5	2.2	E	Reasonably certain
GROUP 4													
Bodega Head	38 18 29.249	29.417	123 03 45.417	45.443	−5.18	−0.63	173	5.22	17.1	2.2	1.4	W	Certain
Tomales Point	38 12 45.732	45 874	122 58 14.449	14.549	−4.38	−2.43	151	5.01	16.4	2.0	1.2	W	Do
Foster	38 08 13.410	13.577	122 54 23.271	23.398	−5.15	−3.09	149	6.01	19.7	1.9	1.2	W	Do
Smith	38 14 51.518	51.522	122 56 08.865	08.839	−0.12	+0.63	259	0.64	2.1	2.6	1.6	E	Do
Mershon	38 10 55.295	55.284	122 54 06.016	06.008	+0.34	+0.20	330	0.39	1.3	1.1	0.7	E	Do
Hans	38 07 58.492	58.479	122 52 02.072	02.093	+0.40	−0.51	52	0.65	2.1	0.5	0.3	E	Doubtful
Hammond	38 04 45.046	45.037	122 48 34.993	35.064	+0.28	−1.73	81	1.75	5.7	1.2	0.7	E	Do
GROUP 5													
Chaparral	38 29 33.905	33.927	123 10 56.207	56.187	−0.68	+0.48	216	0.83	2.7	1.6	1.0	E	Do
GROUP 7													
Black Mountain	37 19 09.810	09.761	122 08 49.462	49.402	+1.51	+1.48	316	2.11	6.9	1.4	0.9	E	Certain
Loma Prieta	37 06 40.971	40.895	121 50 36.521	36.390	+2.34	+3.23	306	3.99	13.1	4.8	3.0	E	Do
Santa Cruz Azimuth Station	36 58 42.106	42.027	122 03 18.728	18.702	+2.44	+0.64	345	2.52	8.3	19	12	W	Do
Gavilan	36 45 21.068	20.961	121 31 11.504	11.341	+3.30	+4.04	309	5.22	17.1	6.4	4.0	W	Do
Point Pinos Light-house	36 38 01.551	01.399	121 55 58.939	58.795	+4.68	+3.58	323	5.89	19.3	39	24	W	Do
Point Pinos Latitude Station	36 37 59.413	59.279	121 55 31.685	31.578	+4.13	+2.66	327	4.91	16.1	39	24	W	Do

The apparent displacements, as shown in the above tables, are of course in part due to the unavoidable errors in the triangulation and in part are doubtless actual displacements of the points. The triangulation furnishes within itself the means of estimating its accuracy. If the observations were absolutely exact, the sum of the observed angles of each triangle would be exactly 180° plus the spherical excess of that triangle, and moreover the computation of the length of the triangle sides would show no discrepancies, starting from a given line and ending on a selected line, but proceeding through the various alternative sets of triangles which it is possible to select connecting said lines. In any actual case neither of these ideal conditions is found. Each triangle has a closing error, and the lengths computed along different paths through the triangulation show discrepancies. These closing errors and discrepancies are a measure of the accuracy of the triangulation.

The triangulation, both old and new, was adjusted by the method of least squares. This method of computation, as applied to triangulation, takes into account simultaneously all the observed facts in connection with a group of triangulation stations and also all the known theoretical conditions connecting the observed facts, such, for example, as those mentioned in the preceding paragraph in regard to closures of triangles and discrepancies in length. It is the most perfect method of computation known. The results of the computation are a set of lengths and azimuths (true directions) of lines joining the triangulation stations and of latitudes and longitudes defining the relative positions of the stations which are perfectly consistent, that is, contain no contradictions one with another, and are the most probable values which can be derived from the observations. In such a computation the measures of the accuracy of the computed results appear in the form of corrections to observed directions from station to station, which it is necessary to apply in order to obtain the most probable results given by the computation. The greater the accuracy of the observations the smaller are the corrections to directions.

In the problem in hand, in which at least for some points the observed apparent displacement is of about the same magnitude as the possible error in the apparent displacement due to accumulated errors of observation, it is necessary to make a careful estimate of the errors of observation and of the uncertainties of the computed displacements. This has been done and the estimates are given in general terms in the following text and are indicated in the last column of the tables. These estimates will help the reader to avoid drawing conclusions in detail not warranted by the facts.

GROUP I. NORTHERN PART OF PRIMARY TRIANGULATION.

In this group, as shown by Tables 1, 2, and 3 (see also map 1), there are 11 points of which the positions were redetermined after the earthquake of April 18, 1906. Of these, 9 had been determined before 1868 and 7 between 1868 and 1906.

There is about one chance in three that each of the two apparent displacements of Rocky Mound, 0.50 meter (1.6 feet), in 1868 (Table 2), and 0.34 meter (1.1 feet), in 1906 (Table 1), is simply the result of errors of observation. Similarly there is about one chance in three that the apparent displacement of Red Hill in 1868, 0.65 meter (2.1 feet), is the result of errors of observation. The chances are about even for and against the apparent displacement of Red Hill in 1906, 0.30 meter (1 foot), being simply the result of errors of observation. The effect of errors of observation upon the apparent displacements are larger at these two points than they otherwise would be on account of the difficulty in this vicinity of separating the triangulation into two complete schemes, one before 1868 and one after that date, each strong and complete.

According to the evidence furnished by the triangulation, the apparent displacement of Ross Mountain in 1906, 0.53 meter (1.8 feet), in azimuth 309° (51° E. of S.), is probably the result of errors of observation. This apparent displacement as computed depends on the accumulated errors of the two triangulations from Mount Diablo to Ross Mountain, a distance of 130 kilometers (81 miles). The apparent displacement of 0.53 meter almost directly toward Mount Diablo corresponds to a shortening on the line Ross Mountain-Mount Diablo by one part in 250 000, too small a change to be detected with certainty by the triangulation.

On the other hand, there is about one chance in fifteen that the apparent displacement of Ross Mountain in 1868, 1.70 meters (5.6 feet), is due to errors of observation. It is reasonably certain that this is a real displacement.

The chances are about even for and against the apparent displacement of Point Reyes Light-house in 1906, 1.09 meters (3.6 feet), being due simply to errors of observation.

There is about one chance in seven that the apparent displacement of Bodega, shown in Table 3, is due to errors of observation. It is reasonably certain that this is a real displacement.

For the remaining six points in group 1, Sierra Morena, Mount Tamalpais, Farallon Light-house, Point Reyes Hill, Tomales Bay, and Sonoma Mountain, each of the apparent displacements given in the tables as observed is real, being in each case clearly beyond the maximum which could be accounted for as due to errors of observation.

Prof. George Davidson has believed for many years that Mount Tamalpais moved during the earthquake of 1868, and that the triangulations made before and after that date showed such a displacement. Accordingly in 1905, at his request, a reexamination was made at the Coast and Geodetic Survey office of the evidence furnished by the triangulations, and the conclusion was reached that a real displacement of Mount Tamalpais occurred in 1868. At that time, however, convincing evidence was not discovered that any other triangulation station moved in 1868. In the more extensive studies made in connection with the present investigation, and with the additional skill acquired in recognizing the effects of earthquakes upon triangulation, it became evident, as shown in Table 2, not only that Mount Tamalpais moved in 1868, but also that the Farallon Light-house and Ross Mountain moved at that time, the three apparent displacements being clearly beyond the range of possible errors of triangulation. The displacements for these three stations are similar. The amount of the displacement is least at Farallon Light-house, 1.39 meters (4.6 feet), and greatest at Ross Mountain, 1.70 meters (5.6 feet). The azimuth of the displacement is least at the Farallon Light-house, 153° (27° W. of N.), and is greatest at Ross Mountain, 182° (2° E. of N.). (See map 1.) The apparent differences in direction and amount of the three displacements may or may not be real. It is certain, therefore, that in 1868 the large part of the earth's surface included between these three stations, at least 700 square miles, moved about 1.5 meters (4.9 feet), about in azimuth 168° (12° W. of N.).

Within the triangle defined by the three stations, Mount Tamalpais, Farallon Light-house, and Ross Mountain, which certainly were displaced in 1868, are the three stations, Point Reyes Hill, Tomales Bay, and Bodega, of group 1. It is therefore believed to be reasonably certain that these stations were displaced at that time. The probable displacements were interpolated from the three displacements observed at the first three stations, taking into account the relative positions of the stations. The resulting interpolated displacements are shown in Table 2. Other evidence tends to show that these interpolated values of the displacements are real.

For the three stations, Point Reyes Hill, Tomales Bay, and Bodega, the positions were determined before 1868 and after the earthquake of 1906, but not during the interval 1868–1906, hence the computation of the positions determined by triangulation for these stations furnishes simply the combined displacements of 1868 and 1906, as shown in Table 3. As noted in the preceding paragraph, the displacement of 1868 has, for these three stations, been interpolated from surrounding stations and entered in Table 2. The differences* between these inferred displacements in Table 2 and the observed combined displacements in Table 3 were then taken and are shown in Table 1, as inferred displacements in 1906. As indicated in the marked column of Table 1, these inferred displacements are believed to be certain for two of these points, and somewhat doubtful for the third, Bodega.

The doubtful apparent displacements at Rocky Mound and Red Hill in 1868 (see Table 2) agree with other displacements which are certain, in having a decided northward component.

In Table 1, showing the displacements of 1906, there are three stations, Sierra Morena, Mount Tamalpais, and Farallon Light-house, at which the observed displacement is certain, and two others, Point Reyes Hill and Tomales Bay, in group 1, at which the displacement inferred from indirect evidence is considered certain. Of these five stations, the four which are to the westward of the fault of 1906 moved to northwestward, and the one which is to the eastward of the fault, Mount Tamalpais, moved southeastward. (See map 1.) The displacements of four of the five points were nearly parallel, their azimuths being for Sierra Morena, Point Reyes Hill, and Tomales Bay, 136°, 143°, and 142°, respectively, with a mean of 140° (40° W. of N.), while that of Mount Tamalpais was 324° (36° E. of S.). The azimuth of the displacement at the fifth, Farallon Light-house, is 118° (62° W. of N.), at an angle of about 22° with the other four. The portion of the fault near these points has an azimuth of about 145° (35° W. of N.), hence the displacement of four of the five points was practically parallel to the fault, the departure being in each case within the range of possible error of the determination of the displacement. For the four points to the westward of the fault, the amounts of the displacement are in the inverse order of their distances from the fault, with the exception of Sierra Morena. For Tomales Bay, which is only 2.1 kilometers (1.3 miles) from the fault, the displacement is greatest, 3.89 meters (12.8 feet), and for the Farallon Light-house, which is 37 kilometers (23 miles) from the fault, the displacement is much less, 1.78 meters (5.8 feet).

From these five stations, one may deduce four laws governing the distribution of the earth movement which occurred on April 18, 1906. First, points on opposite sides of the fault moved in opposite directions, those to the eastward of the fault in a

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*The differences were taken separately for the meridian components, and the prime vertical components, and then combined to secure the direction and amount of the resultants.

southerly direction, and those to the westward in a northerly direction. Second, the displacements of all points were approximately parallel to the fault. Third, the displacements on each side of the fault were less the greater the distance of the displaced points from the fault. Fourth, for points on opposite sides of the fault and the same distance from it, those on the western side were displaced on an average about twice as much as those on the eastern side.

If the proof of these four deduced laws rested upon the evidence of these five stations only, it would be insufficient to convince one. Much other evidence in proof of these four deduced laws will be shown in this paper. The laws are here stated, in order that they may be kept in mind and tested by the evidence as presented.

The apparent displacements of the remaining five points of group 1 may now be compared with the stated laws.

The displacement of Point Reyes Light-house, believed to be determined with reasonable certainty, is apparently about 1.6 meters (5 feet) greater than, and differs about 32° in direction from the displacement which might be inferred from the above laws and from comparison with the surrounding stations.

The displacement of Bodega, of which the determination is somewhat doubtful, is just what would be inferred from the deduced laws, as its amount is greater than for Mount Tamalpais, corresponding to the fact that it is closer to the fault, and its azimuth agrees within 2° with that of the fault.

The displacement of Ross Mountain, of which the determination is doubtful, agrees very closely in amount with that at Mount Tamalpais, and differs only 15° in direction. Ross Mountain is on the same side of the fault as Mount Tamalpais, and at practically the same distance from it.

The apparent displacements of Rocky Mound and Red Hill, 32 and 19 kilometers (20 and 12 miles) from the fault and to the eastward of it, of which the determinations are doubtful, agree with the laws in being small, but are contradictory as to direction.

For Sonoma Mountain the triangulation serves to determine the combined displacements of 1868 and 1906, as shown in Table 3, but not the separate displacements, as this station was not involved in triangulation done between 1868 and 1906. The combined displacements at Sonoma Mountain are of about the same amount and are in approximately the same azimuth as the displacements of 1868 at Mount Tamalpais, Point Reyes Hill, Tomales Bay, Bodega, and Ross Mountain (see Table 2). Some of the internal evidence of computations of triangulation indicate that Sonoma Mountain moved in 1868. According to the general laws of distribution of the earth movement of 1906, as derived from other stations, Sonoma Mountain did not move much, if any, being far to the eastward of the fault, 34 kilometers (21 miles). For these three reasons it is believed to be probable that the whole displacement of Sonoma Mountain, 1.24 meters (4 feet), in azimuth 183° (3° E. of N.), which certainly took place some time between 1860 and July, 1906, all occurred in 1868.

GROUP 2. SOUTHERN END OF SAN FRANCISCO BAY.

In this group there are three new points not yet considered, and Red Hill, which has already been considered in group 1. The three new stations, Guano Island, Pulgas East Base, and Pulgas West Base (see map 1), were determined in 1851–1854 and again after the earthquake of 1906. No determination was made between 1868 and 1906, hence these points are entered in Table 3, the combined displacements of 1868 and 1906 being determined, but not the separate displacements.

A study of the errors of the triangulation shows that the apparent displacement of Guano Island, 0.21 meter (0.7 foot), is probably due to errors of observation, and that there is one chance in three that the apparent displacement of Pulgas East Base, 0.41 meter (1.3 feet), is also due to errors of observation.

The determination of the displacement of Pulgas West Base, 0.74 meter (2.4 feet), is reasonably certain, there being about one chance in twelve that it is due to errors of observation.

Though the determinations of the separate apparent displacements of Red Hill in 1868, 0.65 meter (2.1 feet), and in 1906, 0.30 meter (1 foot), are each doubtful, the combined displacement as observed, shown in Table 3, 0.94 meter (3.1 feet), is certain.

It is therefore reasonably certain that there was a relative displacement of Pulgas West Base and Red Hill, as indicated in Table 3, Red Hill moving 0.94 meter (3.1 feet), in azimuth 227° (47° E. of N.), and Pulgas West Base, 0.74 meter (2.4 feet), in azimuth 344° (16° E. of S.). This lengthened the line Pulgas West Base to Red Hill, 16 kilometers (10 miles) long, 0.50 meter (1.6 feet), or one part in 32 000. It also changed the azimuth of this line by 11″, from 240° 44′ 35″ to 240° 44′ 24″, rotating it in a counter-clockwise direction.

The red arrows on map 1 showing apparent displacements indicate that the apparent displacements of Guano Island and Pulgas East Base, which are considered doubtful, are not inconsistent with the displacements of Red Hill and Pulgas West Base. Apparently the area included between these four stations was distorted by stretching and rotated in a counter-clockwise direction.

There is no evident method of ascertaining whether the displacement of Pulgas West Base took place in 1868 or 1906 or in part at each time. The displacement is nearly in the direction corresponding to the laws governing the displacements of 1906, as already stated in connection with group 1. Pulgas West Base is to the eastward of the fault of 1906 and slightly nearer to it than Mount Tamalpais and Ross Mountain, and hence, according to the laws referred to, should be displaced in the same direction as these two points (see Table 1), and by a similar amount. This is the fact.

GROUP 3. VICINITY OF COLMA.

There are nine points in group 3 all determined by triangulation in 1899 or earlier, and redetermined after the earthquake of 1906 (see Table 1). The earlier determination was made by secondary and tertiary triangulation, extending from the vicinity of Pulgas Base northwest, spanning San Francisco Bay to the Golden Gate, and thence southward to Colma. The earlier positions of these nine points are subject to the effect of accumulated errors in this chain of triangulation about 60 kilometers (40 miles) long. They are subject therefore to an error of position common to them all which may be as great as 7 meters (23 feet). With the exception of Montara Mountain Peak and Bonita Point Light-house these points are all within 13 kilometers (8 miles) of San Bruno Mountain, and therefore their relative positions were determined with considerable accuracy.

In the triangulation of 1906–7, the position of San Bruno Mountain, which is in the midst of this group, was determined by secondary triangulation in connection with group 2, as indicated on maps 1 and 2, a direct and strong determination. The new azimuth was also carried into the triangulation of group 3 with a high degree of accuracy in this same manner. No new determination was made of the starting length in group 3. It was assumed that the length San Bruno Mountain to Black Ridge 2 had remained unchanged during the earthquake of 1906, and the old value of that length was used in the computation of the triangulation of 1906–7. As a check upon the assumption that this length remained unchanged, it is to be noted that the azimuths of this line before and after the earthquake of 1906 were found to differ only by 9″.3, which is within the possible range of errors of observation in the earlier triangulation.

For the reasons stated above, the apparent absolute displacements shown in Table 1 for group 3, as referred to Mocho and Mount Diablo as fixed points, are probably due to errors of observation.

On account, however, of the fact that seven of the nine points in this group are within a rather small area, their relative displacements are determined with considerable accuracy, the errors of length and azimuth having less effect in producing errors in relative positions, the smaller the area covered by a triangulation. Montara Mountain Peak and Bonita Point Light-house are each determined with a low grade of accuracy. They are each far from the stations occupied in the triangulation and the lines which determine them intersect at a small angle, hence even their relative displacements are uncertain. The relative displacements observed for the remaining seven points after omitting these two are certain, being beyond the possible range of errors of observation.

The apparent absolute displacements for this group of points (see Table 1 and map 2), indicate that all points on the eastern side of the fault moved in a southerly direction, and those on the western side in a northerly direction; that the displacements tend to be parallel to the fault, the more doubtful displacements showing the greater angles with the fault, and that the amounts of the displacement are in the inverse order of the distances of the stations from the fault, with two exceptions. These exceptions are San Pedro Rock, of which the relative displacement is determined with sufficient accuracy to establish this as a real exception, and Bonita Point Light-house, for which the apparent displacement as observed is so uncertain that this apparent exception has but little significance. Of the four points, all on the western side of the fault, of which the relative displacements are believed to be certain, as indicated in Table 1, the azimuths of the displacements vary from 151° to 169°, with a mean of 157° (23° W. of N.). The azimuth of the fault in this vicinity is 144° (36° W. of N.).

The relative displacements on opposite sides of the fault and near to it are less in this group (2 to 3 meters) than for points at a similar distance from the fault in group 1, namely, Point Reyes Hill, Tomales Bay, and Bodega (5 to 6 meters).

GROUP 4. TOMALES BAY.

There are seven points in this group (see Tables 1 to 3 and maps 1 and 2). These were fixed in 1856–1860 by tertiary triangulation extending southeastward along Tomales Bay from stations Tomales Bay and Bodega of group 1. They were fixed again in practically the same manner in 1906 after the earthquake.

With these seven points may advantageously be considered the three points, Point Reyes Hill, Tomales Bay, and Bodega, which were fixed in group 1.

No one of these ten points was determined between 1868 and 1906, hence the observations served to determine the combined displacements of 1868 and 1906, as shown in Table 3, but not the separate displacements. The separate displacements have been determined by interpolation from surrounding stations for the three points, Point Reyes Hill, Tomales Bay, and Bodega, as indicated in the discussion of group 1. The same process has also been applied to the seven points of group 4.

Starting with the interpolated displacements of 1868 for the three points, Point Reyes Hill, Tomales Bay, and Bodega, as shown in Table 2, and with map 2 before one, it was a simple matter to interpolate separately the meridian components and the prime vertical components of the displacements of 1868 for the seven stations of group 4. This amounts practically to interpolating the displacements for these points from the three observed displacements of 1868 at Mount Tamalpais, Farallon Light-house, and Ross Mountain. The resulting interpolated displacements of 1868 are shown in Table 2. Each of these being subtracted, component by component, from the corresponding combined displacement of 1868 and 1906, as shown in Table 3, leaves the displacement of 1906 as shown in Table 1.

A study of the possible accumulated errors in the triangulations shows that all of the seven displacements of 1906 in group 2 are certain except for Hans and Hammond. There is about one chance in five that the apparent displacements of 1906 for these two points are simply due to errors of observation.

The ten displacements of 1906 in this group show clearly the four laws already suggested in regard to such displacements. All points to the eastward of the fault moved southerly, and those of the western side northerly. Four of the five points to the westward of the fault moved in azimuths between 141° and 143° with a mean of 142° (38° W. of N.). The azimuth of this part of the fault is about 145° (35° W. of N.). The azimuth of the fifth displacement on the west side, at Bodega Head, is 172° (8° W of N.). The azimuths of the three reasonably certain displacements of points to the eastward of the fault vary from 323° to 348° with a mean of 334° (26° E. of S.), which is within 9° of being parallel to the fault. Of the five points to the westward of the fault, the one nearest to the fault, Foster, has the greatest displacement. The other four, all between 2 and 2.7 kilometers from the fault, have nearly equal displacements. The five displacements for points to the eastward of the fault show a slight tendency to stand in inverse order from the distances from the fault. But one only of these displacements differs by more than 0.42 meter (1.4 feet) from the mean of the five, and the estimated distances from the fault vary only from 0.5 to 2.6 kilometers. When the uncertainty of the position of the fault beneath Tomales Bay is considered, as well as the small variation in distance of these ten points from the fault, difficulties are to be expected in detecting the relation between displacement and distance from the fault in this group. The mean displacement of the points to the eastward of the fault is 1.86 meters (6.1 feet) and of the five points to the westward 2.1 times as much, namely, 3.88 meters (12.7 feet).

GROUP 5. VICINITY OF FORT ROSS.

There are twelve points in this group, all determined by secondary triangulation in 1875–76 and again in 1906, the scheme of triangulation being in each case substantially the same as that shown on map 2. The base from which these positions are determined is not independent of observations made before 1868, but is obtained by making the observations preceding that date conform to those made between 1868 and 1906. From the small size of the necessary corrections to the observed angles, and from the fact that the position of Ross Mountain, which predominates the group, is determined by observations made entirely after 1868, the error of assuming that these twelve points belong to the period between 1868 and 1906 is deemed negligible.

For one point, Chaparral, observations made in 1860 furnish a determination of the position before 1868, and hence the displacement of this point in 1868 (see Table 2) is determined as well as its displacement in 1906. The displacement of 1868 agrees closely, within less than 0.13 meter (0.4 feet) in amount and 9° in direction, with the displacement at that time at Ross Mountain, 5.7 kilometers (3.5 miles) to the eastward.

A study of the possible accumulated errors in the triangulation shows that five of the observed displacements in this group, as referred to Mocho and Mount Diablo, are clearly beyond the range of possible errors of observation, namely, those at Fort Ross, Funcke, Timber Cove, Stockhoff, and Pinnacle Rock. For the remaining seven displacements there are from one to two chances out of ten that they are due entirely to errors of observation and these displacements are therefore reasonably certain. The relative displacements of pairs of points on opposite sides of the fault and near to each other in this group are certain, being in every case clearly beyond the range of possible errors of observation.

The apparent displacements in 1906 of the twelve points in this group conform closely to the four deduced laws governing such displacements. The seven points to the westward of the fault moved in a northerly direction, in azimuth varying from 137° to 158°, with a mean of 144° (36° W. of N.). The azimuth of the fault in this region is about 141° (39° W. of N.). All five points to the eastward of the fault moved southerly, in azimuth varying from 301° to 328°, with a mean of 318° (42° E. of S.). All of the points in this group are within 3.2 kilometers (2 miles) of the fault and therefore give little opportunity to ascertain whether the amounts of the displacements show any relation to distances from the fault. Such a relation is not clearly discernible among the observed displacements. The evidence of the apparent displacement at Ross Mountain (see Table 1), 6.2 kilometers (4.2 miles) to the eastward of the fault, indicates a decrease of displacement with increase of distance from the fault in that direction. The average displacement of the five points to the eastward of the fault is 1.44 meters (4.7 feet) and of the seven points to the westward is 1.5 times as great, namely, 2.11 meters (6.9 feet).

GROUP 6. POINT ARENA.

In this group there are ten points determined by secondary triangulation in 1870 to 1892 that were redetermined by secondary triangulation in 1906, starting from the stations Fisher and Cold Spring, 11.2 and 13.5 kilometers eastward from the fault, respectively (see map 2). A study of the possible errors in the triangulation shows that all of the observed displacements in this group are certain, each being clearly greater than the maximum possible errors of observation. There is a possibility that the assumption that the two stations, Fisher and Cold Spring, remained unmoved in 1906 is in error. The movement, if any, of these stations was probably about the same for both stations and in a southerly direction and parallel to the fault. If such a movement of these stations occurred the computed displacements in 1906, shown in Table 1 and on map 2, are all too small for stations to the eastward of the fault and too great for stations to the westward of it.

The agreement of the observed displacements of the ten points in this group with the four deduced laws is close. The six points to the westward of the fault moved in azimuths varying through a range of 5° only, from 159° to 164°, with a mean of 162° (18° W. of N.). The fault in this vicinity is said to change in azimuth, near the point where it crosses the coast line, from about 144° to about 164° (16° W. of N.), curving to the eastward. The four points to the eastward of the fault moved in azimuths varying from 324° to 340° with a mean of 330° (30° E. of S.). The station Shoemake, comparatively near to the fault, 1.5 kilometers (0.9 mile), on the west side, showed a displacement much larger than any of the other five points on that side, all of which are from 5.7 to 7.6 kilometers from the fault. The two points to the eastward of the fault, which are within less than one kilometer of it, were displaced nearly twice as much as the other two, which are nearly four kilometers from the fault. The average displacement for the four points to the eastward of the fault is 1.16 meters (3.8 feet) and for the six to the westward is 2.3 times as great, namely, 2.71 meters (8.9 feet).

GROUP 7. SOUTHERN PART OF PRIMARY TRIANGULATION.

In this group, extending southward from the line Mocho-Sierra Morena, there are nine points (see map 1) of which the positions were redetermined after the earthquake of 1906. Of these, one, Loma Prieta, had been formerly determined both before and after the earthquake of 1868, five others had been determined before 1868, but not after, and three had been determined after, but not before 1868. (See Tables 1 to 3.) In this group, therefore, but one point is available to show the displacement of 1868.

The triangulation of 1854–55, starting from the line Ridge to Rocky Mound near the Pulgas Base, consisted of a single chain of triangles with all angles measured, down to the line Loma Prieta-Gavilan. The Point Pinos Light-house and the Point Pinos Latitude Station were connected with this chain, with checks, by observations in 1854, 1864, and 1866.

The main triangulation of 1876–1887, from the line Mount Diablo-Mocho to the line Mount Toro-Santa Ana, consisted of a strong chain of figures with many checks being substantially as shown on map 1 if Gavilan be omitted and all stations occupied. In this triangulation, however, no complete independent determinations with checks, were made of Black Mountain, Santa Cruz Azimuth Station, Gavilan, Point Pinos Light-house, and Point Pinos Latitude Station.

The triangulation of 1906–7 was made as shown on map 1. Two separate least-square adjustments were made of the main scheme connecting the points Mount Diablo, Mocho, Sierra Morena, Loma Prieta, Mount Toro, Gavilan, and Santa Ana.

In the first adjustment it was assumed, as for the computations of other groups, that Mount Diablo and Mocho only remained unmoved during the earthquake of 1906. This first adjustment showed an apparent displacement of Santa Ana in 1906 of 3.26 meters (10.7 feet), in azimuth 288° (72° E. of S.), but an examination in detail of the possible accumulated errors in the triangulation showed that this apparent displacement was probably due to errors of observation. The new primary triangulation is much weaker in the figure defined by the five points, Mocho, Loma Prieta, Mount Toro, Gavilan, and Santa Ana, than elsewhere for two reasons. First, the length must be carried without a check through the triangle Loma Prieta, Mocho, Mount Toro, of which only two angles were measured and which is very unfavorable in shape for an accurate determination of length. Second, it so happened that the least accurate observations made in the primary triangulation were in this triangle or in its immediate vicinity.

In the second and adopted adjustment it was assumed that Santa Ana, as well as Mount Diablo and Mocho, remained unmoved during the earthquake of 1906. The astronomic azimuth had been observed at Mount Toro in 1885 and again after the earthquake of 1906. These two determinations measured the absolute change in azimuth of the line between Mount Toro and Santa Ana, and indicated it to be $2''.5$, the later azimuth being the greater. This was utilized to strengthen the adjustment.

In view of the evidence of stations farther north, the assumption that Santa Ana remained unmoved is reasonably safe. Santa Ana is about 27 kilometers (17 miles) to the eastward from the point at which the fault disappeared near the village of San Juan. There is no station anywhere in the triangulation more than 6.4 kilometers to the eastward of the fault for which any displacement in 1906 was determined with certainty.

If Santa Ana was displaced in 1906 the erroneous assumption introduces an error into the computed displacements at the stations Gavilan, Mount Toro, Point Pinos Light-house, and Point Pinos Latitude Station of about the same amount as the actual displacement at Santa Ana. The error produced in the computed displacement at Santa Cruz Light-house and Santa Cruz Azimuth Station must be much smaller, and no error would be produced at Loma Prieta. Taking the uncertainty in regard to the estimated stability of Santa Ana into account, as well as the possible errors in the triangulation, the following estimates of the uncertainties of the apparent displacements were made.

The displacements of Loma Prieta in 1906 and 1868 (see Tables 1 and 2) are both certain.

The displacements of Black Mountain, Santa Cruz Azimuth Station, Gavilan, Point Pinos Light-house, and Point Pinos Latitude Station, as shown in Table 3, are also certain. These are all combined displacements of 1868 and 1906. These stations were not determined between 1868 and 1906, hence it is not possible to determine directly from the observations the separate displacements. If it be assumed that the displacements in 1868 of the last four of these points were the same as that observed for Loma Prieta (see Table 2), then the inferred displacements for each of these points in 1906 is as shown at the end of Table 1. These inferred displacements for these points are, however, very doubtful, as they depend upon a determination of the displacement of 1868 at a single point, Loma Prieta, which is 24 kilometers (15 miles) from Santa Cruz Azimuth Station and more than 48 kilometers (30 miles) from each of the other stations. It should be noted, also, that the displacement of Loma Prieta in 1868, which is certain, is very different from that of the other four points, Mount Tamalpais, Farallon Light-house, Chaparral, and Ross Mountain, for which the displacements of 1868 have been determined directly by observations. It is a displacement to the southward instead of to the northwestward, and is much larger than for the other three points.

The determination of the displacement of Mount Toro as shown in Table 1 is somewhat uncertain. There is still more uncertainty in regard to the apparent displacement at Santa Cruz Light-house.

The very small apparent displacement, 0.12 meter (0.4 foot), of the Lick Observatory small dome in 1906 is probably due to errors of observation.

The two points in this group to the eastward of the fault show apparent displacements in 1906 in accordance with the laws deduced from other groups, Lick Observatory, far from the fault, 36 kilometers (22 miles), having an apparent displacement so small as to be uncertain, and Loma Prieta, within 4.8 kilometers (3.0 miles) of the fault, having an apparent displacement of 0.97 meter (3.2 feet) in a southerly direction and within 9° of being parallel to the fault, which here has an azimuth of about 312° (48° E. of S.).

Mount Toro is the only station to the westward of the fault in this group for which a determination of the displacement of 1906 is not very doubtful. The displacement in 1906 of 0.95 meter (3.1 feet) at Mount Toro is in a northerly direction with a slight inclination to the westward in fair agreement with the deduced laws. Mount Toro is beyond the end of the portion of the great fault of 1906 which has been traced on the surface.

The apparent displacement of Santa Cruz Light-house in 1906, of which the determination is doubtful, is closely parallel to the fault and in a northerly direction, corresponding to other points to the westward of the fault.

The inferred displacement of 1906 for four points shown at the end of Table 1 are all very doubtful, and little significance should be attached to them or to the fact that they are somewhat contradictory to each other and all have a southerly tendency, whereas all other points to the westward of the fault of 1906 moved in a northerly direction. As a check on this conclusion it should be noted that the inferred displacement for 1906 for Santa Cruz Azimuth Station differs by 72° in direction and 1.26 meters (4.1 feet) in amount from the observed displacement of 1906 for Santa Cruz Light-house, a point only 3.9 kilometers (2.4 miles) away. The observed displacement for Santa Cruz Lighthouse is much less uncertain than the inferred displacement for Santa Cruz Azimuth Station, and hence the contradiction throws additional doubt on the latter and the other three points for which the inference is made in like manner.

Though the inferred displacements of these four points for 1906 are all very doubtful, the observed combined displacements of 1868 and 1906 for these four points, as shown in Table 3, are all certain, being clearly beyond the possible range of errors of observation. So, also, are the combined displacements of 1868 and 1906 for Loma Prieta and Black Mountain. It appears, then, that the combined effects of the earthquakes of 1868 and 1906 were to move the whole region from Black Mountain to Point Pinos to the southeastward by from 2.11 to 5.89 meters (6.9 to 19.3 feet). The mean azimuth of these six displacements is 321° (39° E. of S.). The most startling evidence of the combined effects of the two earthquakes is the increase of 3 meters (10 feet) in the width of Monterey Bay from Santa Cruz Azimuth Station to Point Pinos Light-house, both of these points having moved in a southerly direction, but the latter much more than the former. The length of the line Santa Cruz Azimuth Station to Point Pinos Light-house is only 39.8 kilometers (24.7 miles); the increase is therefore one part in 13 000.

Not much significance should be attached to the fact that Point Pinos Latitude Station has apparently moved 1 meter less than Point Pinos Light-house. This 1 meter is the difference of the combined displacements of two earthquakes. It is subject to the errors of observation in two determinations of each point by triangulation in somewhat different ways. Moreover, the determination of the position of Point Pinos Latitude Station after the earthquake of 1906 was made without a check. It is for this reason that the displacement at Point Pinos Light-house is considered to be the more reliable determination of the two.

Distribution of Earth Movement: Summary.

In reaching the conclusions stated below, the evidence has been studied much more in detail than it has been given in the preceding pages. The conclusions are based on both the positive and negative evidence. The positive evidence is given by the displacements marked "certain" or "reasonably certain" in Tables 1, 2, and 3. The negative evidence is given by displacements marked "doubtful," of which Rocky Mound is an example. At this point the observed apparent displacement of 1906 was only 0.34 meter (1.1 feet). The accuracy of the triangulation is such that it is practically certain that any displacement of this station as great as 1 meter would be detected. Hence the evidence given by this station is that the displacement, if any, was less than 1 meter and probably was less than 0.3 meter.

Maps 1 and 2 should be consulted while reading the following conclusions:

During an earthquake in 1868, or about that time, about 1 000 square miles of the earth's crust, comprised between the four stations, Mount Tamalpais, Farallon Light-house, Ross Mountain, and Chaparral, were permanently displaced to the northward about 1.6 meters (5.2 feet), in azimuth 169° (11° W. of N.). The indications are that this whole area moved as a block without distortion or rotation; at least the triangulation furnishes no evidence competent to prove either distortion or rotation of the block (about a vertical axis), or to locate accurately any boundary of the block. It is probable that the block included Sonoma Mountain. It is reasonably certain that Rocky Mound and the group of points near the southern end of San Francisco Bay, Red Hill, Pulgas Base stations, and Guano Island were not on this block, though they were probably displaced somewhat irregularly during the earthquake of 1868.

During the earthquake of 1868, or about that time, Loma Prieta was permanently displaced about 3.03 meters (9.9 feet), in azimuth 307° (53° E. of S.) This displacement is in a direction at an angle of 138° with that of the displacements of the same date referred to in the preceding paragraph. Loma Prieta moved to the southeastward, whereas Mount Diablo, Farallon Light-house, Ross Mountain, and Chaparral moved to the northward.

It is reasonably certain that Santa Cruz Azimuth Station, Point Pinos Light-house, Point Pinos Latitude Station, and Gavilan were similarly displaced. It is probable that the last three stations named were displaced to the southeastward in 1868, being about 3 meters (10 feet) more than Santa Cruz Azimuth Station and Loma Prieta, and consequently the width of Monterey Bay was increased then by about one part in 13 000.

The combined effects of the earthquakes of 1868 and 1906 have increased the distance between Mount Tamalpais and Black Mountain (see map 1 and Table 3) by 3 meters (10 feet). The distance is 79 kilometers (49 miles) and the increase is therefore one part in 26 000. The Golden Gate lies between these two stations. It is interesting to note that the length of part of the Pacific Coast, including the Golden Gate, has been increased just as the distance across Monterey Bay has been increased.

During the earthquake of April 18, 1906, displaced points on opposite sides of the great fault accompanying the earthquake moved in opposite directions, those to the eastward of the fault in a southerly and those to the westward in a northerly direction. Among all the points there are but two apparent exceptions to this rule, namely, Rocky Mound and Red Hill. For both these stations the apparent exceptional movement is so small as to be probably due simply to errors of observation, and therefore they are not significant.

During the earthquake of 1906 the permanent displacements of all disturbed points were approximately parallel to the fault. When the difficulties encountered in determining the direction of these displacements are considered, it is remarkable that the observed displacements follow this law so accurately as they do. The nearest fixed points to which each displaced point is referred are from 30 to 140 kilometers distant (20 to 90 miles). The total displacements are from 0.5 to 4.6 meters (2 to 15 feet). Among all the points examined, there are but five for which the apparent changes in distance from the fault are not so small as to be probably due to errors of observation. The Farallon Light-house apparently moved at an angle of about 27° with the fault, and its increase in distance from the fault of 0.8 meter is reasonably certain. As Mount Tamalpais, nearly opposite to Farallon Light-house across the fault, moved practically parallel to the fault, there was either an opening of the fault beneath the sea in this region or an increase in length of the earth's crust, in a direction at right angles to the fault, of one part in 50 000 (0.8 meter in 44 kilometers, or 3 feet in 27 miles). Point Reyes Light-house also apparently receded from the fault, moving in about the same direction (within 5°) as the Farallon Light-house, but the determination of the displacement of the Point Reyes Light-house is so weak that this apparent displacement has little significance. It is reasonably certain that Bodega Head approached the fault from the western side, while Bodega, on the eastern side of the fault, about opposite, moved parallel to the fault. The apparent closing up of the fault or shortening of the crust at right angles to the fault is 1.6 meters (5.2 feet) between these two points, only 5.4 kilometers (3.4 miles) apart. This is one part in 3 400. It is possible that as much as one-half of this apparent closing up is due to errors of observation, but it is reasonably certain that not all of it is due to that cause. Similarly it is reasonably certain that Peaked Hill in the Fort Ross group receded from the fault on the east side and Pinnacle Rock approached it on the west side, the apparent amounts being 0.4 meter (1.3 feet) and 0.7 meter (2.3 feet), respectively. It is reasonably certain that San Pedro Rock in the Colma group approached the fault from the west side, the apparent amount being 1.1 meter (3.6 feet).

During the earthquake of 1906 the displacements on each side of the fault were less the greater the distance of the displaced points from the fault. On the eastern side of the fault, ten points at an average distance of 1.5 kilometers (0.9 mile) from the fault have an average displacement of 1.54 meters (5.1 feet), three points at an average distance of 4.2 kilometers (2.6 miles) have an average displacement of 0.86 meter (2.8 feet), and one point, Mount Tamalpais, at 6.4 kilometers (4.0 miles) from the fault, has a displacement of 0.58 meter (1.9 feet). These fourteen points are the only ones on the eastern side of the fault for which the observed displacements were determined with reasonable certainty. For no point to the eastward of the fault at a greater distance than 6.4 kilometers (4.0 miles) was any displacement detected with certainty. To the westward, twelve points at an average distance of 2.0 kilometers (1.2 miles) from the fault have an average displacement of 2.95 meters (9.7 feet). Seven at an average distance of 5.8 kilometers (3.6 miles) have an average displacement of 2.38 meters (7.8 feet). The only other point to the westward of the fault of which the displacement was determined with certainty was Farallon Light-house, distant 37 kilometers (23 miles) and displaced 1.78 meters (5.8 feet).

In receding from the fault, either to the eastward or to the westward, the displacement decreases more rapidly near the fault than it does farther from the fault. According to the averages given in the preceding paragraph, the decrease in displacement on the eastern side near the fault is at the rate of 0.25 meter per kilometer (that is, 0.68 meter in 2.7 kilometers) and farther away the rate is 0.13 meter per kilometer (that is, 0.28 meter in 2.2 kilometers). Imagine a straight line before the earthquake of April 18, 1906, starting at the fault and extending eastward at right angles to it. According to this investigation, after the earthquake this line became a curved line, concave to the southward, the point at the fault being displaced southward and distant points on the line remaining fixed. Also according to the above figures, the part of the line which is from 1.5 to 4.2 kilometers from the fault was deflected from its former direction about 52 seconds and that part from 4.2 to 6.4 kilometers from the fault was deflected about 26 seconds, and the deflection probably decreased gradually to zero at distant points. To the westward of the fault the rate of decrease of displacement, according to the averages in the preceding paragraph, is near the fault 0.15 meter per kilometer (that is, 0.57 meter in 3.8 kilometers) and farther away only 0.02 meter per kilometer (that is, 0.60 meter in 31 kilometers). Accordingly the imaginary straight line at right angles to the fault and extending westward from it has become concave to the northward, the point at the fault being displaced to the northward and very distant points remaining fixed. The deflection from its original direction is about 31 seconds for the part from 2 to 6 kilometers from the fault and about 4 seconds on an average for the part from 6 to 37 kilometers from the fault.

Of points on opposite sides of the fault of 1906, and at the same distance from it, those on the westward side are displaced on an average twice as much as those on the eastern side. This statement applies especially to points within 10 kilometers (6 miles) of the fault. For points farther away the ratio becomes more than two to one. It is important to note that this statement applies to displacements, not distortions. The distortion, expressed in angular measure, discussed in the preceding paragraph, is nearly the same on the two sides of the fault, being somewhat less, close to the fault, on the western side than on the eastern side.

The amount of relative displacement of the two sides of the fault by sliding along the fault, as detected by the triangulation, shows no variations for different parts of the fault along its whole length from Point Arena to San Juan, with one exception, which are sufficiently large to be clearly not due to errors of observation. This one exception is the region near Colma where, as already noted, the relative displacements seem to be unusually small.

The permanent displacements and distortions which took place at the time of the earthquake of April 18, 1906, may be pictured by imagining a series of perfect squares drawn on the surface of the ground before the earthquake, with their sides parallel and perpendicular to the fault. At the time of the earthquake every square to the eastward of the fault moved bodily in a southerly direction parallel to the fault, the squares more distant from the fault moving less than those near to it. All sides of squares parallel to the fault remained straight lines, unchanged in length and direction. For the squares to the eastward, the sides perpendicular to the fault became curved lines concave to the southward and changed direction as a whole by rotation in a counter-clockwise direction, the change being 52 seconds or more for squares near the fault, and less for more remote squares. The angles of the squares all took new values differing from 90° by quantities ranging from more than 52 seconds to zero. The squares to the westward of the fault were moved bodily in a northerly direction parallel to the fault, their sides parallel to the fault remaining straight and unchanged in length and direction. Their sides perpendicular to the fault became curved lines concave to the northward and each changed in direction by rotation in a counterclockwise direction, the change being more than 31 seconds for squares near the fault and less for more remote squares. The displacement of squares near the fault was twice as great for squares on the western side as for squares on the eastern, but the distortion was slightly less for squares on the western side than for those on the eastern side. The appreciable displacements extended back much farther from the fault on the western side than on the eastern side.

It is not probable that the actual displacements and distortions were perfectly regular as indicated in the word picture of the preceding paragraph, but the apparent departures from this perfectly regular ideal of the displacements and distortions detected by the triangulation are nearly all so small as to be possibly due to errors of observation. Attention has been called to the few exceptions, of which one can be certain, which have been detected. The earth movements of April 18, 1906, were remarkable for their regularity of distribution.

The triangulation of 1906–7 has extended eastward clearly beyond the region of appreciable permanent displacements by the earthquake of 1906. The disturbed region evidently extended to the westward out under the Pacific beyond the possible reach of the triangulation. To the northward of Point Arena there is little probability of much success if an attempt were made to determine additional displacements by triangulation, for the known fault of 1906 touches the coast for but a short distance anywhere north of Point Arena, and triangulation to the northward of Point Arena before the earthquake consisted simply of a narrow and weak belt of tertiary triangulation. It had been intended to extend the triangulation of 1906–7 far enough to the southward to reach outside of the disturbed region. It was supposed until after the observing party left the southern end of the triangulation that this had been accomplished, but when the additional evidence given by the office computations became available it was evident that the most southern points determined are still within the disturbed region. The fact that the visible evidence of the fault of 1906 does not extend farther southward than San Juan indicates that there are probably few points to the southward of Mount Toro and Point Pinos for which the displacements were large enough to be detected by triangulation.

Discussion of Assumptions.

Certain things have apparently been assumed in this investigation—for example, that appreciable permanent displacements occurred during the earthquake of 1868 as well as during the earthquake of 1906, that the permanent displacements in 1906 occurred suddenly, and that the stations Mocho and Mount Diablo remained unmoved in both earthquakes.

These are called apparent assumptions because in a real sense they are not assumptions but are instead facts detected gradually in studying for fifteen months upon a steadily increasing mass of evidence. However, treating them as assumptions, their validity has been reexamined in the light of all the evidence, and to make this report complete it is now necessary to state why they are believed to be true.

It has been tacitly assumed that the permanent displacements of 1906, detected by the triangulation, took place suddenly. It is certain from evidence entirely distinct from the triangulation that on April 18, 1906, relative displacements by sliding along the great fault of that date took place suddenly, that is, within an interval of a few seconds, without much crushing or separation of the sides of the fault, and that these relative displacements amounted from 2 to 6 meters (7 to 20 feet). These relative displacements were evident at every road, fence, or line of trees crossing the fault, but such evidence does not enable one to ascertain how far back from the fault in each direction the displacement extended. The repetition of the triangulation after the earthquake showed that many points at various distances from the fault had all been displaced parallel to the fault, that the distribution of the displacements is regular, and that for points nearest the fault the relative displacements corresponded in amount to those observed at roads, fences, tree lines, etc., at the fault and which were known to have taken place suddenly. Hence it is certain that the widely distributed displacements shown by the triangulation are a part of the same phenomenon and took place at the same time as the displacements at the fault, that is, suddenly on April 18, 1906.

For the displacements credited to the year 1868 in this report the case is different. It had been known from previous examination of the evidence given by triangulation that Mount Tamalpais had moved between 1859 and 1876. In the course of the detailed studies of the triangulation in connection with the present investigation, it was found that other triangulation stations had moved at or about 1868. It was discovered that wherever triangulation in this part of California before 1868 had been connected with triangulation done after 1868, it was necessary, in order to obtain consistent results, to apply abnormally large corrections to the observed angles. By trial it was found that wherever the observations of angles were separated into two groups and separate computations made connecting identical points marked upon the ground, one group comprising observations before 1868 and the other observations after that year, that the corrections necessary to obtain consistent results from each set of angles were much smaller than before, and about the normal size to be expected from the instruments and methods of observation used. The evidence proves that permanent displacements took place at or about 1868 of a magnitude which the triangulation could detect with certainty. The particular year in which the displacements took place is not fixed, however, by the triangulation, but simply by the fact that it occurred within the interval of several years which elapsed in each part of the triangulation between the last observation before 1868 and the first observation after that year. For this reason considerable care has been taken in stating the dates of the triangulation for each locality. In 1906 it was known that sudden permanent displacements took place on a certain day, hour, and minute along a great fault line and these displacements were similar to those detected later by triangulation. So far as the writers know, no evidence has been found that such large sudden relative displacements took place in 1868 or about that year, but it is known that a very severe earthquake in this region occurred in 1868. Hence the observed displacements, referred in this report to 1868 for the sake of brevity, may have occurred in some other year near 1868 and may have occurred by a gradually creeping motion extending over several years.

No other abnormal discrepancies in the triangulation within this region are known to exist. If there are such discrepancies produced by displacements of the triangulation stations by earthquakes, they are so small as to be effectually masked by the unavoidable errors of observation. In other words, any other permanent horizontal displacements by earthquakes within this region between 1850 and 1907 must have been much smaller than the displacements of 1906 and 1868.

It has been assumed that there was no permanent displacement of stations Mocho and Mount Diablo during the earthquake of 1906. What is the evidence that this assumption is true?

The true direction or azimuth from Mocho to Mount Diablo was determined by observations upon the stars in 1887 and found to be 144° 57′ 35″.71. In 1907 it was redetermined by observations upon the stars and found to be 144° 57′ 35″.66, differing by only 0″.05 from its former value. The maximum possible difference between the two determinations of azimuth which could occur simply as errors of observation is about 1″.* Hence these observations show positively that the true direction from Mocho to Mount Diablo had not changed between these dates by as much as 1″ and probably had not changed by as much as 0″.3.

The true direction or azimuth of the line Mount Tamalpais to Mount Diablo was determined by observations upon the stars in 1882 and again in the same manner in 1907. In 1882 it was found to be 274° 15′ 15″.04 and in 1907, 274° 15′ 14″.49, 0″.55 less than before. The azimuth of the line Mount Tamalpais to Mount Diablo was computed separately from the triangulation between 1868 and 1906 and from the triangulation after the earthquake of 1906, and the two values found to be 274° 15′ 19″.46 and 274° 15′ 17″.89, respectively, the second being 1″.57 less than the first. This apparent decrease of azimuth as determined by the triangulation agrees within 1″.02 with the decrease of 0″.55 determined independently by astronomic observations.† This agreement is within the range of possible errors of observation. In the two computations of the triangulation, the line Mocho-Mount Diablo was assumed to have the same azimuth before and after April 18, 1906, hence the close agreement noted indicates that the azimuth Mocho-Mount Diablo remained unchanged.

In the investigation which has been made, it was found that the absolute displacement decreased with increased distance from the fault, and that no displacement suf-

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* The probable error of observed azimuth in 1887 was ±0″.21 and in 1907 ±0″.20. The expression, "probable error," is here used in the technical sense in which it is used in connection with the least square method of computation.

† The discrepancy of about 4″ on each date between the azimuth determined by astronomic observations and the azimuth determined by triangulation is what is known as "station error" in azimuth and is due to the deflection of the vertical at the observation station. It does not enter into the present discussion, which is based on differences of azimuths of the same kind, either astronomic or geodetic, on different dates at the same station.

ficiently large to be detected with certainty was found farther to the eastward of the fault than Mount Tamalpais, 6.4 kilometers (4 miles) from it. Mocho and Mount Diablo are 53 kilometers (33 miles) from the fault, hence it seems certain that the displacements, if any, at Mocho and Mount Diablo must have been extremely small. It may be objected that this is reasoning in a circle, inasmuch as the computed displacements depend upon the assumption that Mocho and Mount Diablo stood still. Cleared of this objection, the argument reduces to the following: The triangulation shows no relative displacements in 1906, large enough to be determined with certainty, of Mocho, Mount Diablo, Rocky Mound, Red Hill, and Lick Observatory, a group of points far to the eastward of the fault, whereas many points nearer to the fault showed large relative displacements as referred to each other with a marked tendency to be greater the nearer to the fault are the groups of points compared. Hence the reasoning is valid that Mocho and Mount Diablo remained unmoved, these being two points in a group showing no displacements relative to each other, the whole group being far from the fault, and these two particular stations being the two points most distant from the fault.

If either Mocho or Mount Diablo had moved in April, 1906, in such a direction as to decrease (or increase) the azimuth of the line joining them, the effect of the erroneous assumption, used in the computation of the triangulation done after the earthquake, that the azimuth had remained unchanged, would have been to produce a set of computed apparent displacements which would be represented by red arrows on map 1, all indicating a rotation in a clockwise (or counterclockwise) direction around Mount Diablo, the lengths of the arrows being proportional to their distances from Mocho and Mount Diablo. The fact that the computed apparent displacements of 1906 as shown by the red arrows on maps 1 and 2 do not show any such systematic relation to each other, indicates that the line Mocho-Mount Diablo remained unchanged in azimuth on April 18, 1906.

Similarly, if either Mocho or Mount Diablo had moved on April 18, 1906, in such a direction as to increase (or decrease) the distance between them, the effect upon the computations of apparent displacements would have been to produce a set of red arrows on maps 1 and 2, all pointing toward (or from) Mocho and Mount Diablo, the lengths of the arrows being proportional to their distances from Mocho and Mount Diablo. No such systematic relation appears among the arrows.

Another item of evidence is still available which indicates that the absolute displacement of points far to the eastward of the fault was zero on April 18, 1906. From 1899 to date a series of observations of latitude by observations upon the stars have been in progress continuously for the International Geodetic Association at Ukiah, Cal. The purpose of these observations is to detect variations in latitude due to any cause. The observations are of an extremely high grade of accuracy, and they are made on every clear night. Dr. S. D. Townley, in charge of these observations, made a special study of the 233 observations made during the interval April 4–May 4, inclusive, 1906, to determine whether any sudden change of latitude took place on April 18.* He found no such change. The observations are competent to determine with reasonable certainty any change as great as $0''.03$, corresponding to 1 meter (3 feet). It is

* This investigation is published in the "Publications of the Astronomic Society of the Pacific," Vol. XVIII, No. 109, August 10, 1906, under the title "The Latitude of the Ukiah Observatory before and after April 18, 1906."

therefore reasonably certain that the southward component of the motion, if any, of the pier on which Doctor Townley's latitude instrument was mounted at Ukiah was less than 1 meter on April 18, 1906. Ukiah is about 42 kilometers (26 miles) from the fault and to the eastward of it. Mocho and Mount Diablo are much farther from the fault (53 kilometers). It is important to note that the latitude observations determined the absolute displacement rather than the relative displacement, and that they are independent of observations at any other station.

For the reasons set forth above, it is believed to be certain that the permanent displacement, if any, of either Mocho or Mount Diablo on April 18, 1906, must have been extremely small.

During verbal discussions of the earthquake of April 18, 1906, it has been suggested more than once that one of its possible effects may have been to change the position of the earth with relation to its axis of rotation, and so produce a change of latitudes. If an appreciable effect of this kind were possible, the validity of the above reasoning in regard to the latitude observations at Ukiah would be questionable. Accordingly, a computation of this possible effect has been made.* It was found that if it be assumed that the mass displaced in a northerly direction to the westward of the fault comprised 40 000 square kilometers (15 600 square miles) of the earth's crust, having a mean latitude of 38° and thickness or depth of 110 kilometers (68 miles), that this material had an average density of 4.0, and that the northerly component of the displacement was 3 meters (10 feet), the position of the pole of maximum moment of inertia would be displaced by 0".0007, corresponding to 0.002 meter (0.006 foot). This is a limiting value certainly much larger than the actual value, for all assumptions entering the computation as to the area, depth, density, amount of displacement, and mean latitude have been made such as to make the computed value certainly too great. Moreover, the similar displacements of contrary direction to the eastward of the fault would partially cancel those on the westward side which have been considered. When the pole of maximum moment of inertia is displaced, the pole of rotation is not immediately changed with reference to the earth. The pole of rotation tends always to seek the pole of maximum moment of inertia and travels around it in an irregular path. It is the instantaneous position of the pole of rotation with reference to the earth which fixes the latitude at any instant. Hence, even this extremely small displacement of the pole of maximum moment of inertia computed above, 0.002 meter, does not immediately affect the latitude of points in California, but only tends to change them by that average amount in the course of a year or more. The effect of the earthquake on the latitudes of points outside the region of actual displacement of the surface is therefore entirely negligible. The earthquake changed the latitude of marked points on the earth's surface within the disturbed region by the amount of the northward or southward components of the displacement of the points.

Similarly, the possible effect of the displacements on the deflections of the vertical—that is, upon the direction of gravity at any point—is too small to be considered.

The displacements near Point Arena were computed upon the assumption that the triangulation stations Fisher and Cold Spring remained unmoved during the earth-

* The formula and method of computation is shown in "Traité de Mécanique Céleste" par F. Tisserand, Paris, 1891, Gauthier-Villars, Tome II, pp. 485-487.

quake of 1906. Is this assumption true? The station farthest to the eastward from the fault at which a displacement in 1906 has been detected with certainty is Mount Tamalpais, distant 6.4 kilometers and displaced 0.53 meters. Also the rate of decrease of displacements at this distance has been found to be 0.13 meter per kilometer of increase of distance from the fault. At this rate the displacement would become zero at about 11 kilometers from the fault. Fisher is 11.2 and Cold Spring 13.5 kilometers from the fault, hence it is reasonably certain that if the displacement was not zero at these two stations, it was so nearly zero that it could not have been detected with certainty.

A high degree of accuracy has been claimed for the triangulation. There is abundant evidence available from which to determine the actual accuracy, as has been indicated in an earlier part of this report. A large amount of time has been spent in studying this evidence in order to insure that the estimates of the accuracy of the determination of the various apparent displacements might be reliable. The methods necessarily followed in estimating the accuracy are so technical and so complicated that it is not desirable to include them in this paper. Two illustrations of the degree of accuracy attained in the observations may prove interesting, however.

The position of the Lick Observatory small dome was determined after the earthquake of 1906 by intersections upon it from four stations—Loma Prieta, Sierra Morena, Red Hill, and Mocho. There were discrepancies among these observations which were adjusted by the method of least squares and a resulting most probable position adopted and used in computing the apparent displacement given in Table 1. The mean observation from Loma Prieta hit 0.38 meter (1.2 feet) to the left of the position adopted for the dome. The mean observation from Sierra Morena hit 0.22 meter (0.7 foot) to the right, that from Red Hill 0.01 meter (0.03 foot) to the left, and that from Mocho 0.11 meter (0.4 foot) to the left of the adopted position. The words "right" and "left" refer in each case to the Lick Observatory dome as seen from the station named. The distance of the four observation points from the Lick Observatory were: Loma Prieta 31 kilometers (19 miles), Sierra Morena 59 kilometers (37 miles), Red Hill 46 kilometers (29 miles), and Mocho 17 kilometers (11 miles).

Similarly the determination of the position of the Lick Observatory before the earthquake depended upon observations taken from seven stations—Santa Ana, Mount Toro, Loma Prieta, Sierra Morena, Mount Tamalpais, Mount Diablo, and Mocho. The line from Mount Tamalpais, 106 kilometers (66 miles) long, missed the adopted position by 0.36 meter (1.2 feet). The other six all came nearer than this to the adopted position.

The Farallon Light-house was determined between 1868 and 1906 by intersections upon it from three stations—Mount Helena, Mount Tamalpais, and Sierra Morena. The mean observation from Mount Helena, distant 112 kilometers (70 miles), missed the adopted position by 0.30 meter (1.0 foot), and the other two lines came closer. In 1906–7 the Farallon Light-house was determined by intersections upon it from the six stations, Ross Mountain, Tomales Bay, Point Reyes Hill, Sonoma, Mount Tamalpais, and Sierra Morena. The line from Sonoma, 79 kilometers (49 miles) long, missed the adopted position by 0.10 meter (0.3 foot), and all the others came closer.

One other assumption remains to be examined. The displacements of 1868 were computed on the assumption that the line Mount Tamalpais to Mount Diablo had a certain length and azimuth before 1868 and a certain different length and azimuth after 1868, Mount Tamalpais being supposed to be in a new position, but Mount Diablo unmoved. The two positions for Mount Tamalpais were derived from certain computations, based in turn on assumptions that certain other stations remained unmoved in 1868, or practically so.

The azimuth of the line Mount Tamalpais to Mount Diablo was determined by observations upon stars in 1859, and again in 1882. The later observations made the azimuth 7″.84 greater than earlier observations. The two adopted azimuths from the computations of triangulation referred to above also differ by 5″.38, the later adopted value being the greater. The fact that the two independent determinations of change of azimuth, one astronomic and one geodetic, agree within 2″.46 is a strong proof that the adopted geodetic azimuths are correct, 2″.46 being within the possible range of the various observations.

Following the same reasoning as for Mocho and Mount Diablo, the computed displacements of 1868, as shown by red arrows on maps 1 and 2, indicate that the two azimuths and two lengths used for the line Mount Tamalpais to Mount Diablo before and after 1868 must be very close to the truth.

Changes in Elevation.

The preceding portions of this Report have dealt with permanent horizontal displacements caused by the earthquake of 1906. It is important to know whether permanent displacements in the vertical direction also occurred. Upon this point the observations of the Coast and Geodetic Survey furnish evidence for a small area, involving parts of San Francisco, both sides of the Golden Gate, and Sausalito, 1¼ miles north of the Golden Gate.

At the time of the earthquake an automatic tide gauge was in operation at the Presidio Wharf, in San Francisco, on the southern side and about 1¼ miles to the east of the narrowest part of the channel through the Golden Gate. The gauge had been in operation at that point continuously since July 17, 1897, and is still in operation.

The record made by this gauge on April 18, 1906, showed an oscillation with a range of about six inches in the water surface, evidently produced by the earthquake, but it showed no evidence of a change in the relation of the gauge zero to mean sea level. In other words, the record for that day does not indicate that the tide staff had been changed in elevation by the earthquake.

To detect any possible small change in elevation it is, of course, necessary to examine much more record than that for a single day. The examination has now been extended by computation to include a whole year of observations since the earthquake for comparison with nine years of observation before it.

The following table shows the reading of mean sea level on the fixed tide staff for each of ten years, as determined by taking the mean of the hourly ordinates of the tidal curve. The annual means are taken, rather than means for any other period, in order to eliminate annual inequalities, presumably due to meteorological causes, which affect the means for separate months. May 1 is taken as the beginning of the complete year available after the earthquake. Since it is not convenient in the computation to separate any month's observation into two parts, the year is commenced on May 1, rather than on April 18, the date of the earthquake. The first year, 1897–98, is incomplete, because the observations were not commenced until July 17, 1897.

Period	Reading of mean sea level on tide staff
	Feet
July 17, 1897, to Apr. 30, 1898	8.339
May 1, 1898, to Apr. 30, 1899	8.298
Mean, 2 years	8.318
May 1, 1899, to Apr. 30, 1900	8.528
May 1, 1900, to Apr. 30, 1901	8.550
May 1, 1901, to Apr. 30, 1902	8.430
May 1, 1902, to Apr. 30, 1903	8.584
May 1, 1903, to Apr. 30, 1904	8.509
Mean, 5 years	8.520
May 1, 1904, to Apr. 30, 1905	8.667
May 1, 1905, to Apr. 30, 1906	8.659
May 1, 1906, to Apr. 30, 1907	8.631
Mean, 3 years	8.652

The ten annual means show an unmistakable tendency to fall into three groups, as indicated by the means shown for each group. Within each group there is no apparent tendency to increase or decrease. Between the first and second groups the reading of mean sea level increased 0.202 foot and between the second and third groups it again increased 0.132 foot. Such an increase corresponds to a subsidence of the zero of the tide staff with reference to mean sea level. An examination of the monthly means indicates that probably the subsidence occurred suddenly in each case, the movements taking place about June, 1899, and April, 1904. The record must not be considered as proving positively that these two subsidences took place. The changes are not clearly beyond the range of possible error in the determination of mean sea level on account of irregular changes in the water surface due to causes not clearly understood, though they are beyond the possible range of instrumental errors.

The annual mean for the one year after the earthquake, 1906–7, agrees with the two preceding annual means within less than 0.04 foot. In no other case in the table do three successive annual means agree so closely with each other as these three. Apparently, therefore, no change in the elevation of the zero of the tide staff occurred at the time of the earthquake.

As further evidence that no appreciable change in the elevation of the tide staff took place on April 18, 1906, the following table is submitted. Corresponding months of two years, one before and one after the earthquake, are compared to avoid the effects of annual inequalities. The comparison indicates that no change took place in April, 1906.

Monthly mean readings of mean sea level on tide staff.

Month	1905-6	1906-7	Difference	Month	1905-6	1906-7	Difference
	Feet	*Feet*	*Foot*		*Feet*	*Feet*	*Foot*
May......	8.507	8.462	+.045	Dec......	8.479	8.625	−.146
June.....	8.416	8.506	−.090	Jan......	8.701	8.784	−.083
July.....	8.668	8.688	−.020	Feb......	8.877	8.725	+.152
Aug......	8.676	8.797	−.121	Mar......	8.934	8.944	−.010
Sept.....	8.648	8.632	+.016	Apr......	8.558	8.669	−.111
Oct......	8.690	8.442	+.248				
Nov......	8.751	8.295	+.456	Mean.	....	....	+.028

The zero of the tide staff was connected by leveling with the group of bench marks near the gauge at various times during the interval 1898–1907, including a determination after the earthquake. The leveling showed no appreciable change in the relation in elevation of the bench marks and the tide staff. Hence, the preceding statements in regard to a possible subsidence of the tide staff on two occasions and in regard to its constancy of elevation on April 18, 1906, also apply to this group of bench marks.

Before the earthquake the Coast and Geodetic Survey had done leveling which connected the gauge at the Presidio Wharf with various bench marks in San Francisco from Fort Point to the Union Iron Works, and with bench marks at Sausalito. This leveling was not of the grade of accuracy known as precise leveling, nor was it done continuously. There are also available for use in the present investigation certain relative elevations of bench marks before the earthquake, furnished to the Coast and Geodetic Survey by the City Engineer of San Francisco. These include a bench mark near the gauge at the Presidio Wharf.

After the earthquake a line of precise levels was run from the Presidio gauge to Fort Point and Sausalito, and to the eastward through San Francisco to the Union Iron Works, connecting with various old bench marks.

There were 26 bench marks connected by the leveling before the earthquake which were recovered with certainty and the elevations redetermined. The following table shows the elevations of these bench marks before and after the earthquake and their apparent changes in elevations. All of the elevations in the table are referred to the same datum, which is the reading 8.514 feet (2.5951 meters) on the fixed tide staff at the Presidio Wharf, that being approximately mean sea level. All the elevations are computed on the supposition that the zero of the tide staff at the Presidio Wharf remained unchanged at the time of the earthquake.

Locality	Character of bench mark	Bench mark	Elevations			Differences	
			After earthquake, C. & G. S., 1906–7	Before earthquake		New—Old (C. & G. S.)	New—Old (City)
				C. & G. S., 1877–1905	City levels, 1901–1906		
			Meters	*Meters*	*Meters*	*mm.*	*mm.*
Presidio Wharf	Zero of tide gauge	11	−2.5951	−2.5951		0.0	
	Hinge socket of door of brick warehouse.	12	3.8932	3.9002	3.9002	− 7.0	− 7.0
	Copper bolt in granite post	15	2.7426	2.7371		+ 5.5	
Fort Point	Copper bolt in natural rock	4	6.7585	6.6797		+ 78.8	
	Copper bolt in granite post	5	14.7958	14.7237		+ 72.1	
	Copper bolt in granite seawall.	6	3.9275	3.8554	3.8895	+ 72.1	+38.0
	Brass plate on concrete emplacement.	9	60.7745	60.7151	60.7232	+ 59.4	+51.3
Sausalito	Copperbolt in rock	2	1.3909	1.3564		+ 34.5	
	Granite post	3	11.6073	11.5672		+ 40.1	
Van Ness and Lombard avenues.	Star on iron plate in street	27B	29.4047		29.3967		+ 8.0
Fort Mason	Granite post	28	32.5727	32.5606	32.5493	+ 12.1	+23.4
	.....do	29	31.0876	31.0854	31.0649	+ 2.2	+22.7
Lafayette Park	.....do	24A	101.7846		101.7412		+43.4
	Pendulum pier	25	113.9662	114.0414		− 75.2	
	Transit pier	27	115.3477	115.4222		− 74.5	
Union Iron Works	Brass spike in brick building	50	3.7860	3.8384		− 52.4	
	Window shutter socket	47	4.4482	4.4004	4.4299	+ 47.8	+18.3
	Bolt in wall of building	48	6.2121	6.1695		+ 42.6	
Nineteenth and Bryant streets.	Copper bolt in brick building	58	13.6176	13.5889	13.5883	+ 28.7	+29.3
Magdalen Asylum, Potrero avenue.	.....do	61	23.3281	23.3063	23.2977	+ 21.8	+30.4
Appraisers Building	Iron rod	40B	3.3068		3.3241		−17.3
Potrero avenue and Division street.	Fire hydrant	44I	5.9000		5.9695		−69.5
Seventeenth and Carolina streets.	Nail in doorstep	City.	6.0238		5.9978		+26.0
Mariposa street, between Pennsylvania and Iowa streets.	Bolt in concrete on bridge over Southern Pacific tracks.	S. P.	10.4666		10.4110		+55.6
California and Montgomery streets.	Water table of Parrott Building.	41	5.1488	5.0173		+131.5	
East and Mission streets	Iron pillar of brick building	43	2.4828	2.8523		−369.5	
Folsom, between Main and Beale streets.	Granite post set in brick wall.	44	5.4835	5.5516		− 68.1	

The table shows no appreciable change of elevation of the bench marks at the Presidio Wharf. The maximum apparent change in elevation is 7.0 millimeters (0.3 inch), a quantity which is within the possible range of error of the leveling. Mr. G. K. Gilbert, Geologist of the U. S. Geological Survey, at the close of an examination made soon after the earthquake and before the leveling had been done, expressed the opinion that if this group of bench marks had not changed their relative elevations they probably had not changed in absolute elevation. It is probable, therefore, that these two bench marks and the tide staff maintained their absolute elevations unchanged.

At Fort Point the three bench marks near the shore show an apparent rise of 74 millimeters (2.9 inches) on an average, and bench mark 9, high up on Fort Point, shows a slightly smaller apparent rise, 59 millimeters (2.3 inches). All these are on ground supposed to be stable. The rise indicated by the city leveling, in the last column, is considerably smaller.

The two bench marks at Sausalito show an apparent rise of 37 millimeters (1.5 inches). It is not certain that this represents a real change in elevation as referred to the zero of the Presidio tide staff. The errors of the old and new leveling, including the crossing of the Golden Gate (about 1¼ miles) in each case, may account for the apparent change. In the leveling before the earthquake the elevation was transferred from Presidio to Sausalito by water levels and also by wye leveling and vertical angles, with a difference of 13 millimeters (0.5 inch). In the precise leveling after the earthquake the two independent crossings of the Golden Gate, each depending on many hours of observation, differed by 30 millimeters (1.2 inches).

The three bench marks at and near Fort Point showed small apparent changes in elevation.

From an examination made soon after the earthquake Mr. G. K. Gilbert, Geologist, expressed the opinion that the bench marks at Lafayette Park were probably more stable than any of the others examined by him. The table indicates that the two of these bench marks formerly determined by Coast and Geodetic Survey leveling subsided 75 milimeters (3.0 inches) and that the one determined by the city leveling rose 43 millimeters (1.7 inches). There is no apparent reason for the contradiction among the three bench marks of this group.

For the three bench marks at the Union Iron Works the table shows a contradiction, two of them having, apparently, increased in elevation and one having decreased. The greatest change is, however, only 52 millimeters (2.0 inches). The Union Iron Works is said to be partly on filled ground.

The two bench marks near the Magdalen Asylum apparently increased in elevation, as shown by both the Coast and Geodetic Survey and city leveling.

Of these bench marks, the thirteen in the five groups at Fort Point, Sausalito, Fort Mason, Union Iron Works, and Magdalen Asylum showed an average apparent rise at the time of the earthquake of 35 millimeters (1.4 inches) as determined by Coast and Geodetic Survey leveling. As the leveling simply gives relative elevations the question arises: Does this quantity represent an average rise of the thirteen bench marks, or does it represent a settlement of the zero of the tide gauge and the adjacent bench marks at the Presidio Wharf? The tidal observations are not competent to determine this question with certainty. The general experience with determinations of mean sea level, from long series of tidal observations, warrants the statement that the error in determination from a single year is as apt to be greater as less than ¾ inch (19 millimeters), and that it may sometimes be as great as 2½ inches (64 millimeters). It is possible, therefore, that the two bench marks at the Presidio Wharf and the zero of the tide gauge have settled 35 millimeters or that it is, in part, a subsidence at the Presidio and in part a rise at the other places.

The elevations of the group of four bench marks in the table commencing with 40B at the Appraisers Building, were determined before the earthquake by the city engineer but not by Coast and Geodetic Survey leveling. These four, in various parts of the city, show no apparent change in elevation greater than 69 millimeters (2.7 inches). Two of them apparently rose and two subsided.

The apparent changes in elevation of the three bench marks in the table commencing with 41, at California and Montgomery streets, are not supposed to have much significance in connection with the question of whether a general change of elevation took place. These three bench marks were each subject to local disturbances during the earthquake or were near or on filled ground.

In 10 cases the old leveling determined elevations of hydrants and the new leveling determined elevations on hydrants in the same locations but known from the descriptions to be different from the old hydrants. Similarly, in seven other cases, the old leveling established the elevations of points on curbstones, steps, or doors, and in each of these cases in the new leveling it was found to be impossible to recover the old point accurately. In all of these 17 cases there is, therefore, only an approximate connection between the old and the new leveling. The evidence from these bench marks has all been examined carefully and does not lead to any different conclusion from that which may be drawn from the table above.

The general conclusion from both the leveling and the tidal elevations is that, within the region examined, there occurred no general change of elevation of sufficient magnitude to be detected with certainty.

It is an opportune time at present, on account of local changes in elevation at various bench marks, to adopt the best possible determination of mean sea level which is available up to date and to refer all new elevations determined since the earthquake to that datum. Accordingly, the reading 8.652 feet (2.6371 meters) on the tide staff at the Presidio, given in the last column on page 100, which is the mean for the three complete years, May 1, 1904, to April 30, 1907, is adopted as being mean sea level. The values given in column 4 of the table on page 102 are referred to the reading 8.514 feet (2.5951 meters) as mean sea level. Hence, a correction of −0.138 foot (−.0420 meter) should be applied to these values to obtain the elevations now adopted as best.

It is uncertain, as already indicated in this report, whether this correction of −.0420 meter is due to improvement in the determination of the relation of mean sea level to the tide staff or to a subsidence of the tide staff and adjacent bench marks in 1904 or earlier, or to both.

APPENDIX 4

REPORT 1907

SIX PRIMARY BASES MEASURED WITH STEEL AND INVAR TAPES

By

OWEN B. FRENCH
Assistant, Coast and Geodetic Survey

CONTENTS.

SIX PRIMARY BASES MEASURED WITH STEEL AND INVAR TAPES.

By OWEN B. FRENCH, *Assistant.*

GENERAL STATEMENT.

In February, 1906, the writer received instructions to measure six primary base lines, using both steel and invar (nickel-steel) tapes. The invar tapes had never been used for this purpose before, hence the instructions stated that certain of their properties should be investigated, and their lengths and coefficients of expansion determined before beginning the base measures. An extract from these instructions is inserted here to give a clearer understanding of this report.

As soon as the necessary preparations can be made and the expected weather conditions warrant the beginning of such work, you will proceed to measure the following six primary bases: Point Isabel Base, Texas; Willamette Base, Oregon; Tacoma Base, Washington; Brown Valley Base, South Dakota; Stephen Base, Minnesota, and Royalton Base, Minnesota, and to do certain triangulation in the vicinity of the Point Isabel Base as indicated later in these instructions.

Aside from the usual preparations for field work you will arrange for such cooperation and will cooperate with the Bureau of Standards in the following operations:

(*a*) The regraduation * and redetermination of the length of the iced bar;

(*b*) The graduation and determination of the coefficients of expansion of the three 50-meter steel tapes to be used by you, which have not heretofore been used;

(*c*) The graduation and the determination of the lengths and coefficients of expansion of at least four nickel-steel tapes;

(*d*) Such investigations of the properties and behavior of the nickel-steel tapes now in the possession of the Coast and Geodetic Survey as you find time to make. Among the questions which it is especially desired to investigate are: What is the yield point or elastic limit of these particular nickel-steel tapes, and is there any danger, if these tapes are used under a 15-kilogram tension in the field, of an appreciable permanent set being produced; are these tapes subject to an appreciable gradual change of length; does exposure to a large range of temperature cause a semipermanent change of length; do the tapes preserve their lengths when subjected to reeling and unreeling? In making these investigations, and in studying the behavior of the nickel-steel tapes in the field, you should keep in mind that your problem is to investigate the behavior of these particular nickel-steel tapes for the especial purpose of ascertaining the degree of accuracy that may be conveniently secured with them, used in daylight in the field, of ascertaining the best methods of using them in the daylight, and of ascertaining what special precautions must be taken with them to guard against changes in lengths under field conditions. It is not proposed to make a general investigation of nickel-steel tapes under all conditions, hence the tapes should not be subjected to greater tensions, more severe shocks, or more extreme temperatures than are necessary in order to ascertain the particular facts desired.

The field work should be so conducted as to secure:

(*a*) A complete measurement of each base with steel tapes, said measurements to be of a primary standard of accuracy and to be so made that the computations of them can be made independently of any measurements made with nickel-steel tapes;

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* No regraduation was found to be practicable within the limited time available.

(*b*) A complete measurement of each base with nickel-steel tapes, said measurement to be of a primary standard of accuracy, if it is found to be possible to make it so without an excessive amount of remeasurement, but otherwise to be of as high a standard of accuracy as can easily be attained. These measurements of the bases with the nickel-steel tapes are to be so made that the results may be computed independently of any field standardization;

(*c*) To secure by the base measurements themselves as complete an intercomparison of the various tapes as is possible on each base, without any additional measurements made specifically for this purpose only. The following paragraphs indicate the general plan to be followed to accomplish these purposes.

Very little increase in the average accuracy of the lengths of the triangle sides in the triangulation connected with these bases will result from increasing the accuracy of the base measurement beyond that represented by a probable error of one part in 500 000 in the length of each base. The following limits of accuracy are selected with a view of attaining a probable error but little if any greater than one part in 500 000 on each base. You will strive to keep as far within these limits as is possible by the use of good judgment and skill, but you will restrict the time and money expended upon each operation substantially to that required to keep barely within these limits.

You will standardize four steel tapes at the first base measured and at the last base measured, by measuring the length of a 50-meter comparator at least four times with each tape. The measurements by each tape must not be all made on a single night. If four measures do not suffice to reduce the probable error of the mean derived length for any tape below 1 part in 300 000, additional measurements must be made until the probable error is reduced below that limit. The conditions under which each form of apparatus is standardized should be as nearly like those under which it is used in the actual measurements of the bases as it is possible to make them. The length of the comparator is to be determined by measuring it with the iced bar at such times that the longest interval between any such measurement and any measurement of the comparator with a tape shall not exceed thirty-six hours. The measurements of the 50-meter comparator with the iced bar should be made in pairs, the directions of progress of the bar being opposite in the two measurements of each pair and said two measurements being made in quick succession. A sufficient number of measurements of the 50-meter comparator should be made with the iced bar to insure that the probable error of the derived 50-meter length does not exceed ± 0.03mm.

Each base shall be measured in sections approximately one km. in length, except that one shorter section may be used on each base.

Each base shall be measured with three steel tapes at night, using mercurial thermometers attached to the tapes. The fourth steel tape standardized is to be retained for use in case of serious damage to any one of the three remaining tapes. Each section of each base shall be measured with at least two different steel tapes. Different pairs of steel tapes shall be used on different sections of each base, so that the three tapes used on that base shall thereby be thoroughly intercompared on each base. Two, and only two, measurements of each section shall be made with steel tapes unless the discrepancy between these two measurements exceeds 20mm$\sqrt{K}$ (K being the length of the section in kilometers), in which case additional measurements are to be made until two measurements are obtained which agree within the limit stated.

At least four nickel-steel tapes should be standardized at the Bureau of Standards before the beginning of the field work. Each base should be measured with three of these nickel-steel tapes used in daylight. Each section of each base shall be measured with at least two different nickel-steel tapes. Different pairs of nickel-steel tapes shall be used on different sections of each base, so that the three tapes used on this base shall thereby be thoroughly intercompared. Two, and only two, measurements of each section shall be made with nickel-steel tapes unless the discrepancy between these two measurements exceeds 20mm$\sqrt{K}$ (in which K is the length of the section in kilometers), in which case additional measurements must be made until two are obtained which agree within this limit, provided, however, that no section of any base shall be measured more than four times with nickel-steel tapes. The fourth nickel-steel tape standardized, and any additional ones, are to be retained for use in case of serious damage to any of the three tapes with which all nickel-steel measurements would otherwise be made. After the close of the season all the nickel-steel tapes shall again be standardized at the Bureau of Standards. The lengths of the nickel-steel tapes used in the computation shall be made to depend entirely on the standardization at the Bureau of Standards.

Such precautions should be taken to secure accurate horizontal and vertical alignment of the tapes, both steel and nickel-steel, as is necessary to insure that the errors arising from these sources on any section of the base shall be less than 1 part in 1 000 000. It is not desirable, however, to use any more time on this part of the operation than that necessary to keep well within the limit stated. This principle should also be applied to the determination of the tension on the tape while in use.

PARTY ORGANIZATION.

On the Point Isabel and Willamette bases the party consisted of seven persons in all; on the Tacoma Base of six, and on the other three bases of thirteen, for reasons stated later. The measuring party consisted of two observers, one recorder, two tape stretchers, and one or two men to support the tape when it was being carried forward. The two observers were the same on the first three bases. The whole party on the Tacoma Base was the same as the Willamette Base. Another party measured the last three bases.

Only a single party was employed on each of the first three bases, the preparation of the lines being executed by the men employed for the measurement. The preparation of the last three bases was all done by a separate party in charge of the signalman, so that the observing party merely made the measures and ran the levels. This arrangement was due to the fact that the Assistant engaged upon triangulation in this region was instructed to discontinue that work long enough to assist, with his whole party, in the measurement of these three bases. From four to six men were sent with the preparation party, and a total of seven kept for the measuring party.

TIME TABLE.

The following table shows the time of arrival at each base and the time spent in the preparation and measurement, not excluding Sundays or holidays:

Name of base	Date of arrival	Days at base	Days spent traveling to base	Remarks
Point Isabel, Tex.	Mar. 15	27		Includes standardization and the occupation of 6 triangulation stations, but excludes 4 days spent in selling outfit.
Willamette, Oreg.	Apr. 22	22	7	
Tacoma, Wash.	May 18	20	5	
Stephen, Minn..	June 16	7	8	This includes a wait of 3 days for arrival of the triangulation party.
Brown Valley, S. Dak.	June 25	7	2	
Royalton, Minn.	July 3	9	1	Includes standardization.

A new party was organized and equipped at Willamette Base. The table indicates that five days were spent in traveling from Willamette Base to Tacoma Base.

The object of using several different parties during a season was to save traveling expenses. If both observers and the two tape stretchers should continue on the work from the beginning to the end there would be a slight gain in accuracy.

APPARATUS.

Fifty-meter steel tapes 403, 405, and 406, and 50-meter invar tapes, 438, 439, and 440, were used on all the measures during the season, their coefficients of expansion having been determined at the Bureau of Standards in the February standardization.

Steel tape 248 and invar tape 437 were standardized whenever the other tapes were, but not otherwise used. Invar tape 442 was standardized at the Bureau of Standards, but not taken into the field.

The graduation marks of the tapes were on small silver sleeves riveted rigidly to the tapes. The distance between the marks on each tape was very nearly 50 meters.

The average dimensions and mass per unit of length of these tapes, as furnished by the Bureau of Standards, are as follows: For steel tapes, width, 6.14 millimeters; thickness, 0.43 millimeter, and mass, 19.5 grams per meter of length. For invar tapes, width, 6.31 millimeters (ranging from 6.23 to 6.39 millimeters); thickness, 0.51 millimeter (ranging from 0.50 to 0.52 millimeter), and mass, 25.09 grams per meter (ranging from 24.2 to 25.59 grams).

Two thermometers (J. S. Green's, with half-degree graduations) were placed on the top of each tape when in use, the metal backs of the thermometers being clamped to the tape by small springs, thus permitting the thermometers to be slipped on and off the tape very quickly.

All the thermometers used were standardized at the Bureau of Standards before beginning the work. The zero points were examined after the completion of the work and no appreciable change was found. The corrections furnished by the Bureau of Standards were applied to all thermometer readings.

The tape stretcher used on this work is described on pages 414 and 415, Appendix 8 of the Coast and Geodetic Survey Report for 1892.* The heavy platform for the operator to stand upon was removed and a steel point about 4 inches long was bolted to the end of the vertical rod in its place. This change not only lightened the load for the operator—a very material consideration—but expedited the adjustment of the tape over the marking tables, as it was rarely necessary to use the adjusting screw to bring the tape to the right height, this being accomplished by pushing the point into the ground or pulling it out a little.

The spring balance used to indicate the tension on the tapes was attached to the stretcher in the frame with counterpoise, so that it could be used in a horizontal position. The type of balance was the same as that used in the work of 1900.† It has a dial with an index hand moving over it, a complete revolution corresponding to 5 kilograms. The smallest division on the dial is 25 grams, but 10 grams may be easily estimated. Five-kilogram marks are placed on the bar that connects the hook with the spring. A stop is placed at about 15.3 kilograms, so that too great a tension to the spring can not be applied.

Several balances were used on the measures. Nos. 134 and 135 were used on the February standardization and then kept for standards in the field, the working balance being tested frequently by pulling against them. The following comparisons show how well these standard balances held during the work. The readings given were those shown by the balance when a 15-kilogram weight was hung on the hook of the balance by a small cord, which passed over a pulley with practically no friction, the balance being

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* On the measurement of Holton Base, Holton, Ripley County, Ind., and St. Albans Base, Kanawha County, W. Va.

† See page 258, Appendix 3, Coast and Geodetic Survey Report for 1901, "On the measurement of nine base lines along the ninety-eighth meridian."

in a horizontal position. The temperature was also noted, but no account of it was taken in the base reductions, as its effect is very small. Each value here given is the mean of several.

Date		Temperature	Balance	
			No. 134	No. 135
1906		°C.	Kg.	Kg.
Feb.	—	−1	15.050	14.997
Mar.	1	22	15.083	15.045
"	2	22	15.099	15.063
Oct.	1	22	15.100	15.031
"	5	22	-----	15.035

If the first value, taken at a low temperature, be excepted, all of these values, taken before and after the field work, agree well. It is therefore probable that the standard tension during the season was sufficiently accurate, since a change of 25 grams produces an apparent change in length of the tapes not greater than 0.04 millimeter.

INVAR TAPES.

In December, 1905, the Coast and Geodetic Survey purchased from J. H. Agar Baugh, of London, England, several tapes about 53 meters in length, of the alloy of nickel and steel which possesses the property of having a very low coefficient of expansion. Although this alloy has been known for a number of years, it has only recently been produced in the form of tapes. The experiments with the metal by its discoverer, C. E. Guillaume, of the International Bureau of Weights and Measures, near Paris, have been made with wires or bars, as a rule. This alloy has been given the name "Invar," a word derived from the same root as "invariable," and with a similar meaning.

The invar tapes are more nearly like nickel than steel in appearance. They are rather soft, bending easily, and are not nearly as elastic as steel. When laid on a flat surface without tension these tapes appear crooked, being full of small bends in all directions. Although a 15-kilogram tension does not entirely remove these bends they are not at all prominent under this tension, and are probably so nearly eliminated that continued stretching does not affect the length of the tape very materially. The slight increase in length that was developed during the season may be a straightening out of some of these bends.

Oxidation or rust forms much more slowly on the invar tapes than on the steel. Nevertheless, oiling and reasonable care are necessary.

As Guillaume's investigations were with invar wires rather than with tapes, it was considered desirable to make a few tests of the strength and elasticity of these particular tapes before going into the field with them. These were all carried out very carefully under the direction of Albert S. Merrill, of the Bureau of Standards. The following report of the Director of the Bureau of Standards shows the methods employed and the results obtained:

The specimens were submitted in order to determine three things: First, the yield point of the material; second, the tensile strength of the material, third, whether permanent set was produced by light loads. The tests made show: First, the yield point is about 70 per cent of the tensile strength; second, the tensile strength is between 450 and 500 pounds actual, or 100 000 pounds per square inch; third, loads up to 60 pounds (at least) do not cause permanent set.

The tapes submitted were each about 18 inches long and were respectively numbered by one, two, and three punch marks on one end. The average dimensions were as follows:

	Width	Thickness		Area
		Right edge	Left edge	cross section
	in.	*in.*	*in.*	*sq.-in.*
No. 1	0. 24827	0. 01934	0. 01950	0. 004827
No. 2	0. 25118	0. 01927	0. 01942	0. 004861
No. 3	0. 24883	0. 01912	0. 01908	0. 004752

The yield point was determined by the use of a Henning mirror extensometer, the load increments being 20 pounds or less. The extensometer indicated the stretch in the two edge fibers separately. The magnification of the distortion at the reading telescope was one thousand times, enabling readings to be made directly to hundred-thousandths of an inch, and occasionally by estimation, somewhat finer. On passing the yield point, the increasing distortion of the specimen under constant load was revealed by a creeping of the scale reading observed in the telescope, as well as by a sudden increase in the difference between readings. The elongation was measured over a gauge length of 8 inches A summary of the tests follows:

Tape No. 1.

Distortion between 50 pounds and 250 pounds:
- Right edge .... 0. 007765 inch
- Left edge .... 0. 006745 inch
- Average .... 0. 007255 inch

Average distortion per pound per inch of length .... 0. 000004534 inch
Young's modulus 45 700 000
Yield point observed at .... 310 pounds

Tape No. 2.

Distortion between 10 pounds and 210 pounds:
- Right edge .... 0. 007555 inch
- Left edge .... 0. 008365 inch
- Average .... 0. 007960 inch

Average distortion per pound per inch of length .... 0. 000004975 inch
Young's modulus 41 350 000
Yield point not observed.
Maximum load before rupture, between 450 and 500 pounds.
Permanent set measured after rupture, about 0.06 inch in 8 inches.

Tape No. 3.

Distortion between 155 pounds and 375 pounds:
- Right edge .... 0. 00896 inch
- Left edge .... 0. 00821 inch
- Average .... 0. 008585 inch

Average distortion per pound per inch of length .... 0. 000004878 inch
Young's modulus 43 130 000
Yield point observed at .... 380 pounds

Tape No. 1 was subjected to a load of 40 pounds in a closed room for sixty hours. The final reading of the extensometer was identical with that at the beginning, showing that light loads do not produce a cumulative distortion with long time intervals.

Tape No. 3 was tested to determine whether permanent set was produced by light loads. The load in this case was applied by pouring shot into the bucket on the end of the long arm of a lever having a ratio of 10 to 1, the tape with its extensometer being attached to the short arm of the lever. The bucket used had a conical bottom, with an outlet through which the discharge of shot was regulated by a rubber tube and pinch cock. The apparatus being rigidly fixed in position and the tape and extensometer counterbalanced, an initial load of 10 pounds was given the specimen by hanging a 1-pound weight on the long lever. An additional load of 50 pounds was placed on the specimen by the use of shot. This load was withdrawn and applied three successive times, in each case identical readings being obtained for corresponding loads, proving that small loads do not produce permanent set. An attempt previously made to apply increments of 5 pounds to 65 pounds with decrements of the same amount was not so successful, the final zero being somewhat lower than the initial, which would have indicated contraction.

In comparison with the strength of the invar tapes may be placed a specimen of the steel hitherto used in tapes by the Coast and Geodetic Survey. The specimen tested had a cross section 0.248 by 0.018 inch, an area =0.00446 square inch. The maximum load before rupture was 880 pounds, corresponding to 197 000 pounds per square inch.

Although the tensile strength of the invar tapes was shown to be only about half that of the steel tapes, it is certainly far greater than is necessary for merely the measurement of base lines. The results from these experiments are very satisfactory, no properties being developed that are at all derogatory to the use of these tapes for base measuring purposes.

The graduation marks on the invar tapes were ruled on silver sleeves which were riveted to the tapes near the ends, in the same manner as for the steel tapes. The distance between the two marks on each of the invar and steel tapes, at a temperature of 15° (this being the probable average temperature of the field work), was made very nearly the same, the object being to cause as few set-ups and set-backs as possible during the measurement of the base lines.

The reels for the invar tapes were made of aluminum, with a diameter of 16 inches, it being stated by Mr. Baugh that it is safe to give the metal this curvature without fear of a permanent change of length.

During standardization, one of the tapes (No. 438) was subjected to a hundred reelings and unreelings several different times without showing any change in length (see p. 117). A change of 0.05 millimeters, or 1/1 000 000, would undoubtedly have been apparent. This proves that the reels used are large enough to insure that there will be no change in length of the tape on account of the size of the reel. Another tape (No. 437), during the standardization, was kept outdoors when not in use, thus being subjected to temperatures from about −10° to +30° C., without showing any appreciable change in length.

COMPARATOR AT THE BUREAU OF STANDARDS.

Five of the invar tapes were standardized at the Bureau of Standards under the direction of Mr. L. A. Fischer, Chief of the Division of Weights and Measures, the writer cooperating with him. The observations were made on the 50-meter comparator, located in the tunnel joining the two principal buildings of the Bureau of Standards. The comparator room is about 52 meters long and about 2½ meters in width and in height. Along one wall are a number of pipes through which brine at a temperature of −10° may be pumped to get low temperatures, and along the other wall is a bench or mural standard. The ends of the 50-meter comparator are marked by spherical-headed bolts cemented into concrete piers at either end of the tunnel, the tops of the piers being flush with the concrete floor of the tunnel. The length of this comparator was measured with the 5-meter iced bar, B_{17}, each day that comparisons were obtained, usually just before and just after the measurements of the tapes. This was found necessary, as the distance between the comparator bolts was found to vary through a total range of 0.93 millimeter or 1/54 000 during the whole period of measurement, dependent mostly on temperature conditions. The greatest range in any one day between forenoon and afternoon measurements with the iced bar was only 0.052 millimeter.

Each determination of the length of the comparator consists of two measures with the iced bar, one going north and one going south. The probable error of a determination was usually less than 0.015 millimeter.

The iced bar was used in the usual manner.* The microscopes for holding the measure were mounted on iron brackets or arms which were attached in an adjustable manner to the tops of stone piers about 30 inches above the floor. These stone piers were set on concrete piers about 18 inches deep and 16 inches square. The concrete floor was laid directly on the ground, but was separated from the piers by a space of 2 inches. One of the main walls of the building is not more than a foot from the piers, near the south end. The pier at the north end was built through a small room under the tunnel. The base of this pier was about 6 feet square and its height about 8 feet. Each concrete pier at the ends of the comparator is large enough to carry the microscope pier, and also the marking bolt for that end. The slow changes, with a total range of 0.93 millimeter, referred to above, are undoubtedly due to changes in temperature conditions in the walls, floor, and piers.

The microscopes and cut-off cylinders hitherto used with B_{17} were also used here. Each stone pier has a hole cut through its top just below the microscope arm, through which the illumination for the microscope is thrown, an ordinary electric bulb being hung back of each pier for this purpose. This method of illumination proved very satisfactory.

DETERMINATION OF LENGTH OF ICED BAR.

The length of B_{17} was determined in February, before beginning the field work, and again in October, after its completion. One of the 5-meter spaces of the comparator was built with piers 1 meter apart especially for this work. A determination of the length of B_{17} consisted of three measures of this 5-meter space with the prototype meter No. 21 and two with the 5-meter bar, alternating with each other. Six such determinations were made in February and 21 in October.

The February determinations gave the length of $B_{17} = 5$ meters $- 16.6$ microns ± 1.1 microns, differing only 0.4 micron from the old value. The October determinations gave $B_{17} = 5$ meters $- 26.3$ microns ± 1.1 microns. A change in length for B_{17} of almost 10 microns, nearly $\frac{1}{500\,000}$ of the length, is shown.

When this change occurred, or why, is unknown. The bar was always handled by the writer and was never subjected to any bending other than the small bends which always occur when the bar is lifted from its box. The box in which the bar is transported has a notch for the support of the bar about every foot. This box is packed in a larger one whenever shipped. The bar and its packing boxes were examined very carefully to note possible rough handling, but no evidence of such was found. The temperature to which the bar was subjected during this interval was very high at times.

* See Appendix 8 of the Coast and Geodetic Survey Report for 1892, "On the measurement of the Holton base, Holton, Ripley County, Ind., and the St. Albans base, Kanawha County, W. Va."

The purity of the ice used in standardizing the 5-meter bar was determined by very sensitive electric conductivity tests and also by readings of standard thermometers placed in it.

There is no question that the first value should be used for the February determinations and the last for the October determinations, but in the case of the field standardization of the steel tapes the only criterion is the agreement of the various values.

If one length for the bar be used in both field standardizations, the lengths obtained for the steel tapes are from 0.06 millimeter to 0.19 millimeter (averaging 0.11 millimeter) longer on the second than on the first standardization. By assuming that the change in length of B_{17} occurred between the two field standardizations these differences are all reduced, the average becoming only 0.01 millimeter, which is unquestionably very strong evidence that the change actually occurred during that period. The computations for the lengths of the steel tapes were made, therefore, using the first value for the Point Isabel standardization and the second value for the Royalton standardization.

The final determinations for the invar tapes are not sufficiently accurate or numerous either to verify or contradict the assumption that the change in the length of B_{17} occurred between the two field standardizations. One of the invar tapes has the difference increased by this assumption and two of them have it diminished.

METHODS OF STANDARDIZATION OF TAPES AT THE BUREAU OF STANDARDS.

In the determinations at the Bureau of Standards the tapes were used in practically the same manner as in the field. They were supported at the graduation marks and at one point in the middle, all three points being in a straight line and at very nearly the same level. Metal-backed thermometers were attached to the top of each tape 1 meter toward the middle of the tape from the marking sleeves. This enabled the observers to reach them easily and yet have them far enough away not to be affected by the heat of the observer's body, lamps, etc. As the temperatures were not quite the same in different parts of the tunnel, other thermometers were suspended alongside the tapes, with their bulbs at the same height as the tape. Three thermometers were used for the invar tapes and three or five for the steel tapes, uniformly distributed, only two being attached to the tape. One end of the tape was held by an adjustable clamp. At the other end a small hook was clamped to the tape and the balance was attached to it. The other end of the balance was attached to an adjustable ratchet device.

The tapes were suspended under the end microscopes of the comparator, using the cut-off cylinders for the end supports.

Each comparison of a tape consisted of two or more simultaneous pointings upon the graduation marks by the two observers, then of two or more simultaneous pointings after the observers had exchanged places, all thermometers being read after each two pointings. The observer at the balance end looked after the tension and made the reading on the balance, at the instant of making a pointing, agree with that which corresponded to a 15-kilogram tension. The tape was always tapped lightly just before making a pointing, so as to eliminate the effect of friction.

COEFFICIENTS OF EXPANSION OF TAPES.

In the February standardization, 12 or 13 determinations were obtained for each of the five invar tapes, 6 determinations at a temperature of about $+4°$ C. and the remainder at about +25° C. Four steel tapes were also compared, 12 to 14 determinations being obtained for each, 5 to 7 of them at a temperature of about +4° C. and the remainder at about +25° C.

The coefficient of expansion was computed for each tape from these determinations. The coefficients of expansion thus obtained, expressed as the change in the length of the tape (50-meter) for 1° C., are shown in the following table. Their probable errors follow in the next column, and the last column shows the coefficient of expansion of the tapes per unit length per degree centigrade.

Tape No.		Expansion per degree C. for 50 meters	Probable error	Coefficient per unit length per degree C.
		mm.	*mm.*	
Invar	437	0.0207	±0.0009	.000 000 41
	438	0.0213	0.0008	.000 000 43
	439	0.0203	0.0006	.000 000 41
	440	0.0187	0.0006	.000 000 37
	442	0.0220	0.0009	.000 000 44
Steel	403	0.568	±0.003	.000 011 4
	404	0.568	0.003	.000 011 4
	405	0.569	0.004	.000 011 4
	406	0.565	0.003	.000 011 3

LENGTHS OF INVAR TAPES.

After the completion of the measurement of the six base lines the invar tapes were again compared at the Bureau of Standards. Four comparisons for five tapes were obtained in two days. The results of the standardization of the invar tapes, as furnished by the Bureau of Standards, follow.

The quantities in the column headed "Computed length" are obtained by reducing the final mean length of the tape to the temperature of each individual observation. The probable error for each tape was computed from the residuals shown.

Invar Tape 437.

Date 1906		Temperature °C.	Observed length *mm.*	Computed length *mm.*	Residuals *mm.*
Feb.	10	25.0	50 meters + 8.030	50 meters + 8.052	+.022
	12	4.0	7.562	7.617	+.055
	12	4.2	7.597	7.622	+.025
	13	4.0	7.521	7.617	+.096
	13	4.3	7.597	7.624	+.027
	15	3.1	7.653	7.599	−.054
	15	2.5	7.652	7.586	−.066
	17	25.0	8.041	8.052	+.011
	17	24.6	7.978	8.044	+.066
	19	26.1	8.082	8.075	−.007
	19	24.6	7.996	8.044	+.048
Mar.	1	24.1	8.061	8.034	−.027
	1	24.3	8.056	8.038	−.018
February, mean		14.24	7.816		

Invar Tape 437—Continued.

Date 1906		Temperature °C.	Observed length mm.	Computed length mm.	Residuals mm.
Oct.	4	25.4	50 meters +8.096	50 meters +8.060	−.036
	4	25.9	8.063	8.071	+.008
	5	25.4	8.066	8.060	−.006
	5	25.8	8.092	8.069	−.023
October, mean		25.62	8.079		
February and October, mean		19.93	7.947±0.007mm.		

Invar Tape 438.

Date 1906		Temperature °C.	Observed length mm.	Computed length mm.	Residuals mm.
Feb.	10	26.7	50 meters +8.305	50 meters +8.362	+.057
	12	4.6	7.822	7.892	+.070
	12	4.2	7.833	7.883	+.050
	13	3.4	7.736	7.866	+.130
	13	4.1	7.818	7.881	+.063
	15	2.9	7.873	7.855	−.018
	15	2.5	7.892	7.847	−.045
	17	24.7	8.264	8.320	+.056
	17	24.5	8.306	8.315	+.009
	19	25.7	8.293	8.341	+.048
	19	24.6	8.295	8.317	+.022
Mar.	1	23.8	8.259	8.300	+.041
	1	24.4	8.275	8.313	+.038
February, mean		14.26	8.057		
Oct.	4	25.4	8.386	8.334	−.052
	4	25.9	8.388	8.345	−.043
	5	25.5	8.362	8.337	−.025
	5	25.5	8.374	8.337	−.037
	5	25.7	8.389	8.341	−.048
October, mean		25.60	8.380		
February and October, mean		19.93	8.218±.009mm.		

Invar Tape 439.

Date 1906		Temperature °C.	Observed length mm.	Computed length mm.	Residuals mm.
Feb.	10	27.0	50 meters +6.801	50 meters +6.865	+.064
	12	4.0	6.341	6.398	+.057
	12	4.3	6.330	6.404	+.074
	13	3.9	6.378	6.396	+.018
	13	4.3	6.423	6.404	−.019
	15	3.0	6.302	6.378	+.076
	15	2.1	6.390	6.359	−.031
	17	24.4	6.787	6.812	+.025
	17	24.6	6.804	6.816	+.012
	19	25.8	6.825	6.840	+.015
	19	23.8	6.778	6.800	+.022
Mar.	1	24.1	6.786	6.806	+.020
	1	24.5	6.787	6.814	+.027
February, mean		14.24	6.578		

Invar Tape 439—Continued.

Date 1906		Temperature °C.	Observed length mm.	Computed length mm.	Residuals mm.
Oct.	4	25.4	50 meters + 6.890	50 meters + 6.832	−.058
	4	25.8	6.820	6.840	+.020
	5	25.5	6.873	6.834	−.039
	5	25.7	6.871	6.838	−.033
October, mean		25.60	6.864		
February and October, mean		19.92	6.721±0.007 mm.		

Invar Tape 440.

Feb.	10	27.3	50 meters + 9.666	50 meters + 9.696	+.030
	12	4.4	9.208	9.268	+.060
	12	4.3	9.199	9.266	+.067
	13	3.9	9.195	9.258	+.063
	13	4.1	9.186	9.262	+.076
	15	3.3	9.225	9.247	+.022
	15	2.2	9.287	9.227	−.060
	17	24.5	9.587	9.643	+.056
	17	24.6	9.615	9.645	+.030
	19	25.7	9.650	9.666	+.016
	19	24.6	9.616	9.645	+.029
Mar.	1	24.1	9.600	9.636	+.036
	1	24.6	9.596	9.645	+.049
February, mean		14.38	9.418		
Oct.	4	25.7	9.716	9.666	−.050
	4	25.8	9.686	9.668	−.018
	5	25.4	9.685	9.660	−.025
	5	25.9	9.721	9.670	−.051
October, mean		25.70	9.702		
February and October, mean		20.04	9.560±0.008 mm.		

Invar Tape 442.

Feb.	12	4.1	50 meters + 8.898	50 meters + 9.038	+.140
	12	4.1	8.956	9.038	+.082
	13	4.0	8.986	9.035	+.049
	13	4.5	9.007	9.046	+.039
	15	3.0	9.031	9.013	−.018
	15	2.4	9.038	9.000	−.038
	17	24.5	9.419	9.486	+.067
	17	24.5	9.460	9.486	+.026
	19	25.7	9.475	9.513	+.038
	19	24.6	9.457	9.489	+.032
Mar.	1	24.2	9.426	9.480	+.054
	1	24.4	9.465	9.484	+.019
February, mean		14.16	9.218		

Invar Tape 442—Continued.

Date 1906		Temperature °C.	Observed length *mm.*	Computed length *mm.*	Residuals *mm.*
Oct.	4	25.5	50 meters+9.536	50 meters+9.508	−.028
	4	25.5	9.517	9.508	−.009
	5	25.5	9.566	9.508	−.058
	5	25.3	9.573	9.504	−.069
October, mean		25.45	9.548		
February and October, mean		19.80	9.383±0.010 mm.		

These probable errors for the tapes do not include the probable error of the length of the comparator. The probable error of the length of the comparator was introduced directly into the final determination of the probable error of each base line as it affected the length of all the tapes equally.

More observations were obtained in February than in October owing to lack of knowledge regarding the behavior of the comparator tunnel (this being the first work of this character done in it), and also because more results were required in order to derive satisfactory coefficients of expansion for the tapes. In computing the adopted lengths of the tapes, the mean of the October values was given a weight equal to that of the mean of the February values.

All five tapes show a slight lengthening between the February and October standardizations. The change for each tape is as follows:

No. 437	lengthened	0.027 mm. or 1 part in	1 852 000
438		0.081	617 000
439		0.056	893 000
440		0.072	695 000
442		0.081	617 000
Mean		0.063	794 000

This apparent lengthening of the invar tapes may be due to an actual molecular change in the metal, or to a partial straightening out of the numerous small bends in the tapes, or possibly to both. As the graduation lines on some of the tapes are somewhat irregular, and not quite perpendicular to the tape, these differences are probably caused in part by pointing upon different portions of these lines in the two standardizations.

The adopted lengths and coefficients of expansion for the five invar tapes are given below. The probable errors of the lengths and of the coefficients of expansion are also given.

$$T_{437} = 50 \text{ meters} + \overset{mm.}{7.947} + \overset{mm.}{0.0207}\,(t - 19^\circ\!.93\text{C.})$$
$$\pm .007 \pm .0009$$

$$T_{438} = 50 \text{ meters} + 8.218 + 0.0213\,(t - 19.93\text{C.})$$
$$\pm .009 \pm .0008$$

$$T_{439} = 50 \text{ meters} + 6.721 + 0.0203\,(t - 19.92\text{C.})$$
$$\pm .007 \pm .0006$$

$$T_{440} = 50 \text{ meters} + 9.560 + 0.0187\,(t - 20.04\text{C.})$$
$$\pm .008 \pm .0006$$

$$T_{442} = 50 \text{ meters} + 9.383 + 0.0220\,(t - 19.80\text{C.})$$
$$\pm .010 \pm .0009$$

POINT ISABEL COMPARATOR.

In order to standardize the steel tapes, two 50-meter comparators were prepared for use of the iced-bar apparatus, one at the first base near Point Isabel, Tex., and one at the last base, near Royalton, Minn.

The site for the first comparator was about 300 meters north of the middle of the Point Isabel base line. The ground was practically level and the soil a hard loam almost like adobe.

A detailed description of the iced bar, its use, records, etc., may be found on pages 338–350 of Appendix 8 of the Coast and Geodetic Survey Report for 1892, "On the measurement of the Holton Base."

The posts for the support of the microscopes were about 9 by 14 centimeters, set firmly in the ground with about 0.7 meter projecting. These posts were set in line with their centers 5 meters apart. The end microscopes were mounted on heavy iron plates, bolted to posts made by framing together four posts similar to those used for the intermediate microscopes. The ends of the comparator were marked by spherical-headed brass bolts set in concrete blocks of peculiar shape, designed to get stability in the line of the comparator and not be easily disturbed by the movements of the observers. The blocks were 20 by 76 centimeters on the base, 20 centimeters square on the top, and 76 centimeters deep, the top being set flush with the surface of the ground and the long dimension parallel with the line of the comparator. Each was set on a thin bed of sand, and then earth tamped around it solidly. The iced-bar trucks were supported on three 5-meter sections of portable track, which were moved alongside the microscope posts as the measurement progressed, and supported on posts driven midway between the microscope posts. In order to avoid systematic errors * the end posts and cut-off cylinders were usually shaded from the sun by large umbrellas during the measurement, although part of one post might be in the sun for some time while the work was in progress at the other end. The intermediate posts were not shaded at all during the measurement, except when the observer's body happened to do so.

The same microscopes, iced bar, trough, and cut-off cylinders used in 1900 were used on this work, the only changes being the insertion of new level vials in the cut-off cylinders.

The microscopes were leveled very closely to a uniform grade and aligned with a theodolite before beginning the first measurement, and also before the last. As there were post caps enough for all of the posts, the microscopes could be placed in position before beginning the measure, and stops were clamped to the arms to hold the positions while the microscopes were being moved along. The iced bar was aligned by stretching a thread just above the aligning plugs, and leveled with striding level used heretofore. Before each of these operations as much ice was placed in the trough as was possible without interfering with these operations.

The distance between the terminal spheres of the Point Isabel comparator was measured eight times between March 26 and April 3. The same observers made all the readings and pointings on the bar ends, exchanging places, so that each made a

* See p. 245, Appendix 3, Coast and Geodetic Survey Report for 1901, "On the measurement of nine base lines along the ninety-eighth meridian."

pointing and reading on both ends of the bar in each of its positions. The following table gives the data for the length of the comparator. The first column gives the date; the second, the time of day; the third, the direction of the measure; the fourth, the length of the comparator from each measure, using 5 meters − 16.6 microns as the length of the 5-meter bar, as obtained in the February standardization; the fifth, the mean of two measures made in opposite directions, and the sixth, the residuals of the quantities in the fifth column from the mean.

Results for length of Point Isabel comparator.

Date	Time of day	Direction of measure	Length of comparator	Mean, forward and back	Residuals
1906	*hr. m. hr. m.*		*mm.*	*mm.*	*mm.*
Mar. 26	3 30 to 4 12 p. m.	SE to NW	50 meters + 12.240		
	4 27 to 5 05 p. m.	NW to SE	.191	50 meters + 12.216	+ .008
30	10 30 to 11 25 a. m.	NW to SE	+ 12.216		
	11 40 to 12 20 a. m.	SE to NW	.259	+ 12.238	− .014
30	1 20 to 2 00 p. m.	NW to SE	+ 12.228		
	2 15 to 2 47 p. m.	SE to NW	.280	+ 12.254	− .030
Apr. 3	8 40 to 9 10 a. m.	NW to SE	+ 12.183		
	9 25 to 9 45 a. m.	SE to NW	.197	+ 12.190	+ .034
			Mean	50 meters + 12 224	± .009

These results indicate very slight, if any, change in the length of the comparator during the entire period.

As the difference between two measures made in opposite directions is probably due to the effect of the sun's heat on the microscopes and their supports,* it is best eliminated by taking the mean of two measures made in opposite directions with the sun in about the same position; hence, the values in column 5 give the true length of the comparator as accurately as can be obtained from the measures made. Their mean, which is the same as the mean of the individual measures, gives 50 meters + 12.224 millimeters as the length of the comparator, with a probable error of ±0.009 millimeter, obtained from the residuals in the last column.

The probable error of B_{17} is ±1.1 microns, and for ten bar lengths is ±0.011 millimeter; hence the resulting probable error for the Point Isabel comparator is

$$\pm\sqrt{(.009)^2+(.011)^2} = \pm 0.014\text{mm}.$$

ROYALTON COMPARATOR.

This comparator was similar to the Point Isabel comparator, and was prepared in the same manner, except that granite blocks were used in marking the ends of the comparator, instead of concrete. The comparator was located in the lumber yard of the Royalton Lumber Company, at Royalton, Minn., just south of the main part of the town, and was about 2 miles from the north end of the Royalton Base. The direction of the comparator was about southsoutheast and northnorthwest.

The same method of procedure was followed here as at Point Isabel, except that the alignment of the microscopes was obtained by stretching a fine wire between the

* See p. 245, Appendix 3, Report of the Coast and Geodetic Survey for 1901, "On the measurement of nine base lines along the ninety-eighth meridian.

end microscopes and in their foci, and then setting the intermediate microscopes so that each was exactly over this wire, as shown by the image of the wire appearing in the center of the field of the microscope.

The apparatus used was the same as at Point Isabel, except that a new level vial was inserted in cut-off cylinder No. 1 before beginning this work.

Only four measures of this comparator were made, two just before the beginning of the tape comparisons and two immediately after.

The same observers made all of the pointings and readings, exchanging positions in the same manner as usual for each position of the bar. The following table gives the results of the measures in the same form as for the Point Isabel comparator. The length of the iced bar used was 5 meters − 26.3 microns, as obtained in the October standardization.

Results for length of Royalton comparator.

Date 1906	Time of day *hr. m. hr. m.*	Direction of measure	Length of comparator *mm.*	Mean, forward and back *mm.*
July 9	4 12 to 4 46 p. m.	S to N	50 meters + 10. 418	
	5 05 to 5 32 p. m.	N to S	. 478	50 meters + 10. 448
11	9 08 to 9 50 a. m.	S to N	+ 10. 421	
	10 10 to 10 58 a. m.	N to S	. 299	+ 10. 360
			Mean	50 meters + 10. 404

The first two measures were made when the sun's rays were nearly perpendicular to the comparator, and are fairly accordant. The other two were made with the sun nearly in line with the comparator and differ considerably. This is what should be expected if the discrepancies are due to the movements of the microscopes caused by unequal changes of temperature dependent upon the position of the sun.

The determination of July 9 differs from that of the 11th by 0.089 millimeters. This is rather a large change to be considered due to errors of observation, but is well within the possible range of movement of stones set a few hours before. Hence the comparator is considered as having changed length between the two measures, the first value being used for the first tape determinations and the second for the last determinations. This assumption gives more accordant values for all the tapes, thus indicating that it is justified.

METHODS OF FIELD STANDARDIZATION.

Eight tapes were compared with the 50-meter comparators at Point Isabel and Royalton. Two double comparisons at each place were obtained for the four steel tapes, made at night, and one double comparison at each place for the invar tapes, made in daylight. The determinations of the steel tapes were made on two nights at each place, one double determination each night. A measure of the comparator with the iced bar was obtained just before or after the comparisons of the tapes, the constancy of the distance between the terminal marking spheres not being depended upon for more than about twelve hours, except for the Royalton determinations of the invar tapes.

The tapes were supported and used in the comparisons in practically the same manner as in the base measures. The rear end was held by an adjustable clamp fastened to a fixed beam, so that there was no unsteadiness at this end. The tape stretcher and balances used in the base were used in the comparisons. The balances were frequently compared with the standards, and that reading of the balance always used which corresponded to a tension of 15 kilograms. The middle support of the tapes was a wire, hung accurately in line with the end supports and free to swing slightly across the comparator so that small errors in alignment would be corrected automatically. The cut-off cylinders were used for the end supports.

The tapes to be compared were all unreeled and hung on brackets alongside of the comparator before beginning the comparisons, thus permitting them to assume an approximately fixed temperature. A few minutes always elapsed after the tape was brought under the microscopes and the thermometers attached before the first pointings were obtained, hence the thermometers probably indicated the temperature of the tapes very closely, particularly as the changes in temperature were slow and small during the comparisons, and the temperatures indicated by the thermometers at opposite ends of the tapes were practically identical. Care was taken not to bring heat near the tapes while they were in use. Electric hand lamps were used to read the thermometers. The illumination for the microscopes was obtained by mounting acetylene signal lamps about 4 meters away from the tapes, at the Royalton comparator, and by small bull's-eye lanterns mounted about 1 meter from the tapes, at the Point Isabel comparator. A common lantern was used to illuminate the balance both on the comparisons and the base measures, but it was always more than a meter from the measuring part of the tape.

The comparisons were made in the same manner as at the Bureau of Standards. (See p. 115.) Extra pointings were frequently made, however, as the wind effect was sometimes uncertain and difficult to eliminate, particularly on the comparisons of the invar tapes. Frequent delays (except on the last night's work at Royalton) of several minutes were necessary on all of the comparisons to get pointings on the graduation marks of the tapes when the effect of the wind was small. This effect upon accepted pointings was probably less than 1/500 000 (or 0.1 millimeter) and this limit was not often exceeded on the base measures. The invar comparisons were affected by wind more than the steel. The invar comparisons were made merely for use in studying the action of the invar tapes, and no delay was made to get them.

LENGTHS OF STEEL TAPES.

The following table shows the observed values for the steel tapes. The quantities in the column headed "Computed" were obtained by reducing the final mean length for the tapes to the temperature of each individual observation. One determination at Royalton of Tape 406 was rejected, as there was apparently an error in reading the micrometers or in recording the readings.

Determinations of lengths of steel tapes.

Tape	Date	Time p. m.	Corrected temperature	Observed length	Computed length	Computed minus observed
	1906	hr. m.	°C.	mm.	mm.	mm.
248	Mar. 26	7 45	20.99	50 meters + 3.75	50 meters + 3.70	−.05
248	Mar. 26	10 03	19.95	3.14	3.16	+.02
248	Apr. 2	8 05	20.55	3.48	3.47	−.01
248	Apr. 2	10 12	20.52	3.44	3.46	+.02
248	July 9	10 32	19.98	3.15	3.17	+.02
248	July 9	10 47	20.08	3.20	3.23	+.03
248	July 11	9 09	21.64	4.12	4.05	−.07
248	July 11	9 19	21.23	3.79	3.83	+.04
		Mean	20.62	+ 3.51	mm. ±0.010	
403	Mar. 26	8 46	20.18	+11.90	+11.89	−.01
403	Mar. 26	9 12	19.93	11.91	11.75	−.16
403	Apr. 2	8 21	20.58	12.08	12.11	+.03
403	Apr. 2	10 00	20.45	11.94	12.04	+.10
403	July 9	10 18	20.60	12.07	12.13	+.06
403	July 9	10 56	20.30	11.82	11.96	+.14
403	July 11	9 02	21.58	12.71	12.68	−.03
403	July 11	9 26	21.13	12.50	12.43	−.07
		Mean	20.59	+12.12	mm. ±0.024	
405	Mar. 26	8 35	20.38	+12.45	+12.36	−.09
405	Mar. 26	9 30	20.18	12.24	12.24	.00
405	Apr. 2	8 50	20.62	12.40	12.49	+.09
405	Apr. 2	9 30	20.32	12.30	12.32	+.02
405	July 9	10 04	20.90	12.57	12.65	+.08
405	July 9	11 04	21.08	12.73	12.75	+.02
405	July 11	8 56	21.58	13.11	13.04	−.07
405	July 11	9 32	20.90	12.66	12.65	−.01
		Mean	20.74	+12.56	mm. ±0.017	
406	Mar. 26	8 25	21.02	+12.31	+12.42	+.11
406	Mar. 26	9 40	19.95	11.83	11.82	−.01
406	Apr. 2	8 32	20.64	12.10	12.20	+.10
406	Apr. 2	9 50	20.40	12.06	12.07	+.01
406	July 9	9 53	21.14	12.54	12.49	−.05
406	July 11	8 51	21.66	12.87	12.78	−.09
406	July 11	9 38	21.02	12.41	12.42	+.01
		Mean	*20.88	+12.34	mm. ±0.021	

All March and April comparisons were made at Point Isabel and all July comparisons at Royalton.

On March 26 the wind was southeast and light; it was slightly cloudy, and there was a light dew. On April 2 the wind was southeast and moderate, and there was no dew. On July 9 the wind was usually light, but occasionally strong; it was cloudy, and there were showers near and light rain during the comparison of tape 405; no dew. On July 11 it was fair and calm, with a light dew.

An examination of the residuals in the table shows that there was practically no change in the length of any one of these tapes during the season. Tape 406 shows the

* The mean of the three July measures was given the same weight as the mean of the four March and April measures.

largest difference between the first and second standardizations (0.09 millimeter), but this is of the same order as the errors of observation, hence can not be considered as indicating an actual change in the length of the tape.

For the determination of the coefficients of expansion see page 115. No other computation for the coefficients of expansion was attempted, as the coefficients obtained at the Bureau of Standards are as accurate as required, and the observations were made under more favorable conditions for this purpose than the observations in the field.

The adopted lengths and coefficients of expansion of the tapes are given below. The probable errors of the lengths and of the coefficients of expansion are also given. The temperatures shown are the mean temperatures of standardization of the tapes.

$$
\begin{array}{lll}
 & mm. & mm. \\
T_{248} = 50 \text{ meters} + & 3.51 & +0.527\ (t - 20^{\circ}.62\text{C.}) \\
 & \pm\ .010 & \pm\ .003 \\
T_{403} = 50 \text{ meters} + & 12.12 & +0.568\ (t - 20.59\text{C.}) \\
 & \pm\ .024 & \pm\ .003 \\
T_{405} = 50 \text{ meters} + & 12.56 & +0.569\ (t - 20.74\text{C.}) \\
 & \pm\ .017 & \pm\ .004 \\
T_{406} = 50 \text{ meters} + & 12.34 & +0.565\ (t - 20.88\text{C.}) \\
 & \pm\ .021 & \pm\ .003
\end{array}
$$

The probable errors for a single determination for the four tapes are, respectively, ± 0.028 millimeter, ± 0.068 millimeter, ± 0.048 millimeter, and ± 0.056 millimeter.

Tape 248 was used on the base measures of 1900. The coefficient of expansion for this tape, given above, was taken from those measures, no new determination having been made. This tape was not used during the measures of 1906, except at the time of the standardization. The length here given is about 0.1 millimeter shorter than that obtained in 1900.* This may be due partially to the fact that different parts of the graduation line were used in the two standardizations. In the 1900 work the middle of the lines was pointed on.

As it is difficult to make the two graduation lines accurately perpendicular to the line of the tape, the ends of the lines on one side of the tape were used, both in the standardization and base measurement, thus eliminating this possible source of error. A small cross was cut in the silver sleeve near the side used, in order to identify it. This statement applies to the invar as well as to the steel tapes.

CHECK FIELD DETERMINATIONS OF INVAR TAPES.

The following table shows the results obtained from the field determinations of the lengths of the invar tapes. These determinations were made merely as a check or for use in studying the action of the invar tapes. They were made under adverse conditions, frequent delays for lulls in the wind being necessary in order to obtain results that would agree within 0.2 millimeter. Notwithstanding this fact, the results obtained for three of the tapes agree well with those obtained at the Bureau of Standards and the other does not differ from the Bureau of Standards' determination more than might be expected, judging from the size of the residuals.

The instructions issued to the party when this work was undertaken stated that the invar tapes should be standardized at the Bureau of Standards, one of the prin-

* See p. 265, Appendix 3, of the Coast and Geodetic Survey Report for 1901, "On the measurement of nine base lines along the ninety-eighth meridian."

cipal objects in using tapes with a small coefficient of expansion being to eliminate the necessity for field standardization. For this reason, together with the fact that the field determinations were not obtained under satisfactory conditions, the field results were not used in determining the adopted lengths for the invar tapes.

The measurements on March 30 were made at Point Isabel. The weather was fair, the wind was southwest, light and moderate. The measurements on July 10 were made at Royalton. The weather was fair, with a light wind across the line.

Field determinations of lengths of invar tapes.

Tape	Date 1906	Time a. m.	Corrected temperature	Observed length	Computed length	Computed minus observed
		hr. m.	°*C.*	*mm.*	*mm.*	*mm.*
437	Mar. 30	8 32	20.15	50 meters+8.18	50 meters+7.99	−.19
437	Mar. 30	9 00	21.37	8.17	8.02	−.15
437	July 10	8 34	24.07	7.93	8.07	+.14
437	July 10	11 04	30.76	8.01	8.21	+.20
		Mean	24.09	+8.07		
		Length, Bureau of Standards,*		8.04		
438	Mar. 30	8 20	18.85	+8.36	+8.39	+.03
438	Mar. 30	9 10	21.84	8.44	8.45	+.01
438	July 10	8 53	26.55	8.58	8.55	−.03
438	July 10	10 50	29.60	8.61	8.61	.00
		Mean	24.21	+8.50		
		Length, Bureau of Standards,*		8.31		
439	Mar. 30	8 00	16.87	+6.63	+6.61	−.02
439	Mar. 30	9 25	22.94	6.66	6.74	+.08
439	July 10	9 25	26.92	6.86	6.82	−.04
439	July 10	10 30	29.48	6.88	6.87	−.01
		Mean	24.05	+6.76		
		Length, Bureau of Standards,*		6.80		
440	Mar. 30	7 45	15.90	+9.63	+9.56	−.07
440	Mar. 30	9 40	22.89	9.71	9.69	−.02
440	July 10	9 50	29.47	9.79	9.81	+.02
440	July 10	10 12	30.07	9.76	9.82	+.06
		Mean	24.58	+9.72		
		Length, Bureau of Standards,*		9.64		

*An account of the tests and determinations of lengths of the invar tapes at the Bureau of Standards, in February, March, and October, is given on pp. 111–119.

The resulting lengths of the invar tapes are shown on p. 119, and the lengths given above are those values reduced to the mean temperature of the field determinations.

FIELD PROCEDURE.

The method of procedure in the field was practically the same as the measurements with tapes in 1900.*

The base line was first cleared of brush, timber, grass, etc., and flag poles set on the line very accurately with a 7-inch or 8-inch theodolite, at distances of about a half mile. Posts 4 inches square were driven every 50 meters along the line, with their tops about half a meter above the ground. It was found advisable to have the heights of all of these posts very nearly the same, so that it would not be necessary to change the height of the tape stretcher while making the measures. Two by four inch stakes were driven midway between the posts, and a nail driven horizontally into each to support the tapes, each nail being in the straight line between the tops of the adjoining posts, except where the character of the ground made it necessary to elevate the middle support in order to keep the tapes above obstructions. The edges of these stakes were set accurately on the base line, and a line marked on top of the posts on the base line, using a theodolite for this purpose. Short sights were taken, and only a forward line run, hence the errors of alignment were practically nothing. Every twenty tape lengths (1 kilometer), posts, 4 by 6 inches, were set very solidly to hold the measure for a few days if necessary. Whenever a post could not be driven until solid, one or more braces were driven alongside and nailed to it, thus making a very rigid support. Usually all posts at each base were set before the measures were begun.

The tapes were supported, with the thermometers fastened to them, in the same manner as during the standardization. The forward end was always carried by the observer at that end, and the loop slipped over the hook of the balance as soon as the tape stretcher, with balance attached, was placed on the ground near each post. The rear observer carried his end of the tape when moving forward. A small steel bar was used for the stretcher at the rear end. As soon as the tape was in place, and at the correct height resting lightly on the post, the forward observer called "Ready." The rear end being very nearly in contact by this time, the rear observer then perfected the contact and called "Mark." The tension, being held at approximately 15 kilograms thus far, was perfected as soon as the rear observer called "Mark." A mark was then made by the forward observer upon the copper strip, exactly in the prolongation of the graduation mark on the tape. As the rear observer called "Mark" a man near the middle of the tape tapped it lightly from below, so as to eliminate the effect of friction. The forward observer also lifted the tape on the post to be sure that it was free from friction. He always waited to make the mark until the tape became steady, and until the man at the stretcher called "Tension." As soon as the mark was made the forward observer called "Right." Then each observer read the thermometer at his end, unhooked the tape from the stretchers, and the party proceeded to the next 50-meter space. The recorder noted all temperature readings, set-ups, set-backs, time, weather conditions, and all other necessary data. He also watched the forward tape stretcher to see that the correct tension was applied, and held a light to illuminate the balance

* Page 259, Appendix 3, Coast and Geodetic Survey Report for 1901, "On the measurement of nine base lines along the ninety-eighth meridian."

for the night work. The tapes were never allowed to touch the ground or other objects, except by accident occasionally while working through fences or around pools of water.

Three steel and three invar tapes were used on the measurement of each base, the same set of tapes being used on all six bases. Each tape was used on approximately two-thirds of each base, the sections being so arranged as to furnish a complete intercomparison between all the tapes on each base. Two complete and independent measures were made with the steel tapes, and also two with the invar tapes. All of the measures with steel tapes were made at night and all measures with the invar tapes in the daytime.

In order to permit comparison of the various measures of a section all the marks at the kilometer posts were referred to an initial or zero line.

Copper strips, 55 by 11 by 1.4 millimeters, were nailed to the tops of the posts (usually during the first measure) to hold the marks corresponding to tape lengths. The thickness of the copper strips was the same as that of the silver-marking sleeves on the tapes, so that there was no chance for parallax when the tape was brought alongside the copper strip ready for the measure. Large scratch awls were used for making the marks on four of the bases, but were not satisfactory, as the points broke very easily, and occasionally a broken-pointed awl had to be used for part of a measure. At Brown Valley a large leather needle was obtained and proved excellent, the point neither breaking nor wearing off.

All set-ups and set-backs were obtained from a proportional one-fourth-meter scale by taking the distance from the copper strip with a pair of dividers, except a few which were measured directly with a steel tape having millimeter graduations.

The balance used on the base measures was frequently compared with the standard balances, usually twice a day, and further tested by noting its own reading when held suspended by its own hook. The latter test was applied frequently during the measures, and particularly whenever the balance received a jerk that might cause a shifting of the index hand on the pivot.

At the base ends a marking table was set directly over the station mark and a copper strip nailed with its edge exactly over the station mark and in line with the base. A mark was made on the copper strip exactly over the station mark, for the starting point of the tape measures.

All fractional tape lengths were measured with the 50-meter tapes and a 3-meter bar. In order to measure a distance of 25 meters a tape was stretched over this space, using first one end and then the other, a small scratch or line near the middle of the tape being used for both measures. The mean of the two marks on the copper strip then defined one-half the length of the tape. Distances less than 25 meters were measured with a 3-meter steel bar with a wooden supporting back. This bar has been used many times and its corrections are well determined.

The programme usually followed was to make a measure of about 3 kilometers with one invar tape and then measure back with another, for a forenoon's work. In the afternoon computations, etc., were made and in the evening a double measure of 3 kilometers with two steel tapes, thus making a quadruple measure of 3 kilometers in a day. A single measurement of more than 12 kilometers per day was not infrequent, 14.45 kilometers being the greatest distance measured in one day. Eight kilometers were measured in a half day several times. To measure more than 6 kilometers in a half day, however, without sacrificing accuracy requires an experienced party.

The elevation of the top of each post, and of all intermediate stakes which were above the line joining the tops of the two adjoining posts, was obtained by a double line of levels along each base. The rear observer did all of the leveling (except at the Royalton Base), usually at times when the weather was not propitious for tape measures, causing very little delay. At Point Isabel a short side line of levels was run to connect with a tide staff, and another line at the Willamette Base to connect with a United States Geological Survey bench mark. Precise level No. 8, with a self-reading rod graduated to centimeters, was used on all of the leveling.

The correction to the measured length of a base, due to the tape being inclined slightly instead of being horizontal, was obtained very quickly from specially prepared tables.

POINT ISABEL BASE LINE.

Point Isabel Base is situated about 5 miles west of the village of the same name, near the mouth of the Rio Grande River, in Cameron County, Tex. The line is as near the southern end of Laguna Madre as it could well be located, the shore line at one point being only about 100 meters distant.

The length of the base is 7.4 kilometers. The latitude of the middle point of the line is 26°, the longitude 97°, and the mean azimuth 113°4. The east end of the base was the north end of a short base line located in 1886. The original subsurface mark was recovered and the station was re-marked. The underground mark was a cylinder of concrete 8 inches in diameter and 8 inches long. The surface block was a cylinder of concrete 18 inches in diameter and 26 inches long, built around a terra-cotta sewer pipe 6 inches in diameter. The top of the underground block was 2½ feet below the surface of the ground and the top of the surface block flush with the ground. The point of a 12-penny galvanized nail, projecting about a quarter of an inch, was used to indicate the center for both the underground and surface marks. West Base was marked in the same manner, except that a bronze station mark was used for the station mark, a half-inch copper bolt for the underground mark (a cross in each indicating the exact center), and a 4-inch sewer pipe instead of a 6-inch pipe.

Tripods and scaffolds 30 feet in height were erected over these stations for use in the triangulation, which was executed by the base party.

Strong winds which prevailed during the measurement of this base caused some delay and also affected the accuracy of the measures slightly.

The ground over which this base was measured is very nearly level, no tape length having a slope of more than 1.7 per cent, only a few over 0.5 per cent, and in no case was it necessary to raise the support for the middle of a tape above the line joining the ends. The line required little cutting of brush and cacti to open it for measure, but the cutting of tough bunch or wire grass about 18 inches high was necessary over a large part of the line.

The elevation of the base above mean sea level was determined by connecting the leveling along the base with a tide staff, upon which a few readings of low water were obtained. As the range in the tide is very small in this region the tidal plane used (obtained by adding one-half the range in tides) probably does not differ from mean sea level more than 0.25 meter. The height of East Base is 4.242 meters, of West Base 3.000 meters, and the average for the whole base 3.604 meters.

The reduction to mean sea level for the whole base is -4.2 millimeters. The reduction was computed separately for each section, using the formula: $C = s\frac{h}{\rho}$, where C is the reduction to sea level for a section of length s, and mean height h, ρ being the radius of the earth's curvature for this line.

The length of this base was computed from the measurements with the invar tapes and the measurements with the steel tapes, independently, and then these two values combined for a final length.

The following table shows the results of the measures of the various sections.

The time of day is given to tenths of hours. All measures with steel tapes were made at night and all measures with invar tapes in the daytime, hence it is unnecessary to insert a. m. or p. m.

The columns headed "Weather," "Wind," "Temperature," "Temperature, rising or falling," and "Temperature range" are inserted to permit the study of possible sources of errors.

The abbreviations used in these columns are: R = rising; F = falling, for temperature; F = fair; C = cloudy; P = partly cloudy; R = rain; M = mist; and D = dew, for weather conditions; L = light; M = moderate; and H = fresh, for wind, with the usual abbreviations for its direction.

The temperature range is given to tenths of degrees for the steel tapes, but only to degrees for the invar tapes, owing to their smaller coefficients of expansion.

The column headed "Corrected length of section" shows the result of each measurement of a section after all corrections were applied, namely: Correction to reduce to the temperature of standardization, correction for length of tape at the temperature of standardization, correction for set-ups and set-backs, correction for grade, and correction to reduce to mean sea level.

Results of measures of Point Isabel Base.

No. of section and posts	Date	Time of day	Direction of measure	No. of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I Invar, S=Steel	Difference, I—S
	1906	hr.			°C.	°C.				meters	mm.	meters		mm.
1. E. B. to 20	Mar. 31	8.8	E	439	21.09	2	R	F	LN	1 000.1236	−2.0			
	Mar. 31	9.4	W	438	23.64	3	RF	F	LN	.1197	+1.9	1 000.1216	I	
	Mar. 31	8	E	406	15.86	1.1	RF	F		.1151	+1.7			
	Mar. 31	9	W	403	16.28	1.4	FR	F		.1184	−1.6	1 000.1168	S	+4.8
2. 20 to 40	Mar. 31	8.3	E	439	18.55	3	R	F	LN	1 000.1158	+0.2			
	Mar. 31	10	W	438	23.41	3	RF	F	LN	.1162	−0.2	1 000.1160	I	
	Mar. 31	8	E	406	15.53	0.7	FR	F		.1089	+0.9			
	Mar. 31	10.3	W	403	15.45	1.0	F	F		.1107	−0.9	1 000.1098	S	+6.2
3. 40 to 60	Mar. 31	7.5	E	439	15.71	5	R	F	LN	1 000.0964	+2.5			
	Mar. 31	10.5	W	438	24.00	3	RF	F	LN	.1014	−2.5	1 000.0989	I	
	Mar. 31	8	E	406	15.59	0.8	F	F		.0906	+1.8			
	Mar. 31	10.8	W	403	14.98	1.9	F	F		.0941	−1.7	1 000.0924	S	+6.5
4. 60 to 80	Mar. 31	11	W	438	24.62	2	RF	F	LN	1 000.2036	−0.2			
	Apr. 6	9.5	E	440	26.88	3	RF	C	LE	.2031	+0.3	1 000.2034	I	
	Mar. 29	9	E	403	16.74	3.0	RF	PD	L	.2025	−1.4			
	Mar. 29	10	W	405	16.89	2.1	F	PD	L	.1997	+1.4	1 000.2011	S	+2.3
5. 80 to 100	Mar. 31	11.5	W	438	25.44	3	RF	F	LN	1 000.1808	−0.4			
	Apr. 6	9	E	440	25.81	2	RF	C	LE	.1800	+0.4	1 000.1804	I	
	Mar. 29	8	E	403	15.87	1.8	RF	PD	L	.1773	−1.3			
	Mar. 29	11	W	405	14.24	3.2	F	PD	L	.1746	+1.4	1 000.1760	S	+4.4
6. 100 to 101	Apr. 6	....	E	440	24.66	....	R	P		33.8190	.....	33.8190	I	
	Apr. 6	....	E	404	27.28	....	......	P		33.8177	.....	33.8177	S	+1.3
7. 101 to 121	Mar. 28	1.4	W	439	27.52	5	RF	C	LSE	1 000.1692	+0.9			
	Apr. 6	8	E	440	23.32	2	R	C	LE	.1710	−0.9	1 000.1701	I	
	Mar. 28	8.3	W	405	15.92	0.8	F	P	MN	.1671	+4.7			
	Mar. 28	11.0	E	406	15.96	0.5	F	C	HN	.1764	−4.6	1 000.1718	S	−1.7
8. 121 to 141	Mar. 28	2.2	W	439	27.98	5	FR	P	LSE	1 000.1617	+2.3			
	Mar. 28	3.8	E	440	28.16	2	RF	P	LSE	.1663	−2.3	1 000.1640	I	
	Mar. 28	8.7	W	405	16.04	0.9	R	P	MN	.1652	+5.1			
	Mar. 28	10.5	E	406	16.20	0.4	F	P	MN	.1754	−5.1	1 000.1703	S	−6.3
9. 141 to W. B.	Mar. 28	3.0	W	439	29.46	2	R	P	LSE	350.0525	+1.6			
	Mar. 28	3.3	E	440	28.99	3	F	P	LSE	.0548	−0.7			
	Apr. 6	6.6	E	439	21.62	1	F	P		.0551	−1.0	350.0541	I	
	Mar. 28	9.2	W	405	16.54	0.2	R	P	MN	.0545	+0.6			
	Mar. 28	10.0	E	406	16.68	0.4	F	P	MN	.0573	−2.2			
	Apr. 6	7	W	405	20.90	0.6	F	P		.0536	+1.5	350.0551	S	−1.0

The probable error of each section was obtained from the residuals shown in column 12, computing the probable error for the two kinds of tapes independently. These probable errors were then combined with the probable errors of the lengths of the particular tapes used on that section, to get a probable error for the section. In computing the probable error for the length of the tapes, the probable error for the length of the comparator was not included. It was combined with the final determination for the probable error of the whole base. The square root of the sum of the squares of the probable errors of the sections is the probable error of the measurement of the base, giving probable error of measurement, steel tapes, ±5.22 millimeters; invar tapes, ±2.82 millimeters.

These probable errors were then combined with those due to the probable errors of the coefficients of expansion of the two metals, respectively. The probable errors of the coefficients of expansion for the three steel tapes are ±0.003, ±0.004, and ±0.003 millimeter per tape length, per degree C., as previously given. Hence, the average probable error for the mean of any two is ±0.0024 millimeter per tape length or ±0.048 millimeter per kilometer. The mean of two was taken because two steel tapes were used on each section. The average temperature of standardization for the three steel tapes was 20°.74 C. Subtracting this value from the mean temperature of the steel tapes for each section, as given in the table, and multiplying the algebraic sum of these differences by 0.048, there is obtained the probable error of the length of the base, as measured with steel tapes, due to the probable errors of the coefficients of expansion, namely, ±1.70 millimeters.

The probable errors of the coefficients of expansion of the three invar tapes are ±0.0008, ±0.0006, and ±0.0006 millimeter per tape length, per degree C., as previously given. Hence the average probable error for the mean of any two is ±0.0005 millimeter, or ±0.010 millimeter per kilometer. Computed in the same manner as for the steel tapes, as indicated in the preceding paragraph, the probable error of the length of the base, as measured with the invar tapes, due to the probable errors of the coefficients of expansion is ±0.23 millimeter.

These probable errors, due to the probable errors of the coefficients of expansion combined with the probable errors of measurement already given (±5.22 and ±2.82), give ±5.49 and ±2.83 millimeters for the measures with steel and with invar tapes, respectively.

These two probable errors indicate that the measure with invar tapes is considerably more accurate than with the steel tapes and that these two measures should be combined, giving the invar a weight of nearly four to one, if only accidental errors are considered. As there are probably small systematic errors affecting both kinds of tapes, a weight of only two to one was used in the combination for the final length of the base.

The probable error of the weighted mean is $\pm\frac{1}{3}\sqrt{(5.49)^2+(2)^2(2.83)^2}=\pm 2.63$ millimeter.

The probable error for a determination of the length of the comparator rarely exceeded ±0.015 millimeter, and the length of each tape depends upon at least two determinations of the comparator, hence ±0.010 millimeter has been taken as the probable error of the comparator for all this work. The effect of this probable error on the whole base is obtained by multiplying ±0.010 millimeter by 148, the number of lengths of the comparator in the base, giving the probable error of the base, due to this cause, ±1.48 millimeters. This, combined with the probable error of the weighted mean, gives the final probable error of the Point Isabel Base ±3.02 millimeters, or one part on 2 450 000.

The probable errors of the reduction to sea level and the correction for grade are so small that they have an inappreciable effect upon the computed probable error of the base.

The probable errors of the length of the Point Isabel Base, obtained as stated in the preceding paragraphs, are brought together in the following form for convenient reference:

Probable error of measurement:	*mm.*
Steel tapes	±5. 22
Invar tapes	±2. 82
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±1. 70
Invar tapes	±0. 23
Probable error due to measurement and coefficients:	
Steel tapes	±5. 49
Invar tapes	±2. 83
Weighted mean of steel and invar	±2. 63
Probable error due to probable error of comparators	±1. 48
Adopted probable error	±3. 02
or one part in	2 450 000
Length of Point Isabel Base:	*meters*
Steel tapes, weight 1	7384. 9110
Invar tapes, weight 2	7384. 9275
Weighted mean	7384. 9220
	±30
And its logarithm	3. 8683459
	±2

WILLAMETTE BASE LINE.

The Willamette Base is situated near the upper end of the valley of the Willamette River, in Lane County, Oreg., about a mile west of the main line of the Southern Pacific Railroad at Irving.

The length of the base is 14 kilometers; the latitude of the middle point is 44° 08′, the longitude, 123° 12′, and the mean azimuth, 172° 21′. The ground over which the base was measured was so nearly level that it was necessary at only one place in the entire line to elevate the middle support for the tapes above the line joining the end supports. There were only eighteen tape lengths where the slope was greater than 1 per cent and only one where it was over 2 per cent.

Each end of the base was marked underground by a cross in a half-inch copper bolt, 6 inches long, set in a block of concrete, 1 foot thick by 3½ feet in diameter at the South Base, and 1 foot thick by 2 feet in diameter at the North Base, set about 3 feet below the surface of the ground. The surface mark was a cross cut in a bronze station mark, set in a concrete block (the top about flush with the surface of the ground), 3 feet in diameter on the base, 1½ feet in diameter on top, and 2½ feet deep. A concrete block, 18 by 18 inches on the base, 12 by 12 inches on top, and 2½ feet high, was set over each end mark after the completion of the measures.

When this base line was leveled, a side line of levels about a kilometer in length was run to connect with a bench mark established by the U. S. Geological Survey in

1903, on the Southern Pacific Railroad, about 4 miles north of Irving. The height of this bench mark was taken as 340.513 feet, and the resulting height of North Base was 101.278 meters; of South Base, 116.506 meters, and the average height of the base was 108.905 meters.

The reduction to mean sea level for the whole base is −239.8 millimeters, computed in the same manner as for Point Isabel Base.

The following table shows the results of the measures of the various sections.

The measurements with steel tapes and with invar tapes were combined, and the probable errors computed, in the same manner as for the Point Isabel Base.

Results of measures of Willamette Base.

No. of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			°C.	°C.				*meters*	*mm.*	*meters*		*mm.*
1. N. B. to 20	May 9	10.2	N	440	19.60	4	RF	F	MS	1 000.1765	−0.3			
	May 9	10.8	S	438	20.83	2	RF	F	MS	.1759	+0.3	1 000.1762	I	
	May 9	8.5	N	403	10.80	1.9	F	FD		.1685	+2.3			
	May 9	9.0	S	406	10.98	1.3	FR	FD		.1730	−2.2	1 000.1708	S	+5.4
2. 20 to 40	May 9	9.7	N	440	17.99	3	RF	F	MS	1 000.1730	0.0			
	May 9	11.3	S	438	21.74	3	RF	F	MS	.1731	−0.1	1 000.1730	I	
	May 9	8	N	403	13.02	2.5	F	FD		.1727	−1.3			
	May 9	9.8	S	406	10.51	0.8	FR	FD		.1702	+1.2	1 000.1714	S	+1.6
3. 40 to 60	May 9	9	N	440	16.60	4	RF	F	MS	1 000.1719	−1.4			
	May 9	11.6	S	438	22.26	2	RF	F	MS	.1691	+1.4	1 000.1705	I	
	May 9	7.5	N	403	14.42	1.2	F	FD		.1670	−0.1			
	May 9	10.2	S	406	9.87	0.9	F	FD		.1668	+0.1	1 000.1669	S	+3.6
4. 60 to 80	May 12	9.5	N	440	14.09	2	RF	C		1 000.1480	−1.7			
	May 12	9.9	S	438	15.59	3	RF	C		.1446	+1.7	1 000.1463	I	
	May 11	8.8	N	406	7.86	1.8	R	C	LW	.1446	+0.4			
	May 11	9.6	S	403	8.86	0.9	FR	C	LW	.1455	−0.5	1 000.1450	S	+1.3
5. 80 to 100	May 12	9	N	440	13.35	3	R	C		1 000.1949	−0.7			
	May 12	10.6	S	438	16.80	4	FR	C		.1936	+0.6	1 000.1942	I	
	May 11	8.3	N	406	7.26	1.5	FR	C	LW	.1899	−0.1			
	May 11	10.1	S	403	8.22	2.0	F	C	LW	.1897	+0.1	1 000.1898	S	+4.4
6. 100 to 120	May 12	8.6	N	440	12.59	1	R	C		1 000.1652	−0.7			
	May 12	11.0	S	438	17.42	3	RF	C		.1638	+0.7	1 000.1645	I	
	May 11	7.7	N	406	8.28	2.2	FR	C	MW	.1600	+0.4			
	May 11	10.3	S	403	7.10	0.8	RF	C		.1607	−0.3	1 000.1604	S	+4.1
7. 120 to 140	May 10	9.3	N	438	12.76	3	R	P	MW	1 000.1349	−1.4			
	May 10	9.9	S	439	13.99	2	FR	P	MW	.1320	+1.5	1 000.1335	I	
	May 10	7.9	N	403	11.09	0.9	RF	C	MN	.1358	+0.4			
	May 10	8.3	S	405	11.24	0.9	RF	C	MN	.1365	−0.3	1 000.1362	S	−2.7
8. 140 to 160	May 10	8.8	N	438	11.14	1	RF	C	LS	1 000.1394	+0.5			
	May 10	10.3	S	439	15.43	5	RF	P	LW	.1403	−0.4	1 000.1399	I	
	May 10	7.5	N	403	11.24	1.2	F	C	MN	.1396	−0.3			
	May 10	8.9	S	405	11.55	0.9	RF	C	LN	.1390	+0.3	1 000.1393	S	+0.6

Results of measures of Willamette Base—Continued.

No. of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
9. 160 to 180	May 10	8.1	N	438	10.68	1	RF	C	LS	1 000.1721	−1.0			
	May 10	10.8	S	439	15.08	4	FR	P	MW	.1701	+1.0	1 000.1711	I	
	May 10	7.1	N	403	12.18	1.3	F	C	MN	.1724	−0.6			
	May 10	9	S	405	11.64	0.4	RF	C	LN	.1711	+0.7	1 000.1718	S	−0.7
10. 180 to 180a	May 5	....	..	440	13.5	...	....	..	....	17.1162	+0.1			
	May 5	....	..	439	20.9	...	....	..	....	.1163	−0.0	17.1163	I	
	May 5	....	..	406	17.5	...	....	..	....	.1161	....	17.1161	S	+0.2
11. 180a to 200	May 5	8.4	S	440	14.74	2	RF	F	MN	1 000.1144	+0.3			
	May 5	10.8	N	439	19.48	3	FR	F	MN	.1150	−0.3	1 000.1147	I	
	May 5	8	S	406	11.92	4.0	F	FD		.1129	+3.1			
	May 5	10	N	405	10.58	3.4	FR	FD		.1191	−3.1	1 000.1160	S	−1.3
12. 200 to 220	May 5	9.4	S	440	16.25	3	RF	F	MN	1 000.1033	−0.5			
	May 5	10.2	N	439	18.44	2	FR	F	MN	.1022	+0.6	1 000.1028	I	
	May 5	8.4	S	406	12.01	3.3	RF	FD		.1048	+1.2			
	May 5	9.5	N	405	10.54	2.8	FR	FD		.1072	−1.2	1 000.1060	S	−3.2
13. 220 to 240	May 7	8.4	S	440	16.37	4	RF	F		1 000.1593	+0.3			
	May 7	11.6	N	439	22.36	4	FR	F		.1600	−0.4	1 000.1596	I	
	May 7	7.8	S	405	14.14	2.7	FR	FD		.1570	−1.2			
	May 7	10.9	N	406	7.97	1.4	FR	FD		.1545	+1.3	1 000.1558	S	+3.8
14. 240 to 260	May 7	9.2	S	440	17.20	2	FR	F		1 000.2764	−0.1			
	May 7	11.2	N	439	21.33	3	RF	F		.2761	+0.2	1 000.2763	I	
	May 7	8.4	S	405	12.30	2.8	RF	FD		.2737	−0.2			
	May 7	10.3	N	406	9.48	2.1	FR	FD		.2732	+0.3	1 000.2735	S	+2.8
15. 260 to S. B.	May 7	10	S	440	19.15	3	FR	F		1 000.1481	−1.4			
	May 7	10.6	N	439	21.04	3	FR	F		.1453	+1.4	1 000.1467	I	
	May 7	8.7	S	405	11.53	2.8	FR	FD		.1453	−1.1			
	May 7	9.6	N	406	9.93	2.8	FR	FD		.1432	+1.0	1 000.1442	S	+2.5

	mm.
Probable error of measurement:	
Steel tapes	±3.32
Invar tapes	±2.34
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±6.82
Invar tapes	±0.43
Probable error due to measurement and coefficients:	
Steel tapes	±7.59
Invar tapes	±2.38
Weighted mean of steel and invar	±2.99
Probable error due to probable error of comparators	±2.80
Adopted probable error	±4.09
	or one part in 3 430 000

Length of Willamette Base:	*meters*
Steel tapes, weight 1	14 019.3632
Invar tapes, weight 2	14 019.3856
Weighted mean	14 019.3781
	±41
And its logarithm	4.1467287
	±1

TACOMA BASE LINE.

Tacoma Base is situated in Pierce County, Wash., south of the city of Tacoma. It is 12 kilometers in length, 8 kilometers being along the driveway of Pacific avenue and 4 kilometers through fields, a few of which are tilled. The line passes through the eastern edge of the village of Spanaway, 9 miles south of Tacoma.

Each end of this base was marked underground by a cross cut in a half-inch copper bolt, 3 inches long, set in a concrete block 30 inches square and 6 inches thick, placed 3 feet below the surface of the ground. The surface mark was a cross cut in a regular bronze station mark set in a concrete block, 2½ feet in each dimension. The center was also indicated by a 4-inch drain tile set in the concrete block. The tops of the tile, station mark, and concrete block were all set about flush with the surface of the ground.

The latitude of the middle point of the base is 47° 08′, the longitude, 122° 30′, and the mean azimuth, 0° 44′.

On about one-half mile of the base it was necessary to cut much brush and small timber, but the remainder was open. The soil was solid gravel, in which it was difficult to drive the stakes, but in which they held well.

About 7 kilometers of the base line (the straight line between the base ends) at the north end was either in or near Pacific avenue, a somewhat crooked road. As it was impracticable to measure along the center of the road and very difficult to open the line through the brush, logs, etc., bordering the road, the measurement of this part of the base was made in a series of straight lines following the edge of the road and yet very near the base line.

A point for the beginning of the measurement was located on the east side of the driveway of Pacific avenue, on a line from North Base perpendicular to the base line. The line of measurement then followed the east side of the driveway for about 6 kilometers, where it crossed to the west side. Angles were made in this line of measurement wherever necessary to keep clear of the brush on one side and the traffic on the other. A point was located accurately on the base line opposite each one of these angle posts, using an 8-inch theodolite, and the offsets measured accurately. The following table gives these offsets and the corrections necessary to reduce the measured sections to the base line. Each quantity in column "h" is the difference between the offsets at the ends of a section of length "S."

The formula used for computing the grade corrections was also used for computing these corrections.

Correction for alignment.

Section post Nos.	First offset *	Second offset *	h	S	Correction
	meters	*meters*	*meters*	*meters*	*meters*
0– 26	−25.500	−10.565	14.935	1 300	−0.08579
26– 35	−10.565	− 3.985	6.580	450	−0.04811
35– 55	− 3.985	0.000	3.985	1 000	−0.00794
55– 71	0.000	+ 4.295	4.295	800	−0.01153
71– 75	+ 4.295	+ 2.432	1.863	200	−0.00866
75– 77	+ 2.432	+ 2.282	0.150	100	−0.00011
77– 79	+ 2.282	+ 3.295	1.013	100	−0.00513
79– 90	+ 3.295	+ 1.307	1.988	550	−0.00359
90–120	+ 1.307	+ 2.865	1.558	1 500	−0.00081
120–122	+ 2.865	− 2.046	4.911	100	−0.12066
122–136	− 2.046	− 2.606	0.560	700	−0.00022
136–143	− 2.606	− 0.148	2.458	350	−0.00863
143–144	− 0.148	0.000	0.148	50	−0.00022
			Total correction,		−0.30140

The errors caused by measuring a broken line instead of the base line itself are negligible, as they are of the same character as those due to grade corrections, and are certainly not larger. Owing to the roughness of the ground, a measurement along the straight line would undoubtedly have been less accurate than the measurement along this broken line, which followed a graded road. Further, the additional expense of preparing the base line itself for measurement would have been not less than $100, and possibly considerably more.

The weather, during the progress of the measures on this base, was not propitious for rapid and accurate work with tapes. The wind was rather fresh occasionally, and rain interrupted the work considerably. Rain also made the grass and brush on the south end of the line so wet that it was impossible to keep the tapes and thermometers dry. The measurement of sections 10 to 13 with steel tapes was made with the thermometers moist, thus probably causing indicated temperatures somewhat lower than the actual temperatures of the tapes. The lengths of these four sections, as determined with the invar tapes, are each about 5 millimeters longer than the lengths determined with the steel tapes. This could not be caused by an accumulation of moisture on the tapes, as it is in the wrong direction, and an additional weight of one-thirtieth of the weight of the tape would be required to produce it. If, however, the thermometers indicated temperatures 0°.4 too low the whole difference would be accounted for.

The ground over which this base was measured was much more irregular than that of any other base measured during this season. There were many places where the middle support for the tape had to be raised considerably above the line joining the two end supports. On one half-tape length the slope was nearly 10 per cent, but on all others it was less than 5 per cent. The correction for grade on one kilometer section was almost half a meter, double that of any other kilometer on any of the bases measured.

The elevations along this base depend on an elevation of 33.518 meters for the U. S. Geological Survey bench mark on Tacoma City Hall, brought through two figures of the triangulation by trigonometric leveling. The several determinations for the height of North Base agree within 0.22 meter, and the trigonometric difference in

* − is west and + is east of the base line.

height between the base ends agrees within 0.20 meter with the difference obtained from the levels run over the base, thus showing that the trigonometric work is sufficiently accurate. The height of North Base above mean sea level is 124.70 meters; of South Base, 122.57 meters, and the average height of the base is 110.375 meters. The reduction to sea level for the base, computed in the same manner as for Point Isabel Base, is −209 millimeters.

The following table shows the results of the measures of the various sections. The measurements with steel tapes and with invar tapes were combined, and the probable errors computed, in the same manner as for Point Isabel Base.

Results of measures of Tacoma Base.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I−S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
1. N. B. to 20	May 28	9.2	S	438	18.47	3	FR	F	MN	999.8765	−0.5			
	May 28	11.7	N	439	20.61	2	FR	F	MN	.8755	+0.5	999.8760	I	
	May 28	8.6	N	403	13.40	1.0	FR	C	MS	.8764	−1.7			
	May 28	9.3	S	405	12.58	0.8	FR	C	MS	.8731	+1.6	999.8747	S	+1.3
2. 20 to 40	May 28	9.8	S	438	18.96	3	FR	F	MN	999.9641	−0.8			
	May 28	11.3	N	439	20.18	2	FR	F	MN	.9625	+0.8	999.9633	I	
	May 28	8.3	N	403	13.82	0.9	F	C	MS	.9621	−1.4			
	May 28	9.7	S	405	11.82	0.7	F	C	MS	.9594	+1.3	999.9607	S	+2.6
3. 40 to 60	May 28	10.3	S	438	19.37	4	RF	F	MN	999.9399	−1.6			
	May 28	10.9	N	439	19.74	3	FR	F	MN	.9367	+1.6	999.9383	I	
	May 28	7.6	N	403	14.43	0.8	F	C	MS	.9361	−0.1			
	May 28	10.2	S	405	11.04	0.8	FR	C	MS	.9358	+0.2	999.9360	S	+2.3
4. 60 to 80	June 1	1.5	N	438	25.37	4	RF	F	LNW	999.7440	+1.5			
	June 1	2.2	S	439	25.10	5	FR	F	LNW	.7471	−1.6	999.7455	I	
	June 2	7.4	N	403	12.96	3.6	F	C		.7469	−1.1			
	June 2	8.0	S	405	12.52	1.1	FR	C		.7447	+1.1	999.7458	S	−0.3
5. 80 to 100	June 1	2.6	S	439	25.47	3	RF	F	LNW	999.8477	+0.4			
	June 1	4.1	N	440	24.78	4	FR	F	LNW	.8484	−0.3	999.8481	I	
	June 2	8.4	S	405	12.52	1.6	RF	C		.8438	+0.5			
	June 2	10.0	N	406	11.36	1.3	F	C		.8447	−0.4	999.8443	S	+3.8
6. 100 to 120	June 1	3.1	S	439	25.14	2	RF	F	LNW	999.9354	+0.2			
	June 1	3.6	N	440	25.25	2	RF	F	LNW	.9358	−0.2	999.9356	I	
	June 2	8.8	S	405	12.52	1.5	RF	C		.9374	−1.6			
	June 2	9.5	N	406	11.96	1.2	FR	C		.9342	+1.6	999.9358	S	−0.2
7. 120 to 140	June 2	8.7	N	439	21.76	4	RF	F		999.5239	+2.0			
	June 2	9.4	S	440	23.22	4	FR	F		.5279	−2.0	999.5259	I	
	June 4	8.1	N	405	8.96	0.9	F	C		.5176	+2.9			
	June 4	8.7	S	406	8.58	0.9	RF	C		.5235	−3.0	999.5205	S	+5.4
8. 140 to 160	June 2	8.2	N	439	20.51	3	RF	F		1 000.0063	+2.0			
	June 2	10.0	S	440	23.32	4	RF	F		.0103	−2.0	1 000.0083	I	
	June 4	7.7	N	405	9.69	0.8	F	C		.0009	+2.8			
	June 4	9.1	S	406	8.71	0.5	FR	C		.0065	−2.8	1 000.0037	S	+4.6

Results of measures of Tacoma Base—Continued.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean − observed	Mean length of section	I=Invar, S=Steel	Difference, I−S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
9. 160 to 162	June 2	....	S	440	23.96	1	F	F		57.2459	−0.1			
	June 2	....	N	438	26.06	0	F	F		.2457	+0.1	57.2458	I	
	June 2	....	S	406	7.7	....	......	......		.2458	−0.1			
	June 2	....	N	403	10.3	....	......	......		.2457	0.0	57.2457	S	+0.1
10. 162 to 182	June 2	10.4	S	440	23.97	4	RF	F		999.8830	−1.5			
	June 2	11.0	N	438	25.25	4	FR	F		.8837	−2.2			
	June 8	8	S	438	12.30	2	RF	P		.8779	+3.6	999.8815	I	
	June 6	8.4	S	406	6.90	1.2	F	CD		.8770	+1.2			
	June 7	9	N	403	10.12	0.8	FR	CD		.8793	−1.1	999.8782	S	+3.3
11. 182 to 202	June 5	8.1	S	440	14.33	4	RF	C		999.8061	+1.7			
	June 5	10.7	N	438	15.30	2	RF	R		.8095	−1.7	999.8078	I	
	June 6	8.9	S	406	6.31	0.9	FR	CD		.8006	+1.0			
	June 7	8.5	N	403	9.68	0.8	RF	CD		.8027	−1.1	999.8016	S	+6.2
12. 202 to 222	June 5	8.7	S	440	16.14	3	FR	C		999.9755	+0.7			
	June 5	10.2	N	438	16.25	3	FR	CR		.9770	−0.8	999.9762	I	
	June 6	9.3	S	406	5.80	1.1	FR	CD		.9695	+0.6			
	June 7	8.1	N	403	10.03	0.9	FR	CD		.9706	−0.5	999.9701	S	+6.1
13. 222 to S. B.	June 5	9.2	S	440	16.26	3	RF	C		999.8310	+0.4			
	June 5	9.8	N	438	16.18	2	RF	C		.8318	−0.4	999.8314	I	
	June 6	9.8	S	406	5.85	0.8	FR	CD		.8248	+1.0			
	June 7	7.6	N	403	11.51	1.5	F	CD		.8268	−1.0	999.8258	S	+5.6

Probable error of measurement:	*mm.*
Steel tapes	±3.77
Invar tapes	±3.25
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±5.87
Invar tapes	±0.11
Probable error due to measurement and coefficients:	
Steel tapes	±6.98
Invar tapes	±3.25
Weighted mean of steel and invar	±3.18
Probable error due to probable error of comparators	±2.41
Adopted probable error	±3.99
	or one part in 3 020 000
Length of Tacoma Base:	*meters*
Steel tapes, weight 1	12 055.5429
Invar tapes, weight 2	12 055.5837
Weighted mean	12 055.5701
	±40
And its logarithm	4.0811877
	±2

STEPHEN BASE LINE.

This base is situated in Marshall County, Minn., a short distance east of the town of Stephen.

Each end of the base was marked at the surface by a 1-millimeter drill hole in a bronze station mark set in a granite block 2 feet square and 1 foot deep. The underground mark was a ½-inch copper bolt set in a granite block, 6 inches square and 1 foot deep, set 5 feet below the surface. A section of empty 4-inch sewer pipe was set over the subsurface mark and both stones and the pipe were surrounded by a mass of concrete 2 feet square at the base and 4 feet square at the surface of the ground.

This base is 9.2 kilometers in length. The latitude of the middle point is 48° 30′, the longitude 96° 54′, and the azimuth of the line 253° 19′.

The soil on the western half of this base is a kind of gumbo, and is rather elastic when wet. The eastern half is more sandy and not so elastic. A man could not step near the posts on the gumbo section without causing a slight deflection. This probably affected the accuracy of the measures to some extent, particularly as the ground was very wet from frequent rains, but the effect was not sufficiently large to affect the residuals materially. See sections 6 to 10.

The measurement of the base was delayed very materially by rains and strong winds. The measurement of sections 1, 2, and 3 with steel tapes was made during a light drizzle, heavy enough to keep everything wet. The tape was wiped about every 4 or 5 tape lengths but was probably almost as wet after two tape lengths as at any time. Some of these measures were made in one direction before the mist became heavy enough to gather on the tape, hence these errors should show in the column of residuals. The agreement between the measurements with invar and with steel tapes is a further check upon the possible magnitude of these errors.

The residuals of the various sections on this base are larger than on any other base measured this season. This may be attributed to three things, viz, bad weather conditions, movement of posts while standing or walking near them, and inexperience of the man who acted as forward tape stretcher. Even on this base the accuracy is far within the limits required, as shown by the instructions given at the beginning of this appendix.

The height of West Base is 253.4928 meters, as fixed by precise leveling connected with the precise leveling net. The height of East Base, obtained from the levels over the base, is 268.509 meters, and the average height of the base is 259.864 meters. The reduction to mean sea level for the base, computed in the same manner as for Point Isabel Base, is −375.1 millimeters.

The grade on this base was very uniform, there being only one tape length where the middle support had to be elevated above the line joining the two end supports. There was only one tape length where the slope was more than 2 per cent and only four where it was more than 1 per cent.

Grain or grass had to be cut on about half of the base in order to clear the tapes. Nearly all of the remainder of the base was through grain fields, but the measurement was completed before the grain was high enough to interfere with the work. Very little brush cutting was necessary. Only two roads were crossed by the base, and no fences. The site was almost an ideal one for measurement in dry weather.

The following table shows the results of the measures of the various sections.

The measurements with steel and with invar tapes were combined, and the probable errors computed, in the same manner as for Point Isabel Base.

Results of measures of Stephen Base.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean — observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			*°C.*	*°C.*				*meters*	*mm.*	*meters*		*mm.*
1. E. B. to 20	June 19	3.7	E	440	23.74	5	FR	P		1 000.1364	−1.2			
	June 19	4.2	W	439	22.72	4	RF	P		.1339	+1.3	1 000.1352	I	
	June 22	8.6	E	405	10.03	0.5	F	R		.1238	+5.4			
	June 22	9.2	W	406	9.78	0.4	F	R		.1346	−5.4	1 000.1292	S	+6.0
2. 20 to 40	June 19	3.2	E	440	24.92	3	F	P		1 000.1038	−3.4			
	June 19	4.7	W	439	22.87	3	RF	P		.0969	+3.5	1 000.1004	I	
	June 22	8.2	E	405	10.71	0.5	RF	C		.0928	+6.3			
	June 22	9.6	W	406	9.70	0.1	F	R		.1053	−6.2	1 000.0991	S	+1.3
3. 40 to 60	June 19	2.7	E	440	26.34	4	RF	P		1 000.1482	−2.5			
	June 19	5.1	W	439	23.34	3	RF	P		.1432	+2.5	1 000.1457	I	
	June 22	7.8	E	405	10.78	0.5	F	C		.1447	+1.2			
	June 22	10.1	W	406	9.76	0.2	F	R		.1470	−1.1	1 000.1459	S	−0.2
4. 60 to 80	June 19	10.8	E	438	23.01	4	F	P	LW	1 000.1027	−3.3			
	June 19	11.5	W	439	21.34	4	F	P	LW	.0962	+3.2	1 000.0994	I	
	June 16	9.5	E	405	19.69	1.4	R	C	M	.1036	+2.6			
	June 16	10.0	W	403	20.36	0.8	RF	C	M	.1089	−2.7	1 000.1062	S	−6.8
5. 80 to 100	June 19	10.4	E	438	24.25	3	RF	P	LW	1 000.1357	−1.6			
	June 19	12.0	W	439	20.40	2	RF	P	LW	.1325	+1.6	1 000.1341	I	
	June 16	9	E	405	17.83	1.6	FR	C	M	.1386	−1.7			
	June 22	11.0	W	403	9.54	0.2	F	R		.1406	−3.7			
	June 22	11.8	E	405	9.54	0.2	F	R		.1315	+5.4	1 000.1369	S	−2.8
6. 100 to 120	June 19	9.9	E	438	22.88	4	FR	P	LW	1 000.1432	−1.6			
	June 19	12.5	W	439	23.05	7	R	P	LW	.1401	+1.5	1 000.1416	I	
	June 16	8.5	E	405	18.04	1.4	RF	C	LSE	.1426	+2.7			
	June 16	10.4	W	403	15.30	1.0	F	CD		.1480	−2.7	1 000.1453	S	−3.7
7. 120 to 140	June 22	2.8	E	438	11.72	0	F	C		1 000.1774	−0.4			
	June 22	3.3	W	440	11.96	1	RF	C		.1767	+0.3	1 000.1770	I	
	June 18	9.6	E	406	15.44	0.3	F	CD		.1790	+1.9			
	June 18	10.8	W	403	15.13	0.4	F	CD		.1828	−1.9	1 000.1809	S	−3.9
8. 140 to 160	June 22	2.5	E	438	12.31	2	F	C		1 000.2088	+0.3			
	June 22	3.8	W	440	12.22	1	R	C		.2095	−0.4	1 000.2091	I	
	June 18	9.1	E	406	15.67	0.4	F	CD		.2095	+4.8			
	June 18	11.6	W	403	14.63	0.4	F	CD		.2191	−4.8	1 000.2143	S	−5.2
9. 160 to 180	June 22	2.0	E	438	12.40	1	RF	C		1 000.1035	+1.2			
	June 22	4.3	W	440	12.90	1	F	C		.1059	−1.2	1 000.1047	I	
	June 18	8.6	E	406	16.18	0.5	F	CD		.1068	+0.5			
	June 18	12.0	W	403	14.48	0.6	F	CD		.1077	−0.4	1 000.1073	S	−2.6
10. 180 to W. B.	June 22	1.6	E	438	12.56	0	F	C		220.5796	+0.1			
	June 22	4.0	W	440	12.52	0	F	C		.5798	−0.1	220.5797	I	
	June 18	8.5	E	406	16.48	0.1	F	CD		.5789	+2.2			
	June 18	12.5	W	403	14.53	0.1	R	CD		.5833	−2.2	220.5811	S	−1.4

Probable error of measurement:	*mm.*
Steel tapes	±7.41
Invar tapes	±4.12
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±7.99
Invar tapes	±4.12
Probable error due to measurement and coefficients:	
Steel tapes	±3.00
Invar tapes	±0.04
Weighted mean of steel and invar	±3.83
Probable error due to probable error of comparators	±1.84
Adopted probable error	±4.25
	or one part in 2 170 000
Length of Stephen Base:	*meters*
Steel tapes, weight 1	9 221.8462
Invar tapes, weight 2	9 221.8269
Weighted mean	9 221.8333
	±43
And its logarithm	3.9648173
	±2

BROWN VALLEY BASE.

This base is in Roberts County, S. Dak., about 2½ miles west of the town of Brown Valley, Minn.

The terminals were marked in the same manner as at Stephen Base, except that five-eighths-inch copper bolts were used for the surface marks instead of bronze station marks, and that at Southeast Base a cross was made in place of the drill hole.

The base is 8.2 kilometers in length, the latitude of the middle point is 45° 35′; the longitude 96° 52′, and the mean azimuth 149° 08′.

Rain and strong winds caused some delay on this base also, but did not affect the accuracy materially. A large part of the measures at night were made with tapes and thermometers more or less wet, owing to the dews. Heavy rainfalls during the spring of 1906 caused two low places on the base to be filled with water to a depth of 2 feet or more at the time the measurement was made. This made the posts project very considerably above the ground, as they had to be about 0.6 meter above the water. Braces were nailed to both sides of each post, however, and no motion was noticeable during the work. The various measures over these sections (3, 4, and 5) agree very well, thus showing that the posts were apparently not disturbed by working around them. Nearly a kilometer of the base was through these ponds. When the base was located these low places were dry. The residents of that region said that these places were rarely wet, hence no attempt was made to locate to one side of them. Other than a little expense in the preparation of the base for measurement and the extra time necessary for measuring, where the water was over 2 feet in depth (not counting the discomfort of the men), there was no very material loss, in either expense or accuracy, due to the existence of these ponds on the line.

No cutting of brush or timber was necessary. Considerable grass and grain had to be cut, however, along about half of the line, the remainder being through fields where the grass and grain were not high enough to interfere with the tapes. Two frequently traveled roads were crossed by the line and three or four wire fences.

The ground was nearly level along the base, there being only one tape length where it was necessary to raise the middle support above the line joining the end supports. There was no tape length with a greater slope than 3.8 per cent, only 6 over 2 per cent, and 25 over 1 per cent.

The height of the base depends on the trigonometric leveling, controlled by three bench marks fixed by precise leveling connected with the precise level net. Each of the bench marks was a triangulation station and within two figures of the base, two to the north and one to the south of it. The probable error of the height of Northwest Base is about ± 0.24 meter. The height of Northwest Base is 355.26 meters, that of Southeast Base 347.56 meters, and the average height of the whole base is 346.48 meters.

The reduction to sea level for the base, computed in the same manner as for the Point Isabel Base, is -447.1 millimeters.

The following tables show the results of the measures of the various sections.

The measurements with steel tapes and with invar tapes were combined, and the probable errors computed, in the same manner as for the Point Isabel Base.

Results of measures of Brown Valley Base.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I−S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
1. SE. B. to 20	June 27	9.7	SE	440	24.33	6	RF	P	LS	1 000.0970	−0.3			
	June 27	10.2	NW	438	25.28	5	RF	P	LS	.0964	+0.3	1 000.0967	I	
	June 27	9.0	SE	406	21.05	0.6	RF	PD		.1027	−1.5			
	June 27	9.5	NW	403	21.20	0.9	F	PD		.0998	+1.4	1 000.1012	S	−4.5
2. 20 to 40	June 27	9.1	SE	440	22.77	6	R	P	LS	1 000.0398	−0.1			
	June 27	10.7	NW	438	26.40	6	RF	P	LS	.0396	+0.1	1 000.0397	I	
	June 27	8.5	SE	406	20.39	1.4	FR	PD		.0397	+0.3			
	June 27	10.0	NW	403	20.10	1.0	F	PD		.0402	−0.2	1 000.0400	S	−0.3
3. 40 to 60	June 26,27		SE	440	21.15	3	RF	P	LN	999.9955	0.0			
	June 27	11.0	NW	438	24.60	3	F	P	LN	*.9955	0.0	999.9955	I	
	June 27	3.2	NW	439	24.46	3	RF	P	LN					
	June 27,29		SE	406	19.68	2.0	F	PD		.9982	−1.1			
	June 27	10.5	NW	403	19.57	0.6	FR	PD		*.9959	+1.2	999.9971	S	−1.6
	June 29	9.0	NW	405	15.98	0.6	RF	PD						
4. 60 to 80	June 26	4.0	SE	440	22.90	5	FR	P	LN	1 000.0964	+0.9			
	June 26	3.6	NW	439	25.02	5	RF	P	LN	.0982	−0.9	1 000.0973	I	
	June 29	9.9	SE	406	14.72	3.0	RF	DF	LE	.0939	−0.3			
	June 29	9.5	NW	405	13.69	4.1	F	FD	LE	.0933	+0.3	1 000.0936	S	+3.7
5. 80 to 100	June 26	4.4	NW	439	25.50	5	RF	P	LN	1 000.0931	−1.0			
	June 26	5.2	SE	440	24.82	3	RF	P	LN	.0910	+1.1	1 000.0921	I	
	June 29	10.0	NW	405	12.53	1.7	FR	FD	LE	.0901	+0.5			
	June 29	11.0	SE	406	13.16	1.8	FR	FD	LE	.0911	−0.5	1 000.0906	S	+1.5

*This section was measured in part with each of the tapes given.

Results of measures of Brown Valley Base—Continued.

Number of section and posts.	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			*°C.*	*°C.*				*meters*	*mm.*	*meters*		*mm.*
6. 100 to 105	June 26	4.6	NW	439	24.45	3	R	P	L,N	222.9643	+0.2			
	June 26	5.0	SE	440	25.46	2	F	P	L,N	.9647	−0.2	222.9645	I	
	June 29	10.3	NW	405	12.02	0.4	R	FD	L,E	.9636	0.0			
	June 29	10.5	SE	406	12.76	0.5	R	FD	L,E	.9636	0.0	222.9636	S	+0.9
7. 105 to 125	June 26	9.0	NW	438	18.28	3	FR	P	L	1 000.1092	+1.8			
	June 26	11.4	SE	439	20.71	6	RF	P	L	.1128	−1.8	1 000.1110	I	
	June 30	8.5	NW	405	11.20	1.4	FR	FD	L,NE	.1048	+2.9			
	June 30	10.8	SE	403	8.83	1.5	FR	FD	L,NE	.1106	−2.9	1 000.1077	S	+3.3
8. 125 to 145	June 26	9.5	NW	438	19.66	6	RF	P	L	1 000.1036	+1.9			
	June 26	10.9	SE	439	22.32	7	F	P	L	.1074	−1.9	1 000.1055	I	
	June 30	8.9	NW	405	10.47	1.3	FR	FD	L,NE	.1010	+3.3			
	June 30	10.4	SE	403	9.52	1.3	FR	FD	L,NE	.1076	−3.3	1 000.1043	S	+1.2
9. 145 to NW. B.	June 26	9.9	NW	438	20.96	5	RF	P	L	1 000.0675	−0.2			
	June 26	10.5	SE	439	22.34	6	FR	P	L	.0671	+0.2	1 000.0673	I	
	June 30	9.4	NW	405	9.56	0.9	FR	FD	L,NE	.0659	+5.4			
	June 30	9.9	SE	403	9.64	1.0	FR	FD	L,NE	.0768	−5.5	1 000.0713	S	−4.0

Probable error of measurement:	*mm.*
Steel tapes	±4.98
Invar tapes	±2.05
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±2.46
Invar tapes	±0.22
Probable error due to measurement and coefficients:	
Steel tapes	±5.55
Invar tapes	±2.06
Weighted mean of steel and invar	±2.31
Probable error due to probable error of comparators	±1.64
Adopted probable error	±2.83
or one part in	2 910 000
Length of Brown Valley Base:	*meters*
Steel tapes, weight 1	8 223.5694
Invar tapes, weight 2	8 223.5696
Weighted mean	8 223.5695
	±28
And its logarithm	3.9150604
	±1

ROYALTON BASE LINE.

Royalton Base is situated in the valley of the Mississippi River, in Benton County, Minn., east of the towns of Royalton and Rice.

The terminals were marked in the same manner as at Stephen Base, a 1-millimeter drill hole in each bronze station mark indicating the center of the station. The base is

9.6 kilometers in length, the latitude of the middle point is 45° 43′; the longitude, 94° 14′, and the mean azimuth of the line, 157° 10′.

The ground along the line is irregular, but not sufficiently so to cause many of the middle supports for the tapes to be raised above the line joining the end supports. There were 38 tape lengths where the slope was more than 2 per cent; and 3 more than 4 per cent, the maximum being 5.1 per cent.

Cutting of brush was required on only about 150 meters of the line, the greater part of the remainder being through grain fields. Rye fields, with the grain well advanced toward maturity, required cutting for about 4 kilometers of the line. Four roads and about ten fences were crossed by the base line.

The heights along the base depend upon an elevation of 323.19 meters * for Mississippi River Commission P. B. M. △ Back Base, which is 1 917 meters from South Base, the connection being made by trigonometric leveling. The height of North Base is 348.127 meters; of South Base, 324.070 meters, and the average height of the base, 328.544 meters. The reduction to mean sea level, computed in the same manner as for Point Isabel Base, was—497.2 millimeters.

The following table shows the results of the measures of the various sections. The measurements with steel and with invar tapes were combined, and the probable errors computed, in the same manner as for Point Isabel Base.

Results of measures of Royalton Base.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
1. S. B. to 20	July 7	9.8	S	440	27.02	3	RF	P	L	1 000.0256	−1.3			
	July 7	10.4	N	439	27.57	4	FR	P	L	.0231	+1.2	1 000.0243	I	
	July 7	9.0	S	406	15.12	2.2	FR	FD		.0209	+0.6			
	July 7	9.6	N	405	14.69	3.1	F	FD		.0220	−0.5	1 000.0215	S	+2.8
2. 20 to 40	July 7	9.4	S	440	25.34	3	RF	P	L	1 000.0588	−2.7			
	July 7	10.8	N	439	27.18	4	FR	P	L	.0534	+2.7	1 000.0561	I	
	July 7	8.6	S	406	16.43	1.9	FR	FD		.0529	+0.2			
	July 7	10.0	N	405	14.43	0.9	FR	FD		.0533	−0.2	1 000.0531	S	+3.0
3. 40 to 60	July 7	8.9	S	440	24.92	4	FR	P	L	1 000.0281	−2.8			
	July 7	11.1	N	439	27.40	3	FR	P	L	.0224	+2.9	1 000.0253	I	
	July 7	8.3	S	406	17.34	2.4	F	FD		.0240	−2.2			
	July 7	10.5	N	405	14.56	2.3	RF	FD		.0195	+2.3	1 000.0218	S	+3.5
4. 60 to 80	July 5	10.0	S	438	24.30	4	FR	F	L	1 000.1388	+0.3			
	July 5	10.5	N	439	25.20	3	RF	F	L	.1395	−0.4	1 000.1391	I	
	July 5	9.1	S	403	14.23	2.0	FR	FD		.1387	+1.1			
	July 5	9.6	N	405	13.50	1.8	F	FD		.1409	−1.1	1 000.1398	S	−0.7

* See page 493, Appendix 3 of the Report of the Coast and Geodetic Survey for 1903, "Precise Leveling in the United States."

Results of measures of Royalton Base—Continued.

Number of section and posts	Date	Time of day	Direction of measure	Number of tape	Mean temperature	Temperature range	Temperature, rising or falling	Weather	Wind	Corrected length of section	Residual, mean—observed	Mean length of section	I=Invar, S=Steel	Difference, I—S
	1906	*hr.*			°*C.*	°*C.*				*meters*	*mm.*	*meters*		*mm.*
5. 80 to 100	July 5	9.5	S	438	23.62	3	RF	F	L	1 000.1295	+0.8			
	July 5	10.9	N	439	25.54	4	FR	F	L	.1311	−0.8	1 000.1303	I	
	July 5	8.6	S	403	15.40	2.5	FR	FD		.1298	−1.2			
	July 5	10.1	N	405	13.06	1.7	FR	FD		.1274	+1.2	1 000.1286	S	+1.7
6. 100 to 120	July 5	9.1	S	438	22.55	3	FR	F	L	1 000.1033	+2.5			
	July 5	11.4	N	439	25.36	2	FR	F	L	.1083	−2.5	1 000.1058	I	
	July 5	8.3	S	403	16.17	2.5	F	FD		.1050	−0.6			
	July 5	10.5	N	405	12.65	1.9	FR	FD		.1038	+0.6	1 000.1044	S	+1.4
7. 120 to 140	July 6	9.4	S	440	25.24	3	FR	P	L	999.9211	−0.5			
	July 6	10.0	N	438	26.18	4	FR	P	L	.9202	+0.4	999.9206	I	
	July 6	9.3	S	403	15.58	1.5	F	FD		.9186	−1.2			
	July 6	9.9	N	406	15.30	1.0	RF	FD		.9162	+1.2	999.9174	S	+3.2
8. 140 to 160	July 6	8.8	S	440	25.14	3	RF	P	L	1 000.1621	0.0			
	July 6	10.3	N	438	26.83	3	FR	P	L	.1622	−0.1	1 000.1621	I	
	July 6	8.9	S	403	15.64	2.3	RF	FD		.1617	−1.6			
	July 6	10.3	N	406	15.19	2.2	F	FD		.1586	+1.5	1 000.1601	S	+2.0
9. 160 to 180	July 6	8.4	S	440	23.64	4	RF	P	L	999.9968	−0.5			
	July 6	10.7	N	438	26.77	2	FR	P	L	.9959	+0.4	999.9963	I	
	July 6	8.5	S	403	15.86	2.8	FR	FD		.9934	−0.7			
	July 6	10.7	N	406	13.97	2.0	RF	FD		.9920	+0.7	999.9927	S	+3.6
10. 180 to 192	July 10	2.6	S	440	32.10	5	R	F		599.9798	−0.6			
	July 6	8.0	S	440	21.84	3	RF	P	L	.9792	0.0			
	July 6	11.1	N	438	27.04	3	FR	P	L	.9934	Rejected.			
	July 10	2.2	N	438	33.44	6	F	F		.9786	+0.6	599.9792	I	
	July 6	8.4	S	403	16.54	3.5	F	FD		.9813	−1.6			
	July 6	11.2	N	406	13.48	2.4	RF	FD		.9780	+1.7	599.9797	S	−0.5
11. 192 to N. B.	July 6	8.0	S	440	21.00	...	..	P	L	37.0182	+0.1			
	July 6	11.3	N	438	26.44	...	R	P	L	.0184	−0.1	37.0183	I	
	July 6	8.1	S	403	18.10	0.4	F	FD		.0187	−0.3			
	July 6	11.4	N	406	14.26	...	...	FD		.0181	+0.3	37.0184	S	−0.1

	mm.
Probable error of measurement:	
Steel tapes	±2.72
Invar tapes	±3.36
Probable error due to probable errors of coefficients of expansion:	
Steel tapes	±2.66
Invar tapes	±0.50
Probable error due to measurement and coefficients:	
Steel tapes	±3.80
Invar tapes	±3.40
Weighted mean of steel and invar	±2.60
Probable error due to probable error of comparators	±1.93
Adopted probable error	±3.24
	or one part in 2 980 000

Length of Royalton Base:	meters
Steel tapes, weight 1	9 637.5375
Invar tapes, weight 2	9 637.5574
Weighted mean	9 637.5508
	±32
And its logarithm	3.9839667
	±1

SUMMARY OF RESULTS.

The following table gives the lengths of the six bases, together with their probable errors and logarithms.

Base	Length		Probable error	
	meters	logarithm	mm.	
Point Isabel	7 384.9220	3.8683459 ±2	±3.02	or 1 part in 2 450 000
Willamette	14 019.3781	4.1467287 ±1	4.09	3 430 000
Tacoma	12 055.5701	4.0811877 ±2	3.99	3 020 000
Stephen	9 221.8333	3.9648173 ±2	4.25	2 170 000
Brown Valley	8 223.5695	3.9150604 ±1	2.83	2 910 000
Royalton	9 637.5508	3.9839667 ±1	3.24	2 980 000
Average	10 090			1 part in 2 760 000
Total	60 543			

These small probable errors were obtained without any additional expenditure of money than would have been necessary to obtain merely a probable error of one part in 500 000, by a double measure with each kind of tape, as required by the instructions.

The following table gives the probable error of the lengths of the bases from the steel and invar tapes independently, thus affording a means of comparing them more readily.

In determining the probable error of the length of a base line in the preceding computations, the probable error due to the probable error of the comparator was applied after the results from the two kinds of tapes had been combined. It is here applied to the results obtained for each kind of tape independently. The quantities in columns 2 and 3 were collected from preceding pages. The probable error of the comparator was considered the same for both kinds of tapes. Each quantity in the fourth column is the square root of the sum of the squares of the corresponding quantities in the two preceding columns, and shows the probable error of the length of the base as determined with steel and invar tapes separately.

Probable errors for measures with invar tapes.

Base	Partial	Due to comparator	Combined	
	mm.	*mm.*	*mm.*	
Point Isabel	±2.83	±1.48	±3.19 or 1 part in	2 310 000
Willamette	±3.13	±2.80	±4.20	3 340 000
Tacoma	±3.25	±2.41	±4.05	2 980 000
Stephen	±4.12	±1.84	±4.51	2 040 000
Brown Valley	±2.06	±1.64	±2.64	3 110 000
Royalton	±3.40	±1.93	±3.91	2 460 000
			Mean, 1 part in	2 630 000

Probable errors for measures with steel tapes.

Base	Partial	Due to comparator	Combined	
	mm.	*mm.*	*mm.*	
Point Isabel	±5.49	±1.48	±5.68 or 1 part in	1 300 000
Willamette	±7.59	±2.80	±8.09	1 730 000
Tacoma	±6.98	±2.41	±7.39	1 630 000
Stephen	±7.99	±1.84	±8.20	1 120 000
Brown Valley	±5.55	±1.64	±5.79	1 420 000
Royalton	±3.80	±1.93	±4.27	2 260 000
			Mean, 1 part in	1 500 000

The measurements with invar tapes are uniformly better than those with the steel, the probable errors of the former being about one-half those of the latter, except on the Royalton Base. Here measurements with steel tapes are exceptionally accordant, probably due to favorable and constant weather conditions.

These probable errors for the measurements with steel tapes agree very well with those obtained in 1900,* hence the probable errors for the six bases measured with the invar tapes are directly comparable with previous tape measurements.

The change from steel tapes to invar tapes is certainly accompanied by an increase in accuracy.

Point Isabel Base controls the lengths at the southern end of the triangulation along the ninety-eighth meridian, and may be used to control the extension of this triangulation into Mexico by that Republic.

Willamette and Tacoma bases and the Yolo Base of the 39th parallel triangulation control the lengths of the Pacific Coast triangulation from the middle of California to Puget Sound, a distance of about 600 miles.

Stephen and Brown Valley bases control the lengths of the lines on the north end of the ninety-eighth meridian triangulation for about 350 miles.

Royalton Base controls the lengths in one-half of the triangulation between the ninety-eighth meridian triangulation and the triangulation of the Great Lakes, near Duluth, a distance of about 300 miles.

*See page 285, Appendix 3 of the Report for 1901, Nine Bases along the Ninety-eighth Meridian.

The following table shows the actual discrepancy between the measurements with invar and steel tapes of the six bases.

Base	Discrepancy, invar minus steel	
Point Isabel	+16.5 millimeters or 1 part in	448 000
Willamette	+22.4	626 000
Tacoma	+40.8	295 000
Stephen	−19.3	478 000
Brown Valley	+ 0.2	41 000 000
Royalton	+19.9	484 000
	Average, 1 part in	526 000

When compared with other instances where two forms of apparatus have been used on the measurement of a base these results are very gratifying. In the work of 1900 the duplex apparatus gave results differing from those with the tapes by one part in 175 000,* whereas the results with these two forms of tapes differ only one part in 527 000 on an average, the greatest difference being but little more than one-half of the average for the work of 1900. There have been few, if any, instances where measures with two forms of base apparatus have shown any better agreement than that between the duplex apparatus and steel tapes obtained in 1900.

The fact that the discrepancy between the measurements with invar and steel tapes is of the same sign on five of the six bases seems to indicate a constant difference between measures with the two metals. The discrepancy on the Stephen Base, where the sign is opposite, should be omitted from this discussion, as the local conditions (such as wind, rain, and faulty tension) probably caused this reversal of sign. If this discrepancy be considered as due to errors of temperature, it would require a constant error of 5° on the measures with invar tapes, or 0°.17 on the measures with steel tapes, to account for it. The temperatures obtained for invar tapes may be in error a degree, but are certainly not in error as much as 5°. An error of 0°.17 in determining the temperature of the steel tapes, however, either in the standardization or on the measures or on both, is not only possible but probable.

These discrepancies may also be due, either partly or entirely, to the effect of wind on the tapes. The invar tapes are more sensitive to the wind than the steel, as the wide surface of the invar tapes was inclined to the horizontal plane to some extent. The invar tapes were standardized where there was no wind effect. As there was always more or less wind during the measures it may have had more effect than was apparent at that time. Although few tape lengths were marked when any wind effect on the length of the tape was noticeable, still it was probably not entirely eliminated. Any error from this source is probably cumulative.

Although the discrepancies between the measurements with the invar and steel tapes are small enough to be due to any one of the above causes, namely, errors in determination of the temperatures of the tapes, wind effects, errors due to moisture on the thermometers, or others, they are probably the result of a combination of all.

*See page 301, Appendix 3 of the Report for 1901, Nine Bases along the Ninety-eighth Meridian.

COST OF BASE MEASUREMENT.

The cost incurred in all the field operations in the measurement of the six base lines was $6 025. This includes all field expenses of the party, all transportation for party and outfit, beginning and ending in Washington, D. C., all field standardization, and salaries of officers. It does not include the cost of the triangulation executed by this party at Point Isabel, which was estimated as $700.

Owing to the great distances traveled on this work, the expenses for transportation were about one-fourth of this total cost, practically the same in proportion as that obtained on measurement of 1900, notwithstanding the fact that only three men traveled from the East to the Pacific coast and one from the Pacific coast to Washington, D. C. The entire party was transported between the Willamette and Tacoma bases and between the Stephen, Brown Valley, and Royalton bases, but nowhere else.

The costs of the February and October standardizations at the Bureau of Standards were about $300 and $175, respectively. The cost for standardization was large, owing to the extra work needed to study the properties of the invar tapes, as well as results obtained in the new comparator tunnel.

The cost of the office computations and preparing the results for printing was $474. The total cost of the bases was, therefore, $6 974.

The number of kilometers measured during the season was 60.54, hence the cost per kilometer was $115, which is less than three-fourths of the cost per kilometer for the work of 1900. One important item of economy of this work over the work of 1900 is shown in the cost of the office computations, that for 1906 being only about one-third of the cost for 1900.

If the invar tapes only had been taken into the field and all field standardization omitted, the cost per kilometer would have been about $94, as nearly as it can be estimated. This is but little more than one half the cost of the work of 1900, where nearly one-third of the measurements was made with bar apparatus.

The cost of preparing the bases for measurement may be obtained from the last three bases with considerable accuracy, as this part of the work was executed by certain men who did nothing else. The first three bases could not be considered in this manner, as they were prepared by the measuring party.

The preparation of the last three bases was begun by five men on the 10th of June and ended on the 30th. As the actual cost of the various parts of this preparation may be interesting, the following table is appended:

Labor and subsistence	$328.60
Traveling expense	89.50
Lumber for posts and signals	162.40
Team hire for transporting party, etc	50.00
Incidentals	20.00
Total cost for preparing 27.08 kilometers	650.50
Cost per kilometer	24.00

All the expenses of this party, from the time it left the triangulation work until the completion of the preparation of the three bases, are included in this total. The erection of signal poles at the base terminals was required at only one of these bases.

The speed of setting posts for tape supports varies with the character of the soil and the topography of the base. On this season's work a party of five usually set posts at the rate of from 3 to 4 kilometers a day.

SPEED ATTAINED.

The following tables show the speed attained on the various bases, and also the actual time spent on the measures. The time given includes all operations from the beginning of the measure to the end, but does not include the time required to get the tapes ready for the work. The copper marking strips were usually nailed to the tops of the posts as the first measure was being made. This delayed the regular work by about five minutes per kilometer; hence, as the first measurement was usually made with the invar tapes, the rate per kilometer for the invar tapes as shown in the last column has been increased on this account, the time intervals shown in the third column not having been reduced.

Speed with invar tapes.

Date		Base	Time *	Distance.	Kilometers per hour *	Mean, kilometers per hour * on each base	Mean, kilometers per hour, for measurement only, on each base
			Hours	*Km.*			
Mar.	28	Point Isabel	3.08	4.40	1.43		
	31		3.88	8.00	2.06		
Apr.	6		1.42	3.00	2.12	1.84	1.97
May	5	Willamette	2.50	4.00	1.60		
	7		3.42	6.00	1.76		
	9		2.87	6.00	2.09		
	10		3.00	6.00	2.00		
	12		2.33	6.00	2.57	1.99	2.19
May	28	Tacoma	2.75	6.00	2.19		
June	1		2.53	6.00	2.37		
	2		2.77	6.00	2.17		
	5		2.87	6.00	2.09	2.19	2.41
June	19	Stephen	5.55	12.00	2.16		
	22		3.00	6.45	2.15	2.16	2.23
June	26	Brown Valley	5.58	11.15	1.99		
	27		2.53	5.30	2.09	2.04	2.24
July	5	Royalton	2.50	6.00	2.40		
	6		3.00	7.25	2.45		
	7		2.55	6.00	2.35		
	10		0.53	1.20	2.25	2.38	2.62
			Means		2.10	2.10	2.28

Speed with steel tapes.

Date		Base	Time *	Distance.	Kilometers per hour *	Mean, kilometers per hour * on each base	Mean, kilometers per hour, for measurement only, on each base
Mar.	28	Point Isabel	3.17	5.40	1.71		
	29		2.67	4.00	1.50		
	31		3.33	6.00	1.80		1.68

* The time required to nail on the copper strips is included for some of the sections in these three columns.

Speed with steel tapes—Continued.

Date		Base	Time	Distance	Kilometers per hour	Mean, kilometers per hour on each base	Mean, kilometers per hour, for measurement only, on each base
			Hours	*Km.*			
May	5	Willamette	2.08	4.00	1.92		
	7		3.38	6.00	1.77		
	9		2.85	6.00	2.10		
	10		2.50	6.00	2.39		
	11		3.22	6.00	1.87		2.15
May	28	Tacoma	2.92	6.00	2.06		
June	2		2.78	6.00	2.16		
	4		1.53	4.00	2.61		
	6		1.75	4.00	2.29		
	7		1.70	4.00	2.35		2.25
June	16	Stephen	2.42	5.00	1.91		
	18		3.92	7.45	1.90		
	22		3.20	8.00	2.50		2.14
June	27	Brown Valley	2.42	5.30	2.19		
	29		2.68	5.15	1.92		
	30		2.60	6.00	2.31		2.14
July	5	Royalton	2.53	6.00	2.37		
	6		3.07	7.25	2.36		
	7		2.45	6.00	2.45		2.39
			Means		2.12		2.12

These tables show the effect of experience in observers and other members of the party very effectually. Point Isabel Base was measured with inexperienced men. On the Willamette Base the observers only had had experience and they merely on one base. Tacoma Base may be considered as measured with experienced men. At Stephen, again, a new party had to be trained. The new observer had, however, had considerable work of exactly this character several years before, hence required very little practice to become proficient again.

This party, with the same two observers, continued for three bases and on the last base made the greatest average speed attained. The speed depends almost entirely upon the experience of the observers, rather than the remainder of the party, as is shown very clearly in these tables. The means at the bottom of these tables show that the speed attained with the invar tapes is 1.08 times as great as that with the steel tapes. This gain in speed was due almost entirely to the greater convenience of working in daylight.

ERRORS OF TAPE MEASURES.

The errors affecting measurements with tapes have been fully treated in Appendix 8 of the Coast and Geodetic Survey Report for 1892, Part 2, and in Appendix 3 of the Coast and Geodetic Survey Report for 1901, pages 295–300. The errors in grade corrections and reductions to sea level are small and practically of the compensating class, hence do not affect the length of a base materially. The effects of errors of alignment are negligible, an error of a decimeter in a single tape length being necessary to produce a change in length of a tenth of a millimeter. An error of one centimeter in alignment in a tape length of 50 meters would cause a change in length of only 0.001 millimeter, or, if every tape length in the kilometer were out of parallelism a centimeter, the effect would be merely 0.02 millimeter on a kilometer. As the aligning was done with a good theodolite using short sights, there was probably no tape length in which the lack of parallelism to the base exceeded a centimeter, hence the error of alignment is probably much less than 0.02 millimeter per kilometer.

The errors due to observation are more or less compensating and are developed to some extent in the results of the different measures of each section.

The effects of errors of tension are neither well known nor as well compensated as could be desired. It is very difficult to hold the exact tension on the balance long enough to make an accurate marking of the tape length. Another source of error with the form of balance used is the change in the strength of the spring, or a shifting of the index hand on its pivot. The latter can usually be detected by holding the balance up by its own hook and noting the reading of the hand. This was done frequently during the measures and especially after the balance happened to receive a sudden jerk from any cause. Two balances were kept as standards, and the working balances compared with them almost every day. That reading on the balance which corresponded to an actual tension of 15 kilograms was always used in the measures. Changes of 10 grams to 25 grams in the reading of the balance for a 15-kilogram tension were discovered several times. A few instances occurred where a shifting of the hand was noted and the measures corrected accordingly. Occasionally a complete revolution of the hand, or 5 kilograms, occurred without being detected on the balance by the tape stretcher, recorder, or forward observer. The last could not tell very well, even by lifting the tape at the support, whether the tension was 10 or 15 kilograms, the position of the line on the spring bar not being easily seen, as it was almost 1½ meters from the graduation mark on the tape. A steel and an invar tape were tested in the field for a change in tension from 15 to 10 kilograms. The invar tape showed a change of 9.5 millimeters, and the steel tape, 7.7 millimeters. These values were used for corrections wherever an error of 5 kilograms in tension was discovered. There may be a few of these errors uncorrected yet, as there were several sections where the difference between the measures indicated some such error. No time was taken to try to locate them by investigating the copper strips, as the errors were not large enough to be of serious consequence, and the instructions to the party would not warrant any delay for such investigations nor permit a remeasure.

The effect of small errors in the tension may be seen by taking the values found by experiment at the Bureau of Standards for invar tapes Nos. 437 and 438. A change in tension of 25 grams caused a change in length of 0.04 millimeter for a tape length, or 0.8 millimeter per kilometer. As this is of a compensating character to a great extent, and the errors of tension are not often as large as 25 grams, this source of error can not affect the length of a base very materially.

Another source of small errors was the marking awl used on part of the work, particularly on the Tacoma and Stephen Bases. The points would break very easily, and sometimes all of the awls had broken points before the completion of a day's measure. As it was not considered of sufficient consequence to warrant delaying the work to sharpen them, there are a few small errors on this account. They were rarely as great as a quarter millimeter per tape length, however, and were of a compensating character.

TEMPERATURE ERRORS.

The effect of errors in determining the true temperature of the tapes is probably not very great. The range of temperature during the measurement of a section with steel tapes was small. The thermometers probably indicated the actual temperature of the tape very closely. On a large portion of the measures with steel tapes the atmosphere was so damp that moisture collected on the thermometers, and may have caused them to indicate erroneous temperatures. An inspection of the residuals of the various measures of such sections did not reveal any appreciable error from this source, at least nothing certainly distinguishable from other errors.

The temperatures obtained for the invar tapes are undoubtedly erroneous to a small extent, but the coefficient of expansion is so small that an error of a degree in temperature causes an error of only 0.4 millimeter in the length of a kilometer, or one part in 2 500 000. With the thermometers on the top of the invar tape, the temperature of the tape is probably obtained within a degree. On Point Isabel Base and part of the Willamette Base a thermometer was fastened to the bottom of the invar tapes (outside of the graduation marks) and read at the same time the others were read. This thermometer indicated a lower temperature, by about a degree, than the others, as it was shaded by its metal back, as well as by the tape. If this lower temperature were used, it would make the lengths of the bases greater, thus increasing the discrepancy between the measurements with the invar and steel tapes, except on one base where other conditions have produced a difference in the opposite direction.

This apparently shows that the thermometers on top of the tapes indicate too low a temperature for the invar tapes rather than too high.

CONCLUSIONS.

The following are a few conclusions which have been deduced from the season's work with these invar tapes.

The invar tapes may be handled and manipulated in identically the same manner as steel tapes. A little caution is necessary, of course, to prevent giving them small bends, at least to a radius of less than 8 inches, but this causes no material delay.

All measurements with invar tapes may be made during daylight, but measurements with steel tapes must be made at night in order to secure the desired accuracy. In daylight work the errors of observation are smaller, the tapes can be watched more carefully and kept clear of obstructions and moisture, greater accuracy is possible since the party can work more comfortably when each member can see what he is doing, and more speed may be obtained as the party can see to work and travel without bothering with lights.

Any error due to the failure of the thermometers to indicate the temperature of the tapes is probably much less for measures with invar tapes than with steel, as an error of $2^{\circ}.8$ is necessary to produce as large an error in measures with these invar tapes as an error of $0^{\circ}.1$ will produce in measures with steel tapes. This effect is probably not more than three or four times as great in daylight as at night; hence the temperature errors from this source are probably eight or ten times as great for the measures with steel tapes as for those with invar tapes.

The cost for the measures with invar tapes is very materially less than for the measures with steel tapes, as it is not necessary to standardize the invar tapes in the field, and consequently the heavy iced-bar apparatus is not needed. Standardization at the Bureau of Standards is cheaper than in the field, since the comparator is already prepared and a smaller party is required for the work.

The fact that the tapes may be standardized by different observers from those who make the field measures is probably of very little consequence, as in the standardization all pointings are made with microscopes, and in the base measurement, ordinarily, no magnifying power is used. Consequently, there is likely to be as much of a personal equation between the work of standardization and the field measures whether the two operations are performed by the same observers or by different ones.

The work of 1900 proved that measures with steel tapes at night were as accurate as measures with bar apparatus and very much more economical. This season's work has shown that measures with invar tapes in daylight are decidedly more accurate and economical than with steel tapes.

In the future a base line may be introduced into a triangulation scheme with very little increase in expense or delay to the triangulation. Invar tapes may be standardized at the Bureau of Standards and sent to the triangulation party when required. This party is usually capable of making the measures without additional help, the work of the triangulation being interrupted merely long enough for the measurement when the base line is reached. No travel would be required in this case, and the actual cost of the base may be reduced to $75 per kilometer, or even less. The length would then be available for the computations as soon as the angle measures were obtained.

APPENDIX 5

REPORT 1907

RESULTS OF MAGNETIC OBSERVATIONS MADE BY THE COAST AND GEODETIC SURVEY BETWEEN JULY 1, 1906, AND JUNE 30, 1907

By

R. L. FARIS

Inspector of Magnetic Work and Chief of Division of Terrestrial Magnetism,
Assistant, Coast and Geodetic Survey

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RESULTS OF MAGNETIC OBSERVATIONS MADE BY THE COAST AND GEODETIC SURVEY BETWEEN JULY 1, 1906, AND JUNE 30, 1907.

By R. L. FARIS,

Inspector of Magnetic Work and Chief of Division of Terrestrial Magnetism, Assistant, Coast and Geodetic Survey.

INTRODUCTION.

The present publication contains the results of magnetic observations made on land and at sea by officers of the Coast and Geodetic Survey in the prosecution of the magnetic survey of the United States and outlying territories, during the period July 1, 1906, to June 30, 1907.*

Five magnetic observatories † have been in continuous operation throughout the year: At Cheltenham, Md.; Baldwin, Kans.; Sitka, Alaska; near Honolulu, Hawaii; and on Vieques Island, Porto Rico. In April, 1907, the instruments at Vieques were moved from old Fort Isabel, where observations had been made since February, 1903, and installed in a building especially constructed for use as a magnetic observatory, about half a mile west of the fort. There will be found in the tables the values of the magnetic elements at each of the observatories, as based on the observations of December and January.

OBSERVATIONS ON LAND AND THEIR DISTRIBUTION.

The distribution of the stations on land is shown in the following table, from which it will be seen that the work of the year, though distributed over 37 States and Territories, was principally in the West and Northwest, in regions where comparatively few observations had been made previously. The difficulties of travel and transportation in those regions are largely responsible for the fact that the number of stations occupied during the year was smaller than usual. "Repeat" observations were made at 78 places distributed over the whole country, in order to follow as closely as possible the

* For previous results see: United States Magnetic Declination Tables and Isogonic Charts for 1902; Appendix 1, Report for 1897; Appendix 6, Report for 1902; Appendix 5, Report for 1903; Appendix 3, Report for 1904; Appendix 3, Report for 1905; Appendix 3, Report for 1906.

† For description of observatories see Appendix 5, Report for 1902.

secular change of the magnetic elements. Unfortunately, it happens in many cases that the old station can not be reoccupied for one reason or another.

Summary of results on land.

State	Number of localities	Number of stations	Old localities reoccupied	Declinations observed	Dips observed	Intensities observed
Alabama	3	3	2	3	3	3
Alaska	9	10	2	11	4	5
California	10	10	3	10	10	10
Colorado	21	21	2	21	21	21
Connecticut	1	1	0	1	1	1
District of Columbia	1	1	1	1	1	1
Florida	1	1	0	1	1	1
Hawaii	1	1	1	1	1	1
Idaho	8	8	1	8	8	8
Indiana	5	5	1	5	5	5
Indian Territory	1	1	0	1	1	1
Kansas	5	5	4	9	8	9
Maine	2	2	2	3	3	3
Maryland	2	3	2	9	6	9
Massachusetts	3	3	2	3	3	3
Michigan	3	3	1	3	3	3
Minnesota	2	2	1	2	2	2
Missouri	2	2	2	2	2	2
Montana	28	30	6	30	30	30
Nebraska	4	4	2	4	4	4
Nevada	2	2	1	2	2	2
New York	2	2	1	2	2	2
North Carolina	9	10	9	10	10	11
North Dakota	17	18	3	18	18	18
Ohio	5	5	4	5	5	5
Oklahoma	2	2	1	2	2	2
Oregon	28	28	3	28	28	28
Pennsylvania	2	3	2	3	3	2
Porto Rico	2	9	2	10	3	3
Rhode Island	1	1	1	1	1	1
South Dakota	22	23	4	23	23	23
Tennessee	3	4	1	5	5	5
Texas	2	2	0	2	2	2
Utah	11	11	1	11	11	11
Virginia	11	12	6	12	11	12
Washington	4	4	2	4	4	4
Wyoming	19	19	2	19	19	19
Total	254	271	78	285	266	272

OBSERVATIONS AT SEA AND THEIR DISTRIBUTION.

Magnetic observations have been made at sea as often as the regular surveying duties of the ships of the Bureau would permit. Observations were made by the *Bache* during her cruises from Norfolk, Va., to Maine and return, and from Norfolk to Porto Rico and return; by the *Explorer* on her cruises from Norfolk to Massachusetts and return, and from the Atlantic to the Pacific coasts by way of the Straits of Magellan; and by the *Patterson* between Seattle, Wash., and Kodiak, Alaska. The work of the *Explorer* is especially worthy of note. She left Norfolk, Va., in February and was at Magdalena Bay, Mexico, at the close of the fiscal year. During practically all this time she encountered very favorable weather conditions, and as a result it was possible to make a very full series of magnetic observations. Shore observations were made at 12 places, at most of which observations had been made before, thus furnishing valuable secular variation data. At sea observations of the three elements were made during 29 complete swings of the ship with both port and starboard helms, and numerous additional observations were secured on the course and two points either side of the course. The records of these observations were not received in time to include the results in this Appendix. The results of observations at sea which are published herewith are distributed as follows:

Summary of results at sea.

Vessel	General region	Results from swings			Result from observations on 3 headings		
		Declination	Dip	Intensity	Declination	Dip	Intensity
Bache	Atlantic Ocean	18	17	17	1	1	1
Explorer	Atlantic Ocean	9	8	7	1	1	1
Patterson	Pacific Ocean	7	8	8	0	0	0
Total		34	33	32	2	2	2

GENERAL METHODS OF OBSERVING.

LAND WORK.

The methods of observing have been the same as those described in previous publications. Observers engaged exclusively in magnetic work are supplied with a complete outfit, consisting of theodolite magnetometer, dip circle, half-second pocket chronometer, observing tent, and small accessories, while those who are expected to get magnetic results incidental to other work are supplied with more or less complete outfits, according to circumstances. Where only declination results can be secured under the conditions involved, a compass declinometer is supplied; but to those who can attempt more, a dip circle with compass attachment is furnished, with which compact outfit, knowing the azimuth of some reference mark from triangulation or other source, the declination, dip, and total intensity (Lloyd's method) can be obtained with a very fair degree of accuracy.

SEA WORK.

The *Bache*, *Explorer* and *Patterson* are each provided with a Lloyd-Creak dip circle and accompanying gimbal stand, by means of which dip and total intensity can be determined on board ship. Observations for declination (or "variation") are made with the usual standard liquid compass and an azimuth circle of the Ritchie or Negus pattern. Each value of declination, dip, or intensity usually depends upon the mean of observations made on 8 or 16 equidistant headings while steaming in a circle, once with port and once with starboard helm. In some cases, however, observations were made on three headings, namely, on the course, one or two points to starboard of the course, then a like amount to port, and finally on the course again.

In the report for 1905 attention was called to the fact that the Lloyd-Creak dip circle, as originally constructed, could not be used to determine the total intensity in low magnetic latitudes. The experience on the Carnegie Institution magnetic survey vessel, the *Galilee*, with dip circle No. 35, which was modified last year, proved so satisfactory that the dip circles of the *Explorer* and *Patterson* were this year modified in the same manner, except that no astronomic telescope was added. (See Appendix 3, for 1906, page 112.) In the case of the *Explorer* this was necessary, as on her cruise from the Atlantic to the Pacific coast she crossed the magnetic equator twice. She was also provided with a magnetometer so that the intensity constant of the dip circle could be determined at each place where shore observations were made.

ACCURACY OF RESULTS.

The endeavor in general is to secure, on land, declination and dip observations whose absolute error (including everything involved—error of observation and reduction) shall not exceed 2′, and to determine the horizontal intensity within 1 part in 1 000. As stated in previous reports, the experience of the Coast and Geodetic Survey has been that, under all of the conditions involved in a campaign of field work covering a large area, including the standardization of instruments and the determination of reduction errors, this accuracy can not be much increased. In observatory work with special instruments, or when special investigations are made under the best conditions by special observers, there is no difficulty of reducing these limits of error; but in a large organization, where results must be secured from all kinds of observers, under all conditions, and at times under great physical difficulties, and when all sources of error are considered, the degree of accuracy stated must be regarded as satisfactory and sufficient. It happens, of course, that these limits, for one reason or another, are occasionally exceeded, and there may be a few isolated cases in which the errors are two or three times the amounts given.

COMPARISON OF INSTRUMENTS.

Comparisons of field instruments with the standard instruments of the Cheltenham Observatory have been made when conditions demanded it or opportunity offered. In order to compare the magnetic instruments of the Cheltenham and Mount Weather Observatories, observations were made at Cheltenham with a set of portable instruments from the Mount Weather Observatory and at Mount Weather with a magnetometer which had been in use at Cheltenham. At Sitka a full set of observations was made to restandardize the instruments which had been used by Captain Amundsen for his observations in the vicinity of the magnetic north pole. Some comparisons were also made at Baldwin Observatory.

But few changes were required in the instrumental corrections used last year. The various dip circles used and the corrections which have been applied to the results by each are given in the following table. The figures after the decimal point in the fourth column indicate, as in the past, the particular needles to which the correction applies.

Corrections to dip circles.

Number	Pattern	Needles	Designation	Correction
				′
1	Wild-Eschenhagen	Earth Inductor	1. EI	0.0
18	Kew-Casella	5 and 6	18.56	−1.6
22	Wild-Edelmann	Earth Inductor	22. EI	−0.2
23	Kew-Casella	2C and 2D	23.22	−2.3
23	Do.	2C, 2D, and 3	23. III	−1.5
25	Tesdorpf	IV and VIII	25.48	−3.6
28	L. C.-Casella	1 and 2	28.12	−2.0
30	Kew-Dover	1 and 2	30.12	+1.0
31	Do.	1 and 2	31.12	+2.1
31	Do.	3 and 4	31.34	+0.4
32	L. C.-Dover	2	32.2	+0.5
32	Do.	1 and 2	32.12	−2.3
33	Do.	1 and 2	33.12	−4.0
34	Do.	1 and 2	34.12	−1.9
34	Do.	5 and 6	34.56	−9.8
36	Kew-Dover	1 and 2	36.12	−1.0
37	Do.	1 and 2	37.12	−0.6
4655	Kew-Casella	3 and 4	55.34	0.0
56	Do.	1 and 3	56.13	0.0

The corrections to reduce the horizontal intensity results to standard are as follows:

Magnetometer	Correction
No. 10	+.004 H
No. 17	+.002 H
No. 20	+.002 H
No. 22	+.002 H
No. 36	+.001 H
No. 37	+.0025 H
No. 1 C. I.	+.002 H

The correction to Magnetometer No. 22, the Honolulu Observatory instrument, was assigned as the result of comparison with four different magnetometers with which observations had also been made at Cheltenham. The values of H determined with this instrument, heretofore published, should be increased accordingly. Magnetometer No. 36 was overhauled in January, 1907, and some of the fittings of the long magnet had to be renewed, hence the change in the correction. The correction for No. 17 should be applied to the results of observations with that magnetometer, published in Appendix 3 for 1906.

Index corrections have been applied to declination results obtained with compass declinometer or compass needle. In addition the results with several magnetometers have been corrected by small amounts, as the result of careful comparison with standard instruments.

Magnetometer	Correction to west declination
	′
No. 10 in 1906	+2.5
No. 29	−1.5
No. 1 (Carnegie Institution)	+2.0

REDUCTION OF THE OBSERVATIONS.

A first computation is made by the observer in the field, and he is instructed to carry it far enough before he leaves a station to assure himself that the desired degree of accuracy has been attained. This computation is carefully revised in the Office, in the Division of Terrestrial Magnetism, and the necessary corrections are applied to reduce the results to the standard instruments, as indicated in the foregoing section.

Each value of the magnetic declination is then corrected to reduce it to the mean of the particular month in which the observation was made, with the aid of the continuous observations at the nearest magnetic observatory, allowance being made for the change in diurnal variation, with change in magnetic latitude. No attempt has been made to correct the dip and horizontal intensity for diurnal variation.

ARRANGEMENT OF TABLES.

LAND OBSERVATIONS.

The values of declination, dip, and horizontal intensity presented in Table I are arranged by States alphabetically, the results for each State being given in the order of increasing latitudes. The latitudes and longitudes are in most cases the result of solar observations made with the small theodolite which forms a part of the magnetometer. In default of observations the geographic coordinates were scaled from the best available map, either the United States Geological Survey topographic sheets, a Post Route map, or a Rand & McNally State map. In such cases only the nearest whole minute of latitude and longitude is given. The horizontal intensity is expressed as heretofore in terms of the one hundred thousandth part of a C. G. S. unit of intensity of magnetic force, termed a *gamma*, and designated by the letter γ.

In order to include the desired amount of information in the available space the following abbreviations were adopted. Only the month and day of the date are given, since the observations were all made between July 1, 1906, and June 30, 1907, except when otherwise stated in footnote. The names of the months have been abbreviated, as follows:

January	Ja	May	My	September	Se
February	Fe	June	Je	October	Oc
March	Mh	July	Jy	November	No
April	Ap	August	Au	December	De

In the column headed "Instruments" M stands for "magnetometer" and D. C. for "dip circle." Italicised numbers in the magnetometer column indicate that the declination was determined with a compass declinometer of the number given. When the declination was determined with the compass attachment of the dip circle the letter C is placed in the magnetometer column. The dip circles have been given the designations indicated on page 163, the figures after the decimal point denoting the needles used. Values of horizontal intensity printed in italics were obtained by combining the observed dip with the total intensity determined by Lloyd's method.

The observer is indicated by the initials of his name. The names of the observers are as follows:

B. A. Baird	J. W. Green	S. D. Sarason
J. E. Burbank	N. H. Heck	J. H. Simpson
W. H. Burger	W. M. Hill	D. C. Sowers
C. C. Craft	W. B. Keeling	W. M. Steirnagle
S. A. Deel	C. Methven	C. C. Stewart
H. M. W. Edmonds	F. A. Molby	W. F. Wallis
H. W. Fisk	R. S. Patton	P. C. Whitney
J. A. Fleming	F. W. Reed	C. F. Woodyard

Sea Observations.

The results obtained at sea are presented in Table II. The general arrangement is indicated by the headings. Unless otherwise indicated the ship was swung with both port and starboard helms. In the column headed "Sea," sm means smooth; sw, swell; lt, light; hvy, heavy; mod, moderate. The names of the ships taking part in the work and their commanding officers are as follows:

Bache	P. A. Welker and F. B. Loren
Explorer	W. C. Dibrell
Patterson	W. C. Hodgkins

Table I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907.*

ALABAMA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		East ° ′	° ′	γ			
Fort Morgan	30 13.7	88 00.9	Ja 17, 18	4 38.9	60 54.1	26963	29	30.12	CM
Maplesville	32 47.8	86 53.2	Ja 12, 13	2 45.2	64 04.8	25141	29	30.12	CM
Huntsville	34 44.2	86 34.8	De 31, Ja 1	3 57.3	66 16.9	23490	29	30.12	CM

ALASKA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		East ° ′	° ′	γ			
Tongass Narrows	55 20.0	131 38.8	Oc 26	28 46.9	-- ----	-----	744	-----	RSP
Miller Island	56 57.5	154 07.3	Au 30	23 06.0	71 03.9	18010	8	32.2	PCW
Snug Harbor	56 59.7	154 09.4	Je 28*	23 01.4	-- ----	17997	8	-----	WMS
Sitka Magnetic Observatory	57 02.9	135 20.2	De-Ja	30 05.0	74 41.0	15520	25	25.48	HMWE
Slocum Arm	57 32.9	136 02.5	Se 14	30 11.9	-- ----	-----	744	-----	BAB
Khaz Bay	57 34.2	136 05.3	Se 18	30 47.6	-- ----	-----	744	-----	BAB
Kodiak	57 47.5	152 23.8	Se 3, 4	24 16.2	71 58.1	17342	8	32.2	WMS
Kodiak	57 47.5	152 23.8	Oc 26	24 10.4	71 57.9	17373	8	32.2	PCW
Port Chatham	59 13.5	151 45.2	Jy-Se	24 30.0	-- ----	-----	737	-----	SDS
Nuka Bay	59 32.5	150 40.1	Oc 15	26 02.6	-- ----	-----	737	-----	SDS
Wingham Island	59 59.1	144 22.7	Je 20*	28 52.0	-- ----	-----	737	-----	SDS

* Observations in June, 1906, not heretofore published.

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
CALIFORNIA.									
				East					
	° ′	° ′		° ′	° ′	γ			
Barstow	34 53.9	117 01.8	Jy 16, 17.	15 30.1	60 26.2	26411	17	28.12	SAD
Stockton	37 58.6	121 17.0	Jy 14	17 35.4	62 56.4	25100	17	28.12	SAD
Ukiah	39 08.0	123 12.5	Jy 10, 11	18 23.7	63 09.5	24579	17	28.12	SAD
Susanville	40 25.0	120 37.4	Se 21, 23	19 23.8	65 08.3	23511	11	23.III	WMH
Montgomery	40 50.2	121 55.6	Oc 6, 8	19 34.8	64 58.8	23764	11	23.III	WMH
Madeline	41 03.3	120 28.2	Se 25, 26	19 50.7	64 38.7	24271	11	23.III	WMH
Bieber	41 06.6	121 08.9	Oc 3, 4	18 41.4	65 46.5	23173	11	23.III	WMH
Bartle	41 14.8	121 48.6	Oc 11	20 28.4	65 11.3	23360	11	23.22	WMH
Alturas	41 27.8	120 30.3	Se 28, 29	19 01.0	65 49.7	23171	11	23.III	WMH
Yreka	41 43.9	122 37.8	Oc 13, 15	23 46.6	67 37.9	20780	11	23.III	WMH
COLORADO.									
				East					
	° ′	° ′		° ′	° ′	γ			
Pagosa Springs	37 14.6	107 00.6	Se 1	14 02.6	65 09.0	24262	17	28.12	CCS
Cortez	37 20.1	108 38.6	Au 29	14 19.0	64 51.8	24371	17	28.12	CCS
Walsenburg	37 36.2	104 48.4	Se 4	13 28.8	65 37.8	24134	17	28.12	CCS
Rico	37 42.2	107 59.4	Au 27	13 40.6	64 50.2	24687	17	28.12	CCS
Canon City	38 26.4	105 14.6	Se 6	14 03.1	66 12.7	23534	17	28.12	CCS
Delta	38 44.2	108 06.3	Au 25	14 38.0	66 07.3	23396	17	28.12	CCS
Buena Vista	38 48.2	106 08.0	Se 7	15 17.2	66 15.2	23888	17	28.12	CCS
Aspen	39 11.8	106 50	Se 21	14 49.2	66 26.8	23323	17	28.12	CCS
Glenwood Springs	39 32.0	107 20.2	Se 22	15 59.6	-- ----	23473	17	28.12	CCS
Red Cliff	39 34.0	106 20	Se 8	14 18.3	67 28.0	22527	17	28.12	CCS
Boulder	39 54.8	105 16	Oc 3	14 23.3	67 47.6	22387	17	28.12	CCS
Meeker	40 01.3	107 54	Se 19	15 30.3	67 28.5	22497	17	28.12	CCS
Wray	40 04.8	102 12.2	Jy 3, 4	12 52.5	68 16.3	22094	19	56.13	WBK
Sulphur Springs	40 04.8	106 06.2	Se 26	15 16.4	68 00.2	22078	17	28.12	CCS
Toponas	40 05.6	106 48	Se 10	14 37.3	67 33.0	22466	17	28.12	CCS
Greeley	40 28.3	104 40.9	Oc 1	14 04.9	68 24.4	21949	17	28.12	CCS
Steamboat Springs	40 30.6	106 50	Se 12	16 17.8	67 59.5	22210	17	28.12	CCS
Craig	40 31.4	107 31	Se 17	15 30.4	67 55.6	22242	17	28.12	CCS
Holyoke	40 34.6	102 16.7	Jy 6	13 36.2	69 07.4	21542	19	56.13	FAM
Fort Collins	40 38.2	105 06.6	Oc 2	15 05.2	68 40.0	21744	17	28.12	CCS
Hahns Peak	40 48.7	106 57	Se 13	15 44.6	68 10.8	22133	17	28.12	CCS
CONNECTICUT.									
				West					
	° ′	° ′		° ′	° ′	γ			
Stonington	41 19.8	71 55.8	De 5	10 50.2	72 35.8	18075	IIII	34.12	JHS
DISTRICT OF COLUMBIA.									
				West					
	° ′	° ′		° ′	° ′	γ			
Washington, station near Zoo Park	38 55.2	77 02.5	Oc 15–17	4 36.9	70 28.9	20032	1	36.12	CCC

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

FLORIDA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
St. Marks	30 09.0	84 12.5	Ja 21	2 47.0	61 25.6	26548	29	30. 12	CM

HAWAII TERRITORY.

	° ′	° ′		*East* ° ′	° ′	γ			
Honolulu Magnetic Observatory	21 19.2	158 03.8	De–Ja	9 22.4	40 00.5	29206	22	22EI	WFW

IDAHO.

	° ′	° ′		*East* ° ′	° ′	γ			
St. Anthony	43 58.0	111 43.4	Se 27	18 57.4	70 05.4	20347	1	36. 12	CCC
Challis	44 31.2	114 14.8	Se 24	19 17.0	70 12.5	20060	1	36. 12	CCC
Salmon	45 10.6	113 53.5	Se 21, 22	20 26.2	70 33.4	20022	1	36. 12	CCC
Grangeville	45 55.8	116 07.4	Se 25, 26	21 15.6	70 55.0	19880	1	36. 12	CCC
Lewiston	46 24.4	117 02.4	Au 18, 19	21 57.0	71 05.0	19441	1	36. 12	CCC
Pierce	46 29	115 47.8	Au 22	21 43.8	71 16.8	19230	1	36. 12	CCC
Harrison	47 27.1	116 47.4	Au 28, 29	22 32.8	72 22.8	18639	1	36. 12	CCC
Bonner's Ferry	48 41.6	116 18.6	Au 9, 10	23 24.5	73 03.1	17634	1	36. 12	CCC

INDIANA.

	° ′	° ′		*East* ° ′	° ′	γ			
Brookville	39 25.6	85 01.4	Je 24	1 47.6	70 36.3	20088	10	18. 56	CCC
Connersville	39 40.7	85 07.7	Je 25	2 01.3	70 55.9	19915	10	18. 56	CCC
Richmond	39 50.4	84 53.3	Je 28	1 36.2	71 07.0	19730	10	18. 56	CCC
Newcastle	39 57.9	85 22.2	Je 26	2 21.6	70 51.0	19991	10	18. 56	CCC
Winchester	40 09.8	84 57.5	Je 29	0 57.7	71 12.9	19544	10	18. 56	CCC

INDIAN TERRITORY.

	° ′	° ′		*East* ° ′	° ′	γ			
Carson	35 16.4	97 57.5	No 24, 25	9 57.3	64 51.9	24694	29	30. 12	CM

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

KANSAS.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		East ° ′	° ′	γ			
Anthony	37 09.2	98 01.7	Oc 22	9 09.9	66 52.5	23287	29	30.12	CM
Hutchinson	38 04.1	97 55.6	Oc 11, 12	9 55.5	67 33.0	22724	29	30.12	CM
Baldwin Magnetic Observatory	38 47.0	95 10.0	De–Ja	8 31.0	68 46.5	21790	30	55.34	SAD
Do.	38 47.0	95 10.0	Au 17, 18	8 29.2	-- ----	21805	37	-----	DCS
Do.	38 47.0	95 10.0	Se 12–24	8 29.5	68 44.6	21812	19	56.13	FAM
Do.	38 47.0	95 10.0	Oc 5, 9	8 29.0	68 43.6	21806	17	28.12	CCS
Do.	38 47.0	95 10.0	Je 22, 24	8 32.0	68 47.9	21734	36	28.12	SAD
Salina	38 48.9	97 36.2	Oc 9	11 10.6	68 13.3	22298	29	30.12	CM
Brown	39 46.6	98 42.3	Oc 4, 5	12 06.9	69 05.8	21466	29	30.12	CM

MAINE.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		West ° ′	° ′	γ			
Portland	43 38.8	70 16.6	Oc 29	14 57.0	74 02.8	**16595*	C	33.12	JWG
Rockland	44 07.0	69 05.0	Jy 25	16 36.0	74 21.2	**16202*	C	33.12	NHH
Rockland	44 07.0	69 05.0	Oc 19	16 38.4	74 20.9	**16230*	C	33.12	JWG

MARYLAND.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		West ° ′	° ′	γ			
Cheltenham Magnetic Obs'y	38 44.0	76 50.5	De–Ja	5 23.8	70 28.0	20010	26	26.EI	JEB
Do.	38 44.0	76 50.5	Oc 20, 21	5 22.1	70 27.9	20026	1	36.12	CCC
Do.	38 44.0	76 50.5	Ja 16–26	5 24.1	-- ----	20026	17	-----	JEB
Do.	38 44.0	76 50.5	Ja–My	5 24.4	-- ----	20030	19	-----	JEB
Do	38 44.0	76 50.5	Mh–Je	5 24.6	-- ----	19997	36	-----	JEB
Do.	38 44.0	76 50.5	Je 4, 5	- ----	70 29.1	-----	--	23.III	JEB
Do.	38 44.0	76 50.5	Je 14, 15	5 25.4	70 30.8	20038	10	18.56	CCC
Do.	38 44.0	76 50.5	Je 30	5 23.6	-- ----	19996	20	-----	JEB
Baltimore									
Patterson Pk IV	39 17.4	76 34.9	Ja 4, 5	5 51.7	70 50.2	19578	IIII	34.12	JHS
Patterson Pk I	39 17.5	76 34.8	No 17	5 53.6	70 54.0	**19612*	C	33.12	JWG

MASSACHUSETTS.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		West ° ′	° ′	γ			
Vineyard Haven	41 27.0	70 36.0	No 26, 27	12 22.6	72 19.0	17988	IIII	34.12	JHS
Boston	42 20.2	71 00.7	No 7	13 04.0	73 01.0	**17496*	C	33.12	JWG
Salem	42 31.6	70 52.0	No 3	14 28.4	73 40.7	**17385*	C	33.12	JWG

MICHIGAN.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		West ° ′	° ′	γ			
Monroe	41 55.9	83 23.6	Je 25, 26	1 28.1	72 56.4	18019	19	23.22	WMH
Detroit	42 20.4	82 57.6	Je 22	1 29.0	73 05.7	17827	19	23.22	WMH
Mt. Clemens	42 34.9	82 48.1	Je 28, 29	2 09.4	73 16.8	17734	19	23.22	WMH

* For the values in italics the total intensity determined by Lloyd's method was combined with the observed dip.

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

MINNESOTA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Dalton	46 10.4	95 55.0	Jy 7, 9	10 13.6	75 03.1	16288	29	30. 12	WHB
Glyndon	46 51.9	96 34.8	Jy 11	10 29.3	75 43.3	15704	29	30. 12	WHB

MISSOURI.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Kansas City	39 05.6	94 32.6	Je 25, 26	9 12.8	69 14.2	21722	36	28. 12	CFW
Chillicothe	39 47.6	93 32.6	Je 27, 28	7 15.8	70 15.0	20553	36	28. 12	CFW

MONTANA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Red Lodge	45 11.8	109 15.7	Oc 3, 4	18 30.2	72 10.0	18721	1	36. 12	CCC
Birney	45 20.8	106 31.2	Au 29, 30	17 35.3	72 18.2	18657	19	56. 13	FAM
Wisdom	45 37.9	113 27.3	Se 19	20 46.2	71 02.9	19525	1	36. 12	CCC
Divide A	45 45.2	112 45.0	Se 12, 13	17 32.7	71 37.7	19177	1	36. 12	CCC
Divide	45 45.2	112 45.6	Se 16, 17	18 42.0	71 25.0	19513	1	36. 12	CCC
Billings	45 47.1	108 32.6	Oc 6, 7	18 02.5	72 16.8	18702	1	36. 12	CCC
Big Timber	45 49.1	109 59.0	Oc 1	20 03.2	72 07.1	18717	1	36. 12	CCC
Deer Lodge	46 24.5	112 45.2	Se 10, 11	20 36.2	71 59.9	18740	1	36. 12	CCC
Missoula	46 52.3	113 59.3	Au 31, Se 1	21 22.0	71 56.2	18732	1	36. 12	CCC
Neihart	46 55.7	110 43.1	Jy 22	19 49.4	72 19.3	18648	1	36. 12	CCC
Ovando	47 02.0	113 08.5	Se 7	21 26.0	72 06.6	18604	1	36. 12	CCC
Glendive (old)	47 06.0	104 42.4	Jy 21	17 05.8	74 19.8	16874	10	31. 34	HWF
Glendive (new)	47 06.6	104 41.6	Jy 20, 21	17 10.1	74 19.5	16830	10	31. 34	HWF
Great Falls	47 28.0	111 15.9	Jy 20	21 25.7	72 52.2	18032	1	36. 12	CCC
Tokna	47 28.1	104 21.6	Jy 18, 19	17 20.1	74 41.0	16530	10	31. 34	HWF
Ronan	47 32	114 07.4	Se 4, 5	22 19.6	72 23.0	18393	1	36. 12	CCC
Judith	47 44.2	109 38.7	Jy 13, 14	20 24.1	73 41.3	17380	1	36. 12	CCC
Choteau	47 48.2	112 10.2	Jy 25	21 05.4	73 11.7	17641	1	36. 12	CCC
Fort Benton	47 49.2	110 40.7	Jy 17, 18	21 03.0	73 44.8	17344	1	36. 12	CCC
Zortman	47 54.7	108 30.3	Jy 5	20 00.4	74 09.5	16913	1	36. 12	CCC
Poplar	48 06.2	105 11.7	Jy 16, 17	18 14.8	75 17.0	15880	10	31. 34	HWF
Kalispell	48 10.3	114 17.2	Au 4, 5	22 50.3	72 48.8	18020	1	36. 12	CCC
Big Sandy	48 11.0	110 06.7	Jy 11, 16	21 34.2	73 46.0	17209	1	36. 12	CCC
Jennings	48 21.5	115 22.3	Au 7, 8	22 17.2	72 43.2	18006	1	36. 12	CCC
Shelby	48 30.2	111 52.7	Jy 28	22 04.8	73 53.6	17024	1	36. 12	CCC
Havre	48 32.9	109 42.4	Jy 9	20 51.6	74 27.8	16603	1	36. 12	CCC
Browning	48 34.6	113 02.7	Au 2, 3	20 46.4	73 16.8	17806	1	36. 12	CCC
Avery	48 56.0	108 36.2	Jy 2	20 26.5	74 50.5	16237	1	36. 12	CCC
Sweet Grass	48 59.8	111 58.0	Jy 29–31	22 31.1	73 57.0	16993	1	36. 12	CCC
Gateway	49 00.0	115 10.2	Au 6	24 02.2	73 16.4	17544	1	36. 12	CCC

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

NEBRASKA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Shelton	40 46.6	98 44.0	Se 27, 28	11 41.5	70 24.7	20721	29	30.12	WHB
Daily	41 35.8	98 38.9	Se 13, 15	11 42.7	71 08.3	19849	29	30.12	CM
O'Neill	42 27.6	98 38.8	Se 7	11 48.4	71 20.1	19739	29	30.12	WHB
Chadron	42 50.9	102 59.4	Se 10	14 21.8	71 12.7	19754	19	56.13	FAM

NEVADA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Winnemucca	40 58.9	117 44.1	Se 19	18 47.8	66 03.9	23134	11	23.22	WMH
Amos	41 22.7	117 51.4	Se 10	18 34.4	66 37.0	22790	11	23.22	WMH

NEW YORK.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*West* ° ′	° ′	γ			
Ithaca	42 26.8	76 28.9	Je 24, 25	7 31.9	73 43.1	17020	11	31.12	FAM
Auburn	42 57.2	76 32.6	Je 26–28	8 29.7	73 56.4	17044	11	31.12	FAM

NORTH CAROLINA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*West* ° ′	° ′	γ			
Southport	33 54.9	78 00.9	Jy 27	2 14.0	65 48.5	23450	37	18.56	FWR
Newbern	35 06.8	77 02.6	Jy 25	3 13.6	67 03.5	22514	37	18.56	FWR
Goldsboro	35 23.0	77 57.6	Jy 20, 21	- ----	67 07.7	22583	37	18.56	FWR
Morganton	35 43.9	81 43.3	Au 8, 10	0 38.2	67 07.2	22806	37	18.56	FWR & DCS
Morganton	35 43.9	81 43.3	Au 8, 10	0 39.5	-- ----	22799	20	18.56	
Raleigh (old)	35 47.5	78 39.5	Au 1	2 54.2	67 28.3	22438	37	18.56	FWR
Marshall	35 47.8	82 41.0	Au 11	0 16.4	67 15.8	22802	20	18.56	FWR
Raleigh (new)	35 48.0	78 41.5	Au 2	2 21.8	67 36.5	22390	37	18.56	FWR
Chapel Hill	35 54.2	79 04.6	Au 6	1 54.0	67 51.8	21907	37	18.56	FWR
Roan High Bluff	36 05.6	82 08.7	My 17	*East* 1 26.9	67 54.0	22587	29	30.12	CM
Halifax	36 19.0	77 36.8	Jy 19	*West* 2 19.7	68 03.6	21752	37	18.56	FWR

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

NORTH DAKOTA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
				East					
	° ′	° ′		° ′	° ′	γ			
Haley	45 58.2	103 07.5	Au 3, 4	16 08.9	73 40.7	17515	10	31.34	HWF
Hankinson	46 02.3	96 57.1	Jy 23	11 24.4	74 51.7	16435	29	30.12	WHB
Ashley	46 02.9	99 22.9	Se 22	13 18.1	74 29.8	16785	10	31.34	HWF
Linton	46 16.2	100 14.6	Se 19, 20	14 10.3	74 29.6	16793	10	31.34	HWF
Napoleon	46 30.3	99 45.8	Se 24	12 46.7	75 20.9	16191	10	31.34	HWF
New England	46 32.8	102 53.4	Jy 31–Au 1	16 26.9	74 08.7	17092	10	31.34	HWF
Fargo (old)	46 51.0	96 47.1	Se 28, 29	11 33.9	75 38.3	15701	10	31.34	HWF
Fargo (new)	46 52.5	96 47.5	Oc 6	11 10.7	75 41.8	15606	10	31.34	HWF
Dickinson	46 53.2	102 46.4	Jy 24	16 33.7	74 26.6	16793	10	31.34	HWF
Medora	46 55.8	103 31.6	Jy 23	16 34.0	74 23.1	16826	10	31.34	HWF
Fayette	47 16.1	102 56.1	Jy 25, 26	16 41.7	74 46.4	16477	10	31.34	HWF
Garrison	47 37.6	101 25.8	Se 26	15 14.7	75 25.5	15831	10	31.34	HWF
Schafer	47 46.9	103 13.0	Jy 12	17 03.1	75 08.1	16123	10	31.34	HWF
Williston	48 08.9	103 36.9	Jy 13, 14	17 20.3	75 21.2	15873	10	31.34	HWF
White Earth	48 21.5	102 46.5	Jy 9	16 24.2	75 39.9	15596	10	31.34	HWF
Kenmare	48 39.7	102 07.8	Jy 3	16 22.1	76 06.8	15148	10	31.34	HWF
Crosby	48 55.5	103 20.7	Jy 6	17 58.9	75 56.5	15346	10	31.34	HWF
Portal	49 00.0	102 33.1	Jy 4, 5	17 41.5	76 09.2	15196	10	31.34	HWF

OHIO.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
				East					
	° ′	° ′		° ′	° ′	γ			
Cincinnati	39 08.4	84 30.2	Je 21, 22	0 57.4	70 17.4	20475	10	18.56	CCC
				West					
Marietta	39 25.4	81 27.6	Je 19, 20	2 31.2	70 57.1	19866	10	18.56	CCC
Youngstown	41 04.2	80 40.3	Je 14	3 09.4	72 22.5	18416	19	23.22	WMH
Cleveland	41 28.4	81 32.9	Je 17	3 32.7	72 27.0	18464	19	23.22	WMH
Toledo	41 41.6	83 23.8	Je 20	1 10.9	72 46.5	18184	19	23.22	WMH

OKLAHOMA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
				East					
	° ′	° ′		° ′	° ′	γ			
Guthrie	35 53.0	97 24.8	Oc 29	9 37.5	65 40.0	24143	29	30.12	CM
Pond Creek	36 40.3	97 47.9	Oc 25, 26	10 08.7	66 16.7	23742	29	30.12	CM

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

OREGON.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		East ° ′	° ′	γ			
Denio	42 00.0	118 40.4	Se 7, 8	18 50.2	66 47.6	22652	11	23. III	WMH
McDermitte	42 00.0	117 45.8	Se 13, 14	18 54.6	67 00.3	22489	11	23.22	WMH
Lakeview	42 11.0	120 21	Oc 29, 30	20 48.0	66 18.9	22857	11	23. III	WMH
Klamath Falls	42 13.1	121 46	Oc 18, 19	19 45.4	66 08.6	22887	11	23.22	WMH
Bly	42 23.0	121 02	Oc 26, 27	21 06.4	66 38.9	22683	11	23. III	WMH
Plush	42 25.9	119 54.2	No 1	20 51.7	67 05.2	22508	11	23.22	WMH
Andrews	42 27.4	118 38	Se 3, 4	20 47.6	66 42.6	22685	11	23.22	WMH
Paisley	42 41.6	120 38.0	No 7, 8	21 05.0	67 06.6	22181	11	23.22	WMH
Fort Klamath	42 42.0	121 59	Oc 22, 23	20 17.0	66 21.6	22630	11	23. III	WMH
Diamond	43 00.5	118 42	Au 30, 31	18 31.8	68 38.0	21153	11	23. III	WMH
Silver Lake	43 07.3	121 07.2	No 10, 12	20 01.0	67 10.7	22200	11	23. III	WMH
Burns	43 34.9	119 04	Au 27, 28	20 58.5	68 09.1	21774	11	23. III	WMH
Rosland	43 41.7	121 35.4	No 14, 16	21 29.0	67 20.6	21974	11	23. III	WMH
Paulina	44 07.6	119 54	Au 18, 20	21 45.2	68 20.7	21486	11	23. III	WMH
Sisters	44 16.8	121 34	Au 14, 15	20 40.8	67 58.6	21152	11	23.22	WMH
Prineville	44 18.6	120 52	Au 11, 12	21 12.5	68 38.6	21110	11	23. III	WMH
Canyon City	44 23.4	118 58	Au 5, 6	19 42.9	68 34.9	21760	11	23. III	WMH
Mitchell	44 32.5	120 09	Au 8, 9	21 23.2	68 30.2	21257	11	23.22	WMH
Shaniko	44 59.8	120 43.6	Jy 16	21 23.4	69 43.2	20252	11	23.22	WMH
Alba	45 12.2	118 55	Jy 31–Au 1	21 14.5	69 34.8	20413	11	23. III	WMH
Condon	45 13.5	120 11.2	Jy 18, 19	20 28.4	69 31.9	20557	11	23. III	WMH
Tygh Valley	45 13.9	121 02.7	Jy 9, 10	21 09.4	68 49.6	21047	11	23. III	WMH
Heppner	45 20.1	119 33.3	Jy 21, 23	21 53.6	69 40.9	20091	11	23. III	WMH
Moro	45 28.7	120 40.8	Jy 13, 14	21 54.4	69 12.0	20644	11	23. III	WMH
The Dalles	45 35.2	121 12.7	Jy 1	22 03.8	69 22.5	20462	11	23.22	WMH
Three Mile Creek	45 35.4	121 09.2	Jy 2	22 25.0	69 28.5	20599	11	23.22	WMH
Pendleton	45 39.9	118 47.4	Jy 28	21 51.2	69 23.3	20788	11	23. III	WMH
Umatilla	45 54.8	119 20.1	Jy 25, 26	21 45.5	69 58.7	20226	11	23.22	WMH

PENNSYLVANIA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		West ° ′	° ′	γ			
Harrisburg	40 15.2	76 53.0	Je 7, 8	6 40.7	71 43.9	18932	19	23.22	WMH
Allegheny (old)	40 29.2	80 01.0	Je 10, 11	4 08.9	72 04.4	18678	19	23.22	WMH
Allegheny (new)	40 29.2	80 01.1	Je 11, 12	4 09.0	72 09.2	-----	19	23.22	WMH

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

PORTO RICO.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*West* ° ′	° ′	γ			
Vieques									
Cofi A	18 08.8	65 26.9	Se17, No9	1 48.0	-- ----	-----	31	-----	WBK
Cofi B	18 08.8	65 26.9	Se17, No9	1 38.2	-- ----	-----	31	-----	WBK
Cofi C	18 08.8	65 26.9	Se 17	1 49.6	-- ----	-----	31	-----	WBK
Cofi F	18 08.8	65 26.9	No 9	1 53.8	-- ----	-----	31	-----	WBK
Porto Rico Magnetic Obs'y	18 08.9	65 26.4	De–Ja	1 37.0	49 50.7	28890	31	1 EI	WBK
Vieques									
LeBrun A	18 09.1	65 26.4	De 1	2 02.2	-- ----	-----	31	-----	WBK
LeBrun B	18 09.1	65 26.4	De 1	2 01.8	-- ----	-----	31	-----	WBK
LeBrun C	18 09.1	65 26.4	De 1	1 54.8	-- ----	-----	31	-----	WBK
Obispo Cayo	18 20.6	65 37.2	Fe 8–16	1 57.6	49 37.2	**29412*	C	33.12	JHS
Do	18 20.6	65 37.2	My 16	2 05.3	49 38.0	**29372*	C	33.12	JHS

RHODE ISLAND.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*West* ° ′	° ′	γ			
Newport	41 30.5	71 19.7	Au 1, 2	12 20.9	72 40.7	17802	IIII	34.12	JHS

SOUTH DAKOTA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Freeman	43 18.8	97 27.1	Au 27, 28	10 40.3	72 37.8	18592	29	30.12	WHB
Interior	43 42.8	101 57.0	Au 29, 30	14 13.9	72 01.2	19042	10	31.34	HWF
Custer	43 47.3	103 34.4	Se 8	15 23.0	71 42.4	19238	19	56.13	FAM
Stearns	43 50.1	101 18.4	Se 1	13 46.1	72 12.8	18884	10	31.34	HWF
Murdo	43 53.5	100 43.1	Se 3	13 33.9	72 12.7	18874	10	31.34	HWF
Creston	43 55	102 40.4	Au 27, 28	14 43.8	72 04.7	18935	10	31.34	HWF
Presho	43 55.1	100 04.3	Se 5	12 50.9	72 30.3	18670	10	31.34	HWF
Howard	44 00.8	97 31.7	Au 20	10 51.7	73 06.9	18083	29	30.12	WHB
Rapid City	44 04.8	103 12.1	Au 25	15 18.9	71 57.6	19091	10	31.34	HWF
Pierre (new)	44 22.0	100 21.1	Se 8	13 01.9	72 58.0	18245	10	31.34	HWF
Pierre (old)	44 22.0	100 21.5	Se 7	13 03.1	72 53.6	18353	10	31.34	HWF
Highmore	44 30.5	99 25.6	Se 13	12 25.5	73 01.9	18259	10	31.34	HWF
Vale	44 37.4	103 23.0	Au 20–22	15 57.1	72 24.2	18756	10	31.34	HWF
Belle Fourche	44 40.7	103 51.5	Se 6	15 46.6	72 20.6	18673	19	56.13	FAM
Watertown	44 54.3	97 06.3	Au 13, 14	10 18.0	74 08.7	17238	29	30.12	WHB
Bixby	45 09.0	102 33.7	Au 10–18	15 12.8	73 08.1	18013	10	31.34	HWF
Harding	45 24	103 50.4	Au 7	15 50.3	73 02.8	18058	10	31.34	HWF
Chance	45 24.2	102 16.8	Au 11, 13	15 49.2	73 16.8	17949	10	31.34	HWF
Roscoe	45 27.2	99 21.5	Se 18	12 48.1	73 58.9	17249	10	31.34	HWF
Preacher Hill	45 28.3	97 06.3	Jy 30	10 59.5	74 24.7	16888	29	30.12	WHB
Selby	45 30.6	100 03.2	Se 15, 17	13 33.9	74 08.9	17146	10	31.34	HWF
Reva	45 32	103 11.3	Au 9	15 59.0	73 20.8	17841	10	31.34	HWF
Seim	45 45.7	102 12.5	Au 15	15 39.1	73 42.9	17565	10	31.34	HWF

* For the values in italics the total intensity determined by Lloyd's method was combined with the observed dip.

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907*—Cont'd.

TENNESSEE.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Waldensia	35 54.0	84 46.0	Mh 21, 22	0 07.4	66 46.1	23458	29	30.12	CM
Sparta	35 55.3	85 26.5	Mh 13, 15	3 37.9	67 03.6	22965	29	30.12	CM
				West					
Knoxville (new)	35 56.3	83 56.6	Au 16	0 13.6	66 44.7	23230	20	18.56	FWR
Do.	35 56.3	83 56.6	Mh 23–28	0 12.8	66 47.7	23214	29	30.12	CM
Knoxville (old)	35 57.3	83 57.6	Au 15	0 11.0	66 50.2	23177	20	18.56	FWR

TEXAS.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Weatherford	32 45.2	97 48.7	De 7, 8	9 07.9	62 17.5	26309	29	30.12	CM
Bowie N. W. Base	33 37.4	98 00.2	No 28, 30	9 16.9	62 57.8	25883	29	30.12	CM

UTAH.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		*East* ° ′	° ′	γ			
Kanab	37 02.4	112 32	Au 4	15 48.9	63 52.6	24783	17	28.12	CCS
St. George	37 07.7	113 35	Jy 30	16 02.2	63 34.9	24928	17	28 12	CCS
Modena	37 49.2	113 55.5	Jy 24–26	15 53.4	63 46.3	24839	17	28.12	CCS
Panguitch	37 49.7	112 27	Au 7	16 02.2	64 15.5	24697	17	28.12	CCS
Parowan	37 53.3	112 51	Au 2	16 21.4	64 16.4	24492	17	28.12	CCS
Beaver	38 12.9	112 40	Au 9, 10	16 02.4	64 33.3	24369	17	28.12	CCS
Junction	38 16.6	112 15	Au 13	15 38.2	64 34.1	24295	17	28.12	CCS
Richfield	38 47.1	112 07	Au 14	16 53.1	65 11.1	23988	17	28.12	CCS
Green River	38 59.3	110 09.9	Au 20	15 48.2	66 08.0	23446	17	28.12	CCS
Manti	39 16.5	111 40	Au 16	16 50.6	66 01.6	23447	17	28.12	CCS
Dragon	39 47.1	109 06	Au 22	15 38.8	67 08.9	23226	17	28.12	CCS

VIRGINIA.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments DC	Observer
	° ′	° ′		*West* ° ′	° ′	γ			
Bristol	36 36.2	82 10.5	Au 18	0 33.0	67 53.6	22109	20	18.56	FWR
Big Knob	36 39.9	82 30.4	My 8, 9	1 22.5	67 58.8	22290	29	30.12	CM
White Rock	36 39.9	83 27.1	Apr 24, 29	0 39.5	68 19.8	22278	29	30.12	CM
Boydton	36 40.6	78 21.8	Jy 11, 12	2 48.0	68 25.1	21565	37	18.56	JAF
Princess Anne	36 44.6	76 03.7	Jy 16	4 45.1	68 41.7	21385	37	18.56	FWR
Cape Henry	36 55.6	76 00.5	Jy 14	4 41.1	68 53.3	21091	37	18.56	JAF
Little Creek Inlet	36 55.8	76 10.9	Jy 13	4 34.5	68 46.0	21252	37	18.56	JAF
Cahas	37 05.6	80 01.0	Je 12, 17	1 23.6	68 53.9	21416	29	30.12	CM
Charlottesville	38 02.4	78 30.3	Au 22	3 50.0	69 47.2	20472	20	18.56	FWR
King George	38 16.1	77 10.7	Au 23, 24	5 02.2	69 48.0	20546	20	18.56	FWR
Mt. Weather Obsy.									
Pier E	39 03.9	77 53.2	My 17, 18	3 38.7	70 40.7	19835	36	EI	JEB
Outside	39 03.9	77 53.2	My 18	4 06.9	-- ----	19582	36	EI	JEB

TABLE I.—*Magnetic observations on land, July 1, 1906, to June 30, 1907.*—Cont'd.

WASHINGTON.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		East ° ′	° ′	γ			
Stevenson	45 40.8	121 52.1	Jy 5, 6	21 25.0	69 30.3	20418	11	23.III	WMH
Port Orchard	47 32.1	122 38.2	No 20	22 41.1	70 56.5	19437	8	32.2	WMS
Spokane	47 42.4	117 30.0	Au 12, 13	23 21.8	71 49.2	18771	1	36.12	CCC
Colville	48 32.7	117 52.8	Au 15	23 38.2	72 22.6	18151	1	36.12	CCC

WYOMING.

Station	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Instruments M	Instruments D C	Observer
	° ′	° ′		East ° ′	° ′	γ			
Cheyenne	41 09.0	104 50.0	Jy 9, 10	14 59.8	69 08.6	21448	19	56.13	FAM
South Pass	42 28.3	108 46.9	Jy 18	16 19.1	69 00.5	21372	19	56.13	FAM
Myersville	42 34.2	108 07.8	Jy 20	16 45.6	69 41.2	20833	19	56.13	FAM
Lander	42 50.4	108 40.5	Jy 16	16 59.4	69 56.2	20650	19	56.13	FAM
Casper	42 50.6	106 19.8	Jy 11, 12	15 57.6	70 28.1	20451	19	56.13	FAM
Powder River	43 02.5	106 58.9	Jy 13	17 02.3	70 17.5	20562	19	56.13	FAM
Shoshoni	43 13.5	108 05.0	Jy 24	17 25.2	70 08.5	20491	19	56.13	FAM
Thermopolis	43 40.8	108 12.8	Jy 27	17 39.0	70 39.2	20252	19	56.13	FAM
Mayoworth	43 50.9	106 47.1	Au 21, 22	16 42.1	70 59.8	19790	19	56.13	FAM
Worland	44 02.0	107 58.6	Jy 30	17 03.4	70 57.9	19892	19	56.13	FAM
Meeteetsee	44 10.3	108 50.1	Au 14	18 01.6	70 50.2	20001	19	56.13	FAM
Valley	44 10.6	109 32.7	Au 9, 10	18 05.2	70 28.4	20264	19	56.13	FAM
Buffalo	44 22.2	106 40.9	Au 18	17 16.4	71 33.8	19302	19	56.13	FAM
Sundance	44 24.9	104 22.6	Se 4, 5	14 37.0	72 04.5	19008	19	56.13	FAM
Basin	44 25.1	108 05.0	Jy 31, Au 1	18 01.9	71 11.9	19688	19	56.13	FAM
Cody	44 33.1	109 00.2	Aug 7, 13	18 26.3	71 22.4	19407	19	56.13	FAM
Arvada	44 40.4	106 06.6	Se 2, 3	17 14.0	71 54.3	19032	19	56.13	FAM
Lovell	44 50.8	108 22.9	Au 2, 3	18 05.0	71 39.9	19214	19	56.13	FAM
Sheridan	44 50.8	106 57.8	Au 16	17 05.5	71 52.0	18998	19	56.13	FAM

TABLE II.—*Magnetic observations at sea, July 1, 1906, to June 30, 1907.*

ATLANTIC OCEAN.

Place	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Ship	No. of headings	Sea
	° ′	° ′		*West* ° ′	° ′	γ			
Fajardo Roads	18 21	65 36	Fe 9	2 05	49 22	29681	Bache	16	Lt. sw.
Do.	18 21	65 36	Fe 15	2 06	-- --	-----	Do.	8	Mod. sw.
Do.	18 21	65 36	My 17	2 23	49 23	29647	Do.	16	Sm.
At sea	22 12	66 32	My 31	3 20	54 02	28070	Do.	8	Lt. sw.
Do.	22 15	68 55	Fe 2	2 07	54 06	28225	Do.	8	Hvy. sw.
Do.	25 16	71 28	Fe 1	2 51	57 05	27550	Do.	8	Hvy. sw.
Do.	26 13	66 56	Je 1	4 40	58 04	26617	Do.	8	Lt. sw.
Do.	28 53	73 23	Ja 31	3 05	60 38	26210	Do.	8	Hvy. sw.
Do.	32 35	74 20	Ja 30	4 38	-- --	-----	Do.	7 & 3	Rough
Lynnhaven Roads	36 57	76 06	De 14	4 42	68 43	-----	Explorer	16	Sm.
Hampton Roads	36 58	76 22	Jy 20	5 04	68 45	21279	Bache	16	Sm.
Do.	36 58	76 21	Ja 24	4 02	68 39	21289	Do.	16	Sm.
Do.	36 58	76 21	Ja 25	4 30	-- --	-----	Do.	16	Sm.
Do.	36 58	76 21	Je 5	4 35	68 39	21267	Do.	16	Sm.
Do.	37 00	76 18	Jy 25	4 53	68 45	21257	Explorer	16	Sm.
Chesapeake Bay	38 13	76 19	No 16	5 16	69 44	20767	Bache	16	Mod. sw.
At sea	38 15	74 50	De 13	6 59	69 51	20144	Explorer	8	Mod. sw.
Do.	38 35	74 41	De 13	5 32	70 23	19859	Do.	8	Mod. sw.
Do.	39 52	74 00	No 14	7 58	71 20	19304	Bache	8	Sm.
Do.	40 17	73 20	Jy 27	9 15	71 43	18745	Explorer	8	Mod. sw
Do.	40 26	73 55	De 12	9 36	71 46	18409	Do.	3	Lt. sw.
Long Isld. Snd.	41 10	72 43	De 8	9 08	72 36	17740	Do.	8	?
Block Isld. Snd.	41 14	71 46	De 5	11 29	-- --	-----	Do.	16	Sm.
Nantucket Sound	41 29	70 33	No 30	11 46	72 16	18046	Do.	16	Sm.
Newport Harbor	41 30	71 21	Jy 28	12 17	72 38	17824	Do.	16	Sm.
Portland Harbor	43 36	70 10	Oc 26	15 46	74 19	16307	Bache	16	Long sw.
At sea	44 05	69 00	Oc 20	-- --	74 26	16185	Do.	16	Hvy. sw.
Do.	44 05	69 00	Oc 23	-- --	74 21	16333	Do.	10	?
Do.	44 05	69 00	Oc 24	15 37	-- --	-----	Do.	16	Choppy
Rockland Harbor	44 06	69 05	Oc 24	15 59	74 32	16069	Do.	16	Sm.
Do.	44 07	69 04	Jy 25	16 05	74 14	16153	Do.	16	Sm.

PACIFIC OCEAN.

Place	Latitude	Longitude	Date	Declination	Dip	Horizontal intensity	Ship	No. of headings	Sea
	° ′	° ′		*East* ° ′	° ′	γ			
Port Orchard	47 33	122 38	My 31*	-- --	71 30	18773	Patterson	8	Sm.
Do.	47 33	122 38	Je 1*	23 08	71 03	19177	Do.	16	Sm.
Seattle Harbor	47 37	122 23	De 8*	23 28	70 41	19564	Do.	16	Sm.
Baynes Sound	49 35	124 53	Je 19*	25 48	71 29	18849	Do.	16	Sm.
At sea	52 04	132 15	Je 21*	26 18	71 29	18451	Do.	8	Mod. sw.
Do.	55 15	146 50	Je 24*	24 10	70 49	18466	Do.	16	Lt. sw.
Do.	55 43	151 31	Je 25*	22 38	70 23	18631	Do.	16	Lt. sw.
Do.	55 59	155 41	Je 26*	21 53	69 53	18909	Do.	16	Lt. sw.

* 1906.

DESCRIPTIONS OF STATIONS.

Magnetic observers are instructed to mark every station in as permanent a manner as possible, either with a stone or a post of some durable wood, so that it may be available for future occupation. They are also required to furnish a sufficiently detailed description to locate the station, even if the marking should be destroyed, and to determine the bearing of two or three prominent objects in addition to the one used as reference mark in the azimuth and declination observations. The information is given in abridged form on the following pages for each of the stations occupied during the year. Further details can usually be obtained on application to the Superintendent of the Coast and Geodetic Survey. The usual method of marking a station is by a stone post about 3 feet long and 6 or 8 inches square, set so as to project an inch or two above ground, and lettered on top U. S. C. & G. S., with a drill hole in the center to mark the exact point. Whenever the local authorities desired and were willing to bear the expense a second stone was set to denote the true meridian.

The descriptions of stations are arranged alphabetically by States and by names of station.

ALABAMA.

Fort Morgan, Baldwin County.—The magnetic station is in an open space in a pine grove, southeast of the end of the row of officers' quarters, southwest of the large wooden water tank, and 147.6 feet north of a group of live oak trees. The station is 234.2 feet from the iron flow pipe at the center of the water tower, 351.5 feet from the northwest corner of the Peace Storage Magazine, and 303.5 feet north of the ammunition track. The station is marked by a 4 by 26 inch sewer tile filled with cement placed flange down, being flush with the surface of the ground. A ⅛-inch copper wire projecting one-fourth of an inch, marks the center of station. The letters U. S. C. & G. S., 1907, were traced on the surface of the cement. The following true bearings were determined:

	° ′	
Small spire on ventilator to Post Exchange building	74 02.0	west of south
Southeast edge of center flow pipe of water tank	27 51.2	east of north
Northwest corner of masonry at opening of section A, Dearborn Battery	74 09.1	east of south
Northwest corner of Peace Storage Magazine	35 21.7	east of south
Small white rod in line with Sand Island Light-house and triangulation station	77 28.3	west of south

Huntsville, Madison County.—The magnetic station of 1900 being no longer available for observations, a new one was established in the southwestern part of the public school grounds. The grounds are bounded by Clinton and Calhoun streets, and are about one-half mile northeast of the court-house square. The station is 75.5 feet from the southwest corner of the schoolhouse, 18.8 feet south and east from a large oak tree 4 or 5 feet in diameter, and 50.9 feet from the center of the brick sidewalk on Calhoun street. It is marked by a 4 by 26 inch sewer tile, placed flange down, the top being about 1 inch below the surface of the ground. The center of top marks the exact spot. The following true bearings were determined:

	° ′	
Cross on spire of Episcopal Church (mark)	30 51.6	west of south
Court-house spire	40 17.0	west of south
Southwest corner of public school	32 56.2	east of north
Spire of south cupola on Dallas Cotton Mill	3 12.7	west of north

Descriptions of stations—Continued.

ALABAMA—Continued.

Maplesville, Chilton County.—The station is on land belonging to Mr. R. H. Martin, in the northwest part of a cleared space of about 1 acre in extent, situated about 300 feet back or west of Mr. Martin's store and about 150 feet south of the old camp-meeting platform. The station is 210 paces west of the railway station, 178.8 feet southwest of the northwest corner of a picket fence surrounding a negro's cabin, 160.8 feet north and a little west of the northwest corner of the outside brick chimney of another negro's cabin at the south edge of the clearing, and 27.9 feet south and 36.0 feet southeast of two oak trees at the north edge of the clearing. The station is marked by the mouth of a brown glass beer bottle, the top of which is buried 2 feet underground. The surface mark is a rude cross on the top of a rock about 6 inches on a side and about 14 inches long. The top of the rock is flush with the surface of the ground and one apex of the rock points north. The following true bearings were determined:

	° ′
Methodist Church spire (mark)	41 00.1 east of north
Northwest corner of west chimney of Mr. Chas. Plank's house	46 03.7 west of south
Center of stack of Twin Tree sawmill	75 28.0 west of north

ALASKA.

Khaz Bay.—Magnetic observations were made at triangulation station Bald. It is located on the western end of the island at the eastern point of entrance to Khaz Bay. The center is marked by a three-fourths inch hole drilled on top of the gray promontory, or flat part of highest knob. The knob is covered with a grassy patch. Witness marks: (1) A 2 by 4 inch stake driven in crevice 4 feet from center, bearing S. 25° E. (mag.). (2) A small spruce tree distant 85 feet with an 8-inch triangle blazed on side facing the sea and signal, bearing S. 87° E. (mag.). The lower limbs have been chopped off. One branch pointing toward center of signal has been sawed off and a wire nail driven in sawed end. (3) An arrow drilled in the rock, pointing toward center mark, the head of the arrow being distant 3 feet 8 inches from the center mark, and bears N. 80° E. (mag.). The station is about 50 feet above high water. Triangulation station Egg bears 69° 52′.2 west of north.

Kodiak.—The station of 1896 was reoccupied as nearly as could be determined, probably within less than 10 feet. The station is located on a bluff on the north side of St. Paul roadstead and about three-fourths of a mile east of Kodiak. East of the bluff is a small bight. The bluff is about 15 feet high and 200 feet long, and slopes back about 100 feet to low ground, where are some huts. A small stream comes down behind the bluff. The station is marked by a green bottle set in cement, with the neck about 3 inches below the turf. On the bluff are three small spruce trees, each marked with a blazed triangle of nails. The distance to the easterly one is 28.6 feet; to the northerly one, 43.4 feet; to the westerly one, 94 feet; and to the east end of the bluff, 75.5 feet. The station is about 6 feet from the south side of the bluff. The following true bearings were determined:

	° ′
Spire of Greek Church (mark)	36 00.3 east of south
Spire of Baptist Church	29 43.0 east of south
Middle gable large building on Woody Island	28 35.5 east of south
Northeast gable left N. A. C. Co. building on Woody Island	25 54.0 east of south
Northwest gable N. A. C. Co. ice house	24 48.6 east of south
Inner Humpback rock	15 18.9 east of south

Miller Island, Alitak Bay.—The astronomic station is at the summit of the highest hill on Miller Island, Alitak Bay, and is marked by a cement pier 16 by 24 inches projecting about 24 inches above ground. The magnetic station was 225 feet north of the astronomic station in line to the azimuth mark, which bore 0° 00′.8 east of north. This azimuth mark was a pole set up on the ridge back of Point Fassett. The magnetic station was marked by a 2 by 4 post projecting 6 inches above ground, with rocks piled around.

Nuka Bay.—Magnetic observations were made at triangulation station South Base. This station is at the southern corner of northwest arm of Nuka Bay, on grass covered shore about 46

Descriptions of stations—Continued.

ALASKA—Continued.

feet back from high-water mark and about 5 feet above. The subsurface mark is a bottle buried 1.5 feet beneath the surface. The surface mark is a 6 by 18 inch spruce hub, set flush with the surface of the ground. Reference mark No. 1 is a triangle of nails on blazed surface of spruce tree 18 inches in diameter, bearing S. 44° W. (mag.), distant 100.9 feet. Reference mark No. 2 is a square of nails on blazed surface of spruce tree 12 inches in diameter, bearing S. 38° E. (mag.), distant 265.3 feet. Triangulation station Moss bears 78° 03′.9 east of south.

Port Chatham.—Magnetic observations were made at triangulation station Middle Base. This station is on a sand spit on the port side of entrance, N. 66° W. (mag.) from East Base and N. 81° E. (mag.) from West Base. It is in the high grass about 6 feet above high-water mark and about 25 feet from the southern shore of spit. It is marked below the surface by a square bottle placed 14 inches below the surface of the ground. The surface mark is a spruce hub 5 by 18 inches, set 5 inches above the ground. A square of nails on the blazed surface of a spruce tree 18 inches in diameter at base bears N. 45° W. (mag.), distant 15.6 feet. Triangulation station East Base bears 42° 58′.8 east of south.

Sitka Magnetic Observatory, Sitka.—In the absolute building. For description of the observatory see Appendix 5, Report for 1902.

Slocum Arm.—Magnetic observations were made at triangulation station West Base. It is on a rocky point projecting out from bluff, which at this point projects out as an overhanging rock from main line. It is 1 004 feet from East Base, the latter bearing S. 73° E. (mag.). A ⅝-inch copper bolt 2 inches long is set in the highest point of an irregularly shaped rock about 1½ to 2 feet in greatest diameter. Reference marks are: (1) A cross (+) drilled in the perpendicular face of the projecting point of bluff mentioned above. The cross is about 6 feet above the ground and directly over a small can-like opening near the base of the rock. Station bears N. 70° E. (mag.) from cross, distant 16 feet. (2) An arrow drilled on the vertical face of a rock about 4 feet high, the third of three in line from the main cliff. The face of the rock on which the arrow is drilled is turned away from the station, so that the arrow points directly toward it. Arrow is about 3 feet above ground. Station bears north from arrow, distant 14 feet. Station is at about mean high water. Triangulation station Stream bears 24° 53′.9 east of north.

Snug Harbor.—The station is on the northern side of the entrance to Snug Harbor, Moser Bay, at the northwestern corner of Alitak Bay. It is very nearly true west of Point Fassett and about 2 600 feet southwest along the beach from the low sand spit opposite Point Fassett. The station is upon the bluff, 30 feet above the third shingly beach from the sand spit, 500 feet from the rocky ledge separating the second and third beaches, and 650 feet from the second beach. Fifty feet west of the station is a very small ravine, which can be recognized as a streak far up the mountain side. The station mark is a half inch drill hole, 2 inches deep, in a smooth granite bowlder, the only rock to be seen. The stone is 3 feet long, 2 feet wide, and rests about 2 feet in the ground on a level with the tundra, which partly covered it. The following true bearings were determined:

Second notch from shore in rocks just off Entrance Point on northern end of Miller Island (mark)	39	55.6	east of south
Miller triangulation station	27	26.1	east of south

Tongass Narrows.—Magnetic observations were made at Tongass Narrows Southeast Base, the southeast end of a short check base near the lower end of Tongass Narrows.

Wingham Island.—Magnetic observations were made at triangulation station Pen. It is a tripod signal of 4 by 4 inch fir, located on the southeast end of Wingham Island (to the south of Kayak settlement) on a high neck of land running out into the Pacific Ocean in a southeasterly direction. Near the signal, on the westward side of the neck, is a triple pine tree, the most westerly limb of which points seaward. The subsurface mark is a bottle buried neck up 1½ feet below surface. The surface mark is a hub of 4 by 4 inch fir, 1.6 feet long, sunk flush with the surface. Reference marks are a square of nails on blazed surface of most westerly limb of triple pine, distant 25.0 feet, and a square of nails on blazed surface of most easterly limb of triple pine, distant 25.8 feet. Triangulation station Slope bears 84° 25′.5 east of north.

Descriptions of stations—Continued.

CALIFORNIA.

Alturas, Modoc County.—The station is in the southeastern corner of the Alturas Fair Grounds, about 1¾ miles southeast of the center of town. It is 93.4 feet north of the fence bounding the fair grounds on the south, 95.5 feet west of the fence on the east, and 122.5 feet south of the inside fence around the race track. It is marked by an oak stake, 3½ by 6 by 30 inches, projecting about 1 foot above ground, with a cross sawed in top to indicate the exact spot. The following true bearings were determined:

	° ′
Flagstaff on cupola of county court-house (mark)	57 39.3 west of north
Flagstaff on cupalo of public school	42 44.9 west of north
Church spire	45 53.6 west of north
Cupola of high school	46 40.0 west of north
Flagstaff on judges' stand	71 54.7 west of north

Barstow, San Bernardino County.—The station of May, 1906, was reoccupied (July, 1906). It is about 1 000 feet north of the Harvey Hotel and between a line of fence posts just north of town and a fence on the southern boundary of a field immediately on the south bank of the river. It is 142 feet south of this fence in a line with the north gable of the Harvey Hotel and the top of the hill south of the hotel. The station is marked by a rough piece of red tufa rock, 5½ by 6½ by 30 inches, showing about 6 inches above ground, with the biggest point at the top to mark the exact spot. The following true bearings were determined:

	° ′
North gable of Harvey Hotel (mark)	12 30.5 west of south
Edge of prominent rock on east edge of short range to the north	0 36.0 west of north
Top of right-hand edge of iron oil tank	38 52.5 east of south

Bartle, Siskiyou County.—The station is in a pasture southeast of the hotel. The pasture is the first inclosure on the south side of the county road east of the hotel. The station is about 200 feet south of the fence on the south side of the county road, and about 32 feet north of a small piece of ground about 200 feet by 50 feet, inclosed by a wooden fence. It is 86 feet northeast of the northwest corner of the above inclosed ground and 131 feet northwest of the northeast corner of this inclosure. It is marked by a cedar post of irregular cross section about 5 by 6 by 30 inches, projecting about 5 inches above the surface of the ground, with a cross cut in the top to mark the exact spot. The following true bearings were determined:

	° ′
East gable of hotel (mark)	47 27.2 west of north
Highest point on Shasta Mountain	60 20.5 west of north
East side of front of saloon just under top board	66 49.1 west of north

Bieber, Lassen County.—The station is about 1 200 feet southeast of the center of town and directly east of the church, on land owned by N. Bieber. It is 157 feet a little north of east from the southeast corner of the church, 145.5 feet a little south of east from a bench mark of rough stone, lettered B. M. 14 and 13 W. S. R. S. 144.16. It is 159 feet a little south of east of the northeast corner of the church. It is marked by an oak stake 4 by 5 by 12 inches, set flush with the ground. A cross sawed in the top indicates the exact spot. The following true bearings were determined:

	° ′
East gable of schoolhouse (mark)	9 39.1 west of north
East gable of flour mill	66 42.3 west of south
Extreme upper west corner on front of N. Bieber's general store	67 41.1 west of north

Madeline, Lassen County.—The station is near the northeastern corner of the corral used for cattle, sheep, etc., which is about 700 or 800 feet south of the public school. It is 338 feet north of the branch railroad track running east and west on the south side of the corral and 177.5 feet east of the northeast corner of the corral. It is marked by an oak stake 3 by 3 by 30 inches, projecting about 4 inches above ground, with a cross sawed in the top to mark the exact spot. The following true bearings were determined:

	° ′
East gable of schoolhouse (mark)	21 15.0 west of north
West gable of hotel	63 59.7 east of north
South gable of railroad station	78 36.5 east of north

Descriptions of stations—Continued.

CALIFORNIA—Continued.

Montgomery, Shasta County.—The station is on a small knoll or hill along the county road and about 800 feet a little west of south of the hotel. It is in a pasture immediately south of the hotel grounds. It is 89 feet a little north of west from the fence on the west side of the county road, measured at right angles to the fence, and 65.5 feet a little west of south from a lone oak tree at the top of the knoll. It is marked by an oak stake, the bark being left on, 36 inches long by 3.8 inches in diameter, showing about 1 foot above ground, with a cross sawed in the top to mark the exact spot. The following true bearings were determined:

	°	′	
Post at southwest corner of upper veranda of hotel (mark)	48	30.2	east of north
South edge of ornament at top of hotel roof	48	55.0	east of north
Western gable of old tollhouse	4	59.0	east of south

Stockton, San Joaquin County.—The station of 1897 was reoccupied. It is located in the northwestern corner of the rural cemetery, about 2½ miles north of the county court-house. The azimuth station is marked by a smooth white marble post 4 inches square on top and 4 feet long, projecting 18 inches above the ground. The post is lettered on its vertical faces: Magnetic Station; U. S. C. & G. S., 1897. The post is placed on a dike, 16 feet from the north fence of the cemetery and 30.5 feet from the northwest corner, as measured along the fence line. The magnetic station is in the line joining the center of the marble post with the top of the statue on the court-house dome and is 10 feet from the center of the post. The following true bearings were determined:

	°	′	
Top of statue on court-house (mark)	5	35.9	east of south
Spire of Central Methodist Episcopal Church	6	22.2	east of south
Pole on roof of a square tank house	14	52.7	west of south

Susanville, Lassen County.—The station is about 1 mile southeast of the center of town, in the southwestern part of the Susanville fair grounds, about 350 feet west of the judges' stand at the race track and about 300 feet northwest of the grand stand. It is in the northeastern corner of the fence inclosing the grand stand and stables and about 225 feet north of the stables. It is 57 feet southwest of the northeast fence and 65 feet a little south of east of the northwest fence inclosing the grand stand. It is marked by an oak stake (one-half wagon axle) 3 by 4 by 30 inches, projecting 7 inches above the ground, with a cross-cut in the top to mark the exact spot. The following true bearings were determined:

	°	′	
Base of flagstaff on cupola of public school (mark)	79	35.9	west of south
Flagstaff over entrance to high school	74	49.3	west of south
Flagstaff on cupola of Emerson Hotel	85	30.6	west of north
Flagstaff on belfry of engine house	79	11.8	west of north
Steeple on brick church	89	48.9	west of south

Ukiah, Mendocino County.—The south monument of the meridian line established here in 1897 was reset, it having been removed by the owner of the ground. The line is 777 feet long. Magnetic observations were made at a point in the meridian line 10.6 feet north of the center of the south monument. The magnetic station is about 20 feet from the south fence and 35 feet from the east fence of the lot, and is very near the point at which magnetic observations were made in 1897. The following true bearings were determined:

	°	′	
Base of pole on grammar school building (mark)	2	37.4	west of north
Base of pole on court-house	3	47.8	east of north
Center of north monument	0	01.3	west of north

Yreka, Siskiyou County.—The station is about one-half mile northwest of the center of town, in the southwest corner of the ground surrounding the county high school, about 400 feet southwest of the high school building. It is 34.6 feet north of the fence bounding the high school grounds on the south and 38.3 feet east of the fence bounding the grounds on the west. The station is marked with

Descriptions of stations—Continued.

CALIFORNIA—Continued.

a sandstone post 8 by 6½ by 28 inches, lettered U. S. C. & G. S., 1906, set flush with the surface of the ground. The following true bearings were determined:

	° ′
Flagstaff on cupola of court-house (mark)	3 04.6 east of south
Flagstaff on cupola of house	10 57.1 east of south
Flagstaff on cupola of high school	84 47.2 east of south

COLORADO.

Aspen, Pitkin County.—The station is situated in the southwest part of the fair grounds, just inside the race track. It is 125 feet east of the west fence and 100 feet north of the south fence. The station is marked by a cross cut in a large stone which shows a surface of about 1 by 2 feet above the ground. The following true bearings were determined:

	° ′
Flag pole on judges' stand (mark)	3 09.9 east of north
Brick smokestack	28 21.2 west of south

Boulder, Boulder County.—The station is on a hill in the west part of the new cemetery, south of town. It is 153 feet east of the west fence, and is marked by a large rough brown stone covered with green fungus, which shows about 2 square feet of surface. A cross cut in the stone indicates the exact spot. The following true bearing was determined:

	° ′
College flag pole (mark)	4 09.3 west of north

Buena Vista, Chaffee County.—The station is situated on property about two and one-half blocks south of the Denver and Rio Grande Railroad tracks. It is between the Episcopal and Methodist churches, about 8 feet north of a line drawn from the southwest corner of the Episcopal Church to the southwest corner of the Methodist Church, being 74 paces from the former and 107 paces from the latter. It is marked by a waterworn stone 20 inches long and 6 inches in diameter, with the letters U. S., 1906, on top. The following true bearings were determined:

	° ′
Cross on Catholic Church (mark)	76 44.2 west of north
Flag pole on Hotel Princeton	48 12.8 west of north
Methodist Church spire	67 51.7 east of south

Canon City, Fremont County.—The station is situated on the grounds of the north high school, outside the southeast corner of the same. It is 84 feet from the corner of the sidewalk across the street to the south, 74 paces from the southeast corner of the school building, and 36 feet from the center of the street east. It is marked by a cement post 8 by 8 by 24 inches, lettered U. S., 1906. The following true bearings were determined:

	° ′
Flag pole on Jefferson public school (mark)	9 36.9 east of north
Flag pole on high school building	78 07.8 west of south

Cortez, Montezuma County.—The station is situated on ground in the west part of town belonging to the baseball club. It is near third base, 126 feet southeast of the southeast corner of the bleachers and 132 feet north of the center of Main street, which runs east and west. It is marked by a hickory post 24 inches long and 5 inches in diameter, driven so that the top is even with the surface of the ground. The following true bearings were determined:

	° ′
Top of church steeple (mark)	40 50.4 east of north
Flag pole on schoolhouse	53 13.2 east of north

Craig, Routt County.—The station is situated in the street just outside of the baseball grounds. It is 60 feet from lot line across the street west and 147 feet from northwest corner of bleachers. It is

Descriptions of stations—Continued.

COLORADO—Continued.

marked by a brown sandstone post 6 by 6 by 30 inches, projecting 8 inches above the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Church spire (mark)	34 46.2 east of north
Flag pole on Hugus & Co. store	60 03.2 west of north

Delta, Delta County.—The station is situated on the east edge of the south half of the public school ground. It is 15 feet inside of the east line, 50 paces from the southeast corner of the schoolhouse, and 51 paces from the fence across the street to the south. The station is marked by a stone post, 6 by 6 by 26 inches, lettered U. S. C. & G. S., 1906, and projecting 1 inch above the ground. The following true bearings were determined:

	° ′
North water tank of city water works (mark)	54 38.6 east of south
South tank	54 06.6 east of south

Fort Collins, Larimer County.—The station is situated in the southeast part of the cemetery, which is west of town and near the fair grounds. It is 93 feet west of the east fence of the cemetery and 84 feet north of the south fence. The station is marked by a wooden post 6 by 8 by 24 inches, with a cross to indicate the exact spot. The following true bearings were determined:

	° ′
Flag pole on grand stand at race track (mark)	52 35.3 east of south
Near post on east gate to cemetery	33 13.2 east of north

Glenwood Springs, Garfield County.—The station of 1905 was reoccupied. It is in a fenced field in the eastern part of the Glenwood Fair Grounds, about 1 mile south of the center of town. It is in the southeastern corner of this field near the northeastern corner of the polo grounds and east of the grand stand and race track. It is 81.5 feet west of the east fence of the fair grounds and 116 feet north of the north fence around the polo grounds. The station is marked by a sandstone post 8 by 8 by 35 inches, projecting about 5 inches above the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined in 1905:

	° ′
East edge of standpipe at base (mark)	28 09.9 west of north
South point of red cupola	2 17.6 west of north
Eastern point of roof of exhibition building	83 56.0 west of north
Southeast edge of flag pole on polo clubhouse	37 53.7 west of south

Greeley, Weld County.—The station is situated just outside the race track at the fair grounds in the northwest part of town. It is 84 feet south of the fence inclosing the track and 240 feet southeast of the southeast corner of the grand stand. It is marked by a marble post showing a surface of 3 by 5 inches, projecting one-half inch above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Flag pole on judges' stand (mark)	4 03.2 west of north
Smokestack at pumping plant	41 30.4 west of south

Hahns Peak, Routt County.—The station is located on vacant land west of the town's main street. It is on the south side of the street running west between two large frame buildings, the only ones in town. It is 30 feet northwest of the road running southwest at a point about 150 paces from the hotel. It is almost due south of Hahns Peak (mountain). It is marked by a stake driven flush with the surface of the ground and covered with stones. The following true bearing was determined:

	° ′
Point of west gable of hotel (mark)	76 00.7 east of north

Holyoke, Phillips County.—The station is on the southwest corner of the block on which the public school building stands. The block adjoining on the west belongs to the city, and at the center of it is the standpipe of city waterworks. The station is 116.5 feet southwest from the corner of school

Descriptions of stations—Continued.

COLORADO—Continued.

building and 270.5 feet from the standpipe on a line bearing south of east. The station is marked by a cement block 9 by 9 by 30 inches, set even with the surface of the ground and lettered U. S. C. & G. S., 1906. The exact spot is marked by a three-eighths-inch hole in the top of this block. The following true bearings were determined:

	° ′
Presbyterian Church spire	17 58.2 west of north
Baptist Church spire	29 33.0 west of north
Windmill, 2 miles away	78 51.9 east of south

Meeker, Rio Blanco County.—The station is situated near the southeast corner of the public school grounds, 42 feet from the east street and 51 feet from the south street and about 150 yards from the school building. The station is marked by a stone post 8 by 8 by 32 inches, projecting 10 inches above the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Methodist Church spire (mark)	29 51.7 west of south
Flag pole on Odd Fellows Hall	43 28.1 east of south

Pagosa Springs, Archuleta County.—The station is located on the top of a small hill 224 paces east of the railroad tracks, at a point 280 paces south of the depot. It is at the top of the bluff overlooking the San Juan River. It is marked by a large natural stone showing about 2 feet of surface. A cross cut on this stone indicates the exact spot. The following true bearings were determined:

	° ′
Flag pole on schoolhouse (mark)	11 02.4 east of north
Middle stack on sawmill	0 04.8 east of south
Church steeple	23 39.4 east of north
Railroad water tank	17 42.6 west of north
Highest flag pole on old bath house	45 08.3 east of north

Red Cliff, Eagle County.—The station is situated just outside the cemetery on a mountain southwest of town. It is 12 feet southeast of the cemetery fence at a point 25 feet southeast of the large gate. The station is marked by a small stake driven into the ground and covered with stones. The following true bearing was determined:

	° ′
Gravestone of J. W. Groom (mark)	30 08.2 west of north

Rico, Dolores County.—The station is situated on property belonging to the United Rico Mining Company, in the northeast part of town on one of the foothills overlooking the town. It is about one-half mile east of the Rio Grande and Southern tracks, about 200 feet north of an elevated tramway running from the mines to the railroad tracks and 25 feet northeast of a large stone. The station is marked by a stake driven into the ground and small stones piled around it. The following true bearings were determined:

	° ′
Top of steeple on church (mark)	39 07.8 west of south
Flag pole on court-house	51 18.7 west of south
Flag pole on schoolhouse	75 23.0 west of north

Steamboat Springs, Routt County.—The station is situated on ground belonging to the town site company, 66 paces from the northwest corner of the schoolhouse fence, and 21 feet west of the diagonal road. It is marked by a white limestone, 6 by 7 by 30 inches, lettered U. S. C. & G. S., 1906, projecting 8 inches above the ground. The following true bearings were determined:

	° ′
Cupola on Methodist Church (mark)	56 09.0 west of south
Flag pole on school house	36 23.5 west of south

Descriptions of stations—Continued.

COLORADO—Continued.

Sulphur Springs, Grand County.—The station is situated on open land east of town. It is 102 feet north of Main street continued at a point 415 paces east of the Bank Block. It is marked by a post, 5 by 24 inches, set flush with the surface of the ground. The following true bearings were determined:

	° ′
Church spire (mark)	36 52.5 west of south
City flag pole	85 22.6 west of south

Toponas, Routt County.—The station is situated on property belonging to Mr. Terrel. It is 58 feet west of the fence surrounding the house and 41 paces from the fence across the road to the south. The station is marked by a rough stone extending 1½ inches above ground. The following true bearing was determined:

	° ′
Northeast corner at eaves of log shed directly south of house (mark)	45 27.4 east of south

Walsenburg, Huerfano County.—The station is situated on the public school grounds, 59.3 feet a little south of west of the east street, 62.7 feet a little east of south of the north street. It is 200.8 feet from the southeast corner of the schoolhouse. It is marked by a flint sandstone post, 6 by 6 by 30 inches, lettered on top U. S., 1906, and projecting 4 inches above the ground. The following true bearings were determined:

	° ′
Point of cupola on court-house (mark)	79 57.5 west of south
Flag pole on schoolhouse	70 11.7 west of south
Church spire	18 17.8 west of south

Wray, Yuma County.—The station is in the street west of the court-house. It is 24.3 feet from the east line of the street and 91.7 feet from the southwest corner of the court-house. The station is marked by a cement block, 8 by 8 by 36 inches, set 1 inch below the surface and lettered U. S. C. & G. S., 1906. The precise location is over a ⅜-inch hole in the top of the block. A similar block was set 232.8 feet due north of the magnetic station, marking a meridian line. This block is also set 1 inch below the surface of the ground. The following true bearing was determined:

	° ′
Middle of ornamented gable on post-office building	63 29.1 west of north

CONNECTICUT.

Stonington, New London County.—The station is marked by a drill hole in a flat rock, 2 by 3 feet in size, on the highest point of land on Wamphassuck Point, on the west side of the harbor of Stonington. There is a large bowlder 18 feet northwest from the station. The following true bearings were determined:

	° ′
Latimer Reef Light-house (mark)	20 26.3 west of south
Watch Hill Light-house	61 43.7 east of south
Inner Breakwater Light	55 13.9 east of south
Outer Breakwater Light	37 27.0 east of south
North Dumpling Light-house	60 48.5 west of south
Morgan Point Light-house	76 04.0 west of south

DISTRICT OF COLUMBIA.

Washington.—The station of 1904, near the Zoological Park, was reoccupied. It is about 50 feet south of the wire fence of the Zoological Park, about 18 feet southwest of a tree, and about 32 feet northeast of an oak tree 20 inches in diameter. It is marked by an oak stub. The following true bearings were determined:

	° ′
Southeast corner of small brick house on Cincinnati street (mark)	18 58.2 west of south
Dome of The Ontario	61 02.8 east of south

Descriptions of stations—Continued.

FLORIDA.

St. Marks, Wakulla County.—Observations were made at St. Marks Astronomical station, located at the confluence of the St. Marks and Wakulla rivers, just south of old Fort St. Marks, and just east of the center of the highest part of the open grassy plot at the point; 5 paces from high water on the southeast at the landing from the St. Marks River; 11 paces south of the point where the old road grade from the fort joins the grassy plot, and 11 paces from high water mark to the west. The station is marked by a 4-inch sewer tile set with flange down and 2 inches below the surface of the ground. The mark used was a small flag pole at Magnetic Azimuth triangulation station, distant 2 432.4 feet, and located in the center of the old railway grade running from St. Marks to Port Leon. It (the mark) is 460.2 feet south from North Base measured along the grade and is marked by an 18-inch piece of 4-inch sewer tile with top 2 inches below ground. The following true bearings were determined:

	° ′
Magnetic Azimuth (mark)	81 07.1 east of north
Stack of planing mill in St. Marks	39 39.8 east of north
Tank of sawmill in St. Marks	54 40.7 east of north

HAWAII.

Honolulu Magnetic Observatory, Oahu Island.—The observatory is about 12½ miles west of Honolulu and about three-fourths of a mile south of the station Sisal on the Oahu Railway. The observatory is described in Appendix 5, Report for 1902.

IDAHO.

Bonner's Ferry, Kootenai County.—The station is located in the cemetery, in the roadway, and in a street. It is 71.6 feet from the barb wire fence bounding the cemetery on the north and 34.0 feet from the base of marble monument marked Dr. Thomas A. Bishop. The station is marked by a hickory post, 2 by 6 by 26 inches, set flush with the surface of the ground and having a copper tack in the top to mark the exact spot. The following true bearings were determined:

	° ′
Pine tree on hill about 1 mile from cemetery	83 09.3 east of south
Extreme south edge of cross-arm of Fitzpatrick monument, which is of dark granite and about 10 feet high	83 41.5 east of south

Challis, Custer County.—The station is located west of the northwest portion of the cemetery, being 195.7 feet from the northwest corner of cemetery fence, and 190.5 feet from the north gatepost of gate leading into cemetery. The above measurements were taken over sage brush. The station is marked by an irregular rock, weighing about 60 pounds, planted flush with the surface of the ground and having a hole three-fourths of an inch in diameter by one-half of an inch deep drilled into it to mark the exact spot. The marking rock has smaller rocks piled over it for protection. The following true bearings were determined:

	° ′
Flag pole Odd Fellows' Hall (mark)	21 49.6 west of north
Flag pole public school	7 57.4 east of north

Grangeville, Idaho County.—The station is located on a level piece of ground to the east of the town. It is south of the portion of ground now being used as a baseball diamond, and is 187.7 feet from the northwest corner of the grand stand and 142.5 feet from the southwest corner. (The above property belongs to a Mr. Hall.) The station is marked by a pine post, 2 by 4 by 16 inches, planted flush with the surface of the ground and having a copper tack driven in top to mark the exact spot. The following true bearings were determined:

	° ′
Catholic Church spire (mark)	83 41.2 west of south
Flag pole Grangeville Roller Mill	36 49.1 west of north

Harrison, Kootenai County.—The station is located in the center of roadway leading into cemetery and is 84.6 feet from the base of tombstone of Blanche O. Knight. It is also 31.3 feet from a large pine

Descriptions of stations—Continued.

IDAHO—Continued.

stump south and east from station (measurements taken through underbrush). The station is marked by a red fir post 3 by 8 by 16 inches planted flush with the surface of the ground and having a copper tack driven in top to mark the exact spot. The following true bearing was determined:

	° ′
Pinnacle of Frederick Grant's monument (mark)	4 50.2 west of south

Lewiston, Nez Perces County.—The station of 1881 being no longer available, a new station was located in the center of the north street of the cemetery, being 73.4 feet from the base of Corporal Michael Collins's tombstone, 177.0 feet from the east side of tool house and 173.4 feet from the tombstone of Sergeant W. J. Johnson, the last measurement being taken along street to a point in street opposite tombstone. The station is marked by a rough granite post, 6 by 6 by 16 inches, planted flush with the surface of the ground and having a hole three-fourths of an inch in diameter and three-fourths of an inch deep drilled into top to mark the exact spot. The post is unlettered. The following true bearings were determined:

	° ′
Flag pole of Normal School (mark)	13 07.9 west of north
Church spire (across river)	72 45.1 west of north

Pierce, Nez Perces County.—The station is located on a hill to the east of town and to the south and west of the schoolhouse. It is 44.0 feet from the southwest corner of the school yard fence, 54.6 feet from the west gatepost, and 78.0 feet from the southwest corner of the schoolhouse. The station is marked by a pine post, 5 inches in diameter and 26 inches long, projecting about 4 inches above the surface of the ground and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	° ′
I. O. O. F. flag pole (mark)	60 58.3 west of south
Town flag pole (center of Main street)	59 00.0 west of south

Salmon, Lemhi County.—The station is located west of the northwest corner of the cemetery and is about 1½ miles south and east of town. It is 100.0 feet from the northwest corner of cemetery fence; 124.6 feet from base of monument to Lester P. Withington, and 100.0 feet from the first fence post north of the steps over the fence. The station is marked by an irregular shaped rock, weight about 35 pounds, planted flush with the surface of the ground and having a hole three-fourths of an inch in diameter by three-fourths of an inch deep drilled into it to mark the exact spot. The marking rock has smaller rocks piled over it for protection. All of the above measurements were taken over sagebrush. The following true bearings were determined:

	° ′
Flag pole public school (mark)	24 26.0 west of north
Flag pole Brown Block (1897)	27 31.1 west of north

St. Anthony, Fremont County.—The station is located about the center of the cemetery and is in the center of what appeared to be a circular street. On account of the sagebrush, however, it was impossible to get any accurate idea as to how the cemetery is laid out. The station is 186.8 feet from the base of Eli M. Hopkins's tombstone, 164.1 feet from the base of that of William M. Hopkins, and is 169.5 feet from that of Jane E. Russell. The above measurements were taken over sagebrush. The station is marked by a pine post, 24 inches long by 3 inches in diameter, planted flush with the surface of the ground and having a copper nail driven in top to mark the exact spot. The following true bearings were determined:

	° ′
Public school flag pole (mark)	48 32.2 east of north
Episcopal Church spire	64 07.1 east of north
Latter Day Saints' Church spire	81 52.5 east of north

Descriptions of stations—Continued.

INDIANA.

Brookville, Franklin County.—The station is in the southeastern corner of Elm Grove Cemetery, being in the third intersection from the east and south. It is 27.5 feet from the base of a tombstone marked Skinner and 25.8 feet from the base of one marked Fread. The station is marked by a limestone post, 5 by 6 by 28 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Public school cupola flag pole (mark)	60 28.2 east of north
Presbyterian Church spire	88 53.4 east of south

Connersville, Fayette County.—The station is in Roberts Park, about 3 miles north of the town. It is to the northeast of the main fair building and is north and west of the race track. The race track is on low ground and can not be seen from station. A large hickory tree to the north and east of station is distant 24.8 feet, and a small tree to the south and west is distant 43.4 feet. The station is marked by a marble post, 6 by 6 by 20 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Maplewood schoolhouse cupola (mark)	20 29.1 west of south
Mr. Mount's barn cupola (weather vane)	13 44.8 east of north

Newcastle, Henry County.—The station is located on the grounds of the State Home for Epileptics and is near the crest of the high grounds on which the buildings are located. It is 77.9 feet about southwest from a large sugar-maple tree on the side of the hill and 207.7 feet from the southeast corner of the doctor's residence. The station is marked by a Bedford limestone post, 8 by 8 by 30 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Court-house cupola (mark)	5 45.6 west of south
Public school flag pole	2 10.9 west of south

Richmond, Wayne County.—The station of 1900 was reoccupied. Observations were made over a stone post, 6 by 6 inches on top and 3 feet long, set about 2 feet in the ground. The top of this stone is lettered U. S. B. & G. S., with a cross in its center. The center of this cross marks the point. This post is located on the campus of Earlham College, about 1½ miles west of the city. It is placed in the open space in the rear and south of the college buildings and southwest of the dormitory, in line with the last row of shade trees between the campus proper and the adjoining field. It is distant about 63, 45, and 51 feet, respectively, from three adjacent trees. The following true bearings were determined in 1900:

	° ′
Tip of large monument in cemetery (mark)	62 31.2 west of south
Right-hand edge of chimney on Mr. Martin's house	13 12.8 east of south
Spire of Irish Church in Richmond	87 38.2 east of north

Winchester, Randolph County.—The station is located in the eastern part of Fountain Park Cemetery, and is on the ground just south of the part in present use. It is in an alley, 215.2 feet from the base of a tombstone marked Frank A. and Mary Hamilton, 72.7 feet from a small tree nearly west from station and bordering a driveway, and 59.0 feet from a similar tree nearly north from station and bordering a driveway. The station is marked by a limestone post, 6 by 6 by 30 inches, sunk flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Tip of Heaston monument (mark)	84 03.4 west of south
Tip of Wysong monument	40 08.9 west of north

INDIAN TERRITORY.

Carson, Chickasaw Nation.—The magnetic station is near Carson triangulation station, which is about 3 miles south and 1 mile west of Minco. The station is on land formerly leased to Kit Carson,

Descriptions of stations—Continued.

INDIAN TERRITORY—Continued.

of Minco, and is in a large wheat field on the highest point of a prominent ridge. It is in sec. 8, T. 9 N., R. 7 W. The Chicago, Rock Island and Pacific Railroad runs through a deep cut about three-fourths of a mile to the eastward of the station. The magnetic station is marked by a copper nail in a small wooden hub, distant 102.2 feet from the triangulation station, and in exact line between the triangulation station and the belfry of the Elmeta Bond College, of Minco. The following true bearings were determined:

	° ′	
Belfry of Elmeta Bond College at Minco	14 09.4	east of north
Center of south gable of house one-half of a mile distant	36 32.1	east of north
Center of west gable of house 1 mile distant	80 26.1	east of north
Center of east gable of house three-fourths of a mile distant (mark)	64 29.9	west of north

KANSAS.

Anthony, Harper County.—The station of 1902 was reoccupied. It is in the northeast corner of the court-house yard. It is 12 feet from the north fence, 44.7 feet from the east fence, and 150 feet from the northeast corner of the old court-house. The station is marked by a stone post 4 by 4 inches, set in the ground by the county surveyor. The top of the stone has the shape of a truncated pyramid, being 4 inches square at the top of the ground and 1½ inches square 2½ inches above ground. The following true bearings were determined.

	° ′	
Spire of Baptist Church	32 13.5	west of north
Southwest corner of square house	51 49.8	east of north
Spire of high school	27 50.7	east of south
Southeast corner of east chimney of new jail	19 02.7	west of south

Baldwin Magnetic Observatory, Baldwin, Douglas County.—Observations were made in the absolute house of the magnetic observatory. The mark used is the flag staff on Science Hall, Baker University, and bears 48° 20′.6 west of true north.

Brown, Smith County.—The old magnetic station was recovered and found in good condition, but as the station was surrounded by high trees, observations were made at Brown triangulation station. It is located in a field of Kaffir corn on land of Mr. C. F. Shade, living three-eighths of a mile southwest in southwest corner of section. It is on the west brow of elevated ridge crossed by half section line road running east from Smith Center, and is 100 paces east of NW. corner NE. ¼ SW. ¼ sec. 20. The hedge mentioned in description is likely to be soon removed, but as it is on the fence line, the distance from station to fence is same as distance of station to hedge. The magnetic station is marked by a copper nail in a stub set in exact line from triangulation station to center of standpipe at Smith Center, and distant 182.6 feet. The following true bearings were determined:

	° ′	
Center of standpipe, Smith Center	89 11.2	west of north
Center of chimney on white house	52 23.0	west of north
Center of west chimney of Mr. Shade's house	45 17.8	west of south
Center of chimney on house 1½ miles distant	27 07.4	west of north

Hutchinson, Reno County.—The station of 1904 was reoccupied. It is on the east side of the grounds of the Central Kansas State Fair Association, about three-fourths of a mile north of the business section of Hutchinson. It is 64.2 feet west of the east boundary fence, 115.6 feet southwest from the southwest corner of east fence horse sheds, and 72.1 feet and 56.4 feet, respectively, from small elm trees standing southward from it. It is marked by a Bedford limestone post 6 by 6 by 27 inches, lettered U. S. C. & G. S., 1904. The top of the stone is 4 or 5 inches below level of surrounding ground in a small hollow or cup. The following true bearings were determined:

	° ′	
Spire North Side School	4 21.8	east of south
Smokestack of Light and Power Company	23 49.1	west of south
Southeast corner of stock barn	63 26.1	west of north

Descriptions of stations—Continued.

KANSAS—Continued.

Salina, Saline County.—The station of 1904 was reoccupied. It is on the grounds of the Kansas Wesleyan University at a point 327.6 feet northeast of the northeast corner of the main building, 209.2 feet south and a little east of the southeast corner of the dwelling across the street, and about 300 feet west of the tracks of the McPherson Branch, Union Pacific Railroad. It is marked by a limestone post 6 by 6 by 30 inches, set flush with the ground and lettered U. S. C. & G. S., 1904. The following true bearings were determined:

	° ′
Spire of old Logan School (mark)	16 06.3 east of north
Square dwelling house, southwest corner, 270 feet distant	26 25.5 east of north
Northeast corner of foundation of main building	55 56.8 west of south
Southeast corner of girls' dormitory	70 37.6 west of north

MAINE.

Portland, Cumberland County.—The station of 1903 could not be located on account of changed surroundings and not being marked. Observations were taken over the middle monument of the meridian line in the city park on Bramhall Hill, and along what is called Western Promenade. The mark used was the north monument of the meridian line.

Rockland, Hancock County.—The station of 1905 was reoccupied. It is situated on the golf links of the Samoset Hotel on Jamesons Point near Rockland. It is most easily reached from Rockland Harbor by landing at the Breakwater landing, follow breakwater and road beginning at its end to where this road joins the main road going north. Near the junction of the roads, 10 feet east of the main road, 20 feet north of the breakwater road, there is found a granite bowlder with a cross cut in its highest part. This marks the station. The following true bearings were determined in 1905:

	° ′
Breakwater Light-house (mark)	14 02.5 east of south
Owl's Head Light-house	48 11.5 east of south
Left tangent Atlantic Wharf	30 48.7 west of south
Flag pole in front of Samoset Hotel	85 01.5 west of south
Flag pole on Samoset Hotel	69 02.0 west of north

MARYLAND.

Baltimore, Patterson Park I, Baltimore City County.—The station of 1905 was reoccupied. It is a little to the eastward of the center of Patterson Park, about 200 feet south of a shelter house and on a terrace below the same. It is 43.2 feet northwest from the edge of a roadway. This roadway leads south to the Luzerne street entrance on Eastern avenue. It is 13.8, 29.8, and 41.2 feet west-northwest, north by east and northeast, respectively, from small trees. The distance to the foot of the embankment to the northward is 20.5 feet (approximately). The station is marked by a stone post 6 by 6 by 30 inches, lettered U. S. C. & G. S., 1905, and sunk flush with the sod. The following true bearings were determined in 1905:

	° ′
Dome of insane asylum (mark)	88 10.4 east of north
Church spire to southeast	62 47.8 east of south

Baltimore, Patterson Park IV, Baltimore City County.—The station, Patterson Park III, could not be found. A new station was established in the immediate vicinity. It is in the northeastern part of the park, in the open field, about 600 feet northeast of a large stone building formerly used as a casino. It is marked by a marble post 6 by 6 by 30 inches, set 2 inches below the surface of the ground, with top lettered U. S. C. & G. S. It is 63.7 feet north-northwest from a sycamore tree near a driveway, and 23 feet south of a small maple tree 6 inches in diameter. The station is in range with an elm tree

Descriptions of stations—Continued.

MARYLAND—Continued.

about 250 feet to the eastward and the center of Lombard street, Highlandtown. The following true bearings were determined:

	° ′
Dome of insane asylum (mark)	87 19.3 east of south
Sacred Heart Church spire	55 01.8 east of south
Cross on St. Elizabeth's Church	41 56.1 east of north
Weather vane on Park shelter house	7 23.8 east of south

Cheltenham, Prince George County.—The station is at the Coast and Geodetic Survey magnetic observatory, on the grounds of the State Reform School.

MASSACHUSETTS.

Boston, Suffolk County.—The station is on Castle Island south of Fort Independence, about 50 feet northwest of the station of 1905. It is 143 paces from the south entrance to the fort, and is 6 feet west of a direct line from the south entrance of fort to a large tank on a distant hill to the south. It is also 142 paces from the southeast corner of the fort, 135 paces from the southwest corner, and 63 paces from a small walk, in a direct line to the south entrance. The station is marked by a limestone post 6 by 6 by 32 inches, projecting 1 inch above the surface of the ground, and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Central flagpole on Marine Park Headhouse (mark)	67 36.4 west of south
White spire in South Boston	81 40.6 west of south
Southwest corner of fort, above stone foundation	18 02.5 west of north
Southeast corner of fort, below top coping	38 23.5 east of north
Long Island Light-house	80 56.4 east of south
Spectacle Island Light-house	64 48.4 east of south

Salem, Essex County.—The station was established on the Government reserve around the Fort Pickering Light-house. The old fort has been torn down and only the embankments remain. The station is on the south embankment and is almost due east from the light-keepers' dwelling. The light-house is distant 82 paces from the station and bears 15° east of south. The head of the steps leading down from the embankment to the light-house is distant 42 paces. The station is marked by a limestone post 6 by 6 by 32 inches, projecting 1 inch above the surface of the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Catholic Church spire (in Salem) (mark)	71 32.6 west of south
Prominent spire in Salem	76 46.0 west of south
Church spire	76 16.8 west of south
Spire in Beverly	29 06.5 west of north
Spire in Marblehead	11 05.2 east of south

Vineyard Haven, Dukes County.—The station is on the reservation of the United States Marine-Hospital Service on the lawn in front of the building. It is 88.5 feet southeast of the flagstaff and 193 feet east-northeast from the northeast corner of the brick basement of the building. It is 1.5 feet southeast from the line of tangency of the east end of the hospital building and the east end of the attendants' quarters to the rear. The station is marked by a granite post 5 by 5 by 30 inches, set flush with the surface of the ground. The following true bearings were determined:

	° ′
Center of East Chop Light-house (mark)	49 01.7 east of north
Town Hall spire	44 29.6 west of north
Center of standpipe	55 09.0 east of south

Descriptions of stations—Continued.

MICHIGAN.

Detroit, Wayne County.—The station of 1900 was reoccupied. It is on the southeastern shore of Belle Isle, in the Detroit River, about 200 yards west of the light-house. It is marked by a blue limestone post, 8 inches square, lettered on top U. S. C. & G. S., and sunk flush with the surface of the ground. This stone is 83.5 feet east of a flower bed, 75 feet from the river shore, and 64.5 feet from the edge of a driveway. The following true bearings were determined in 1907:

	° ′
North gable of house across river (mark)	36 31.0 west of south
Only visible church steeple	67 15.8 west of south
Belfry to southwest	63 15.2 west of south

Monroe, Monroe County.—The station is on a farm belonging to St. Mary's Academy about three-fourths of a mile northwest of the center of town. It is in the third fenced-in field north of the orphanage, near a cellar lined with stone. It is 182.6 feet north of the south fence, 185.8 feet west of the east fence, and 105 feet northwest of the northwest corner of the above cellar. It is also between two tree stumps in this field. It is marked by a Bedford limestone post 6 by 6 by 30 inches, projecting 4 or 5 inches above ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Cross on steeple of German Catholic Church (mark)	20 19.3 west of south
Cross on cupola of the Academy	24 37.8 east of south
Northeast edge of smokestack of power house	31 09.5 east of south

Mount Clemens, Macomb County.—The station is in a pasture belonging to Mr. John Irwin, about 1½ miles northeast of the center of town. It is about 300 or 400 feet a little south of east of Mr. Irwin's house and about 95 feet a little north of west from the west bank of the Clinton River in line with Mr. Irwin's house. The station can be found by referring to the city engineer or to Mr. Irwin. It is marked by a Bedford limestone post 6 by 6 by 26 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Flagstaff on cupola of City Hall	70 58.9 west of north
Catholic Church steeple	62 47.0 west of north

MINNESOTA.

Dalton, Ottertail County.—The station is located in a vacant lot owned by Mr. M. T. McMahon, who lives in Fergus Falls and owns the Dalton Lumber Company. It is 65.5 feet from the Dalton Astronomic station and in direct line to Dalton triangulation station. It is marked by a wooden stub. The astronomical station is on the top of a small knoll one block south of Main street and about 400 feet from the Great Northern Railway, and is marked by tile and concrete. The following true bearings were determined:

	° ′
Triangulation station (mark)	89 01.9 west of south
North spire on Dalton Creamery	87 19.5 west of north
South gable of bank of Dalton	24 38.7 east of north
East gable of cupola of elevator near lumber yard	2 34.2 east of south

Glyndon, Clay County.—The station of 1900 was recovered and is in apparently good condition. Top is now just below surface of ground and covered with grass. Marked by a 6-inch sewer tile, center of top of tile being used as center of station. It is in the old city park of Glyndon, 40 feet from the north fence and 106.5 feet from the east fence, and almost due south of east post of north entrance to grounds. The following true bearings were determined:

	° ′
Center of tall square brick chimney of Doctor Lowe's residence (mark)	14 31.0 east of south
Spire of schoolhouse	23 06.8 west of south
North edge of cupola of elevator near depot	70 57.8 west of south
Northeast edge of house of Misses Olson (across street)	18 34.4 west of north

Descriptions of stations—Continued

MISSOURI.

Chillicothe, Livingston County.—The station of 1903 was reoccupied. It is on the grounds of the State Industrial Home for Girls. It is south from the fence along Third street 91.5 feet, 73 feet northwest from an oak tree, 92.2 feet northeast of an elm tree, and about 200 feet from the main building of the home. It is marked by a gray sandstone post 6 inches square, projecting about 2 inches above the surface of the ground and lettered U. S. C. & G. S. The following true bearings were determined.

	° ′
West edge of standpipe (mark)	45 40.5 east of south
Left edge of brick chimney	12 41.4 east of south

Kansas City, Jackson County.—The station of 1900 was reoccupied. It is in Elmwood Cemetery, in block 3, midway between the northeast corner of lot No. 90 and the southeast corner of lot No. 108. It is marked by a white marble post 6 inches square on top, sunk flush with the surface of the ground and lettered U. S. C. & G. S. The following true bearing was determined:

	° ′
Extreme right edge of monument marked Albin (mark)	1 32.6 west of south

MONTANA.

Avery, Chouteau County.—The station is located to the west of Mr. Murray's house (the only house in Avery) and is 317.1 feet from the southwest corner of the blacksmith shop. It is between the dwelling house and barn and a little to the south of a straight line joining the two. Station is marked by a round quart bottle, planted base downward, mouth about flush with surface of ground, and having rocks and small stones piled around it so as to form a circle around bottle. Center of mouth of bottle marks the exact spot. The following true bearing was determined:

	° ′
Extreme edge of southeast corner of Mr. Murray's house (mark)	88 06.1 east of north

Big Sandy, Chouteau County.—The station is located on a little hill to the south of the town and railroad track. It is 432.7 feet from the southwest corner of John Lafeldt's dwelling house and 142 feet from the center of a fence post in range with the southwest corner of Mr. Lafeldt's house. The station is marked by a hickory post, 3 by 4 by 14 inches, planted a little below the surface of the ground and having a copper tack driven in top to mark the exact spot. The schoolhouse flag pole was used as a mark and standing on station the center of chimney, Mr. John Beeker's residence, and flag pole are in range. The following true bearings were determined:

	° ′
Flag pole of schoolhouse (mark)	81 46.2 west of north
Flag pole on general merchandise store and post-office	46 58.4 west of north

Big Timber, Sweet Grass County.—The station is located in the cemetery about 2 miles to the south and west of town. It is in the roadway leading into the cemetery and is about five streets from the entrance. It is 54.5 feet from the base of Maurice A. Whitney's tombstone, 57.8 feet from that of Hattie Vestol, and 83.0 feet from that of John E. Sheridan. The station is marked by a pine post, 2 by 4 by 18 inches, planted flush with the surface of the ground and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	° ′
Town school flag pole (mark)	55 22.0 east of north
High school flag pole	47 37.4 east of north
Court-house flag pole	33 51.4 east of north

Billings, Yellowstone County.—The station of 1896 being no longer available, a new station was located to the east of the cemetery, in a roadway leading through an alfalfa field belonging to Mr. O'Donnell. It is 236.0 feet from the gate opening into the cemetery on the east and 232.7 feet from a point in the cemetery fence opposite the third tree to the north of gateway. The station is marked by a

Descriptions of stations—Continued.

MONTANA—Continued.

granite post, 6 by 6 by 24 inches, planted about 2 inches beneath the surface of the ground and lettered on top U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Spire, First Congregational Church (mark)	64 18.9 east of south
Court-house cupola	65 25.8 east of south
Flag pole, City Hall	68 32.8 east of south
Flag pole, public school	76 18.7 east of south

Birney, Rosebud County.—The station is located in a pasture on the south side of the county road, about 80 rods east from the point at which Hanging Woman Creek empties into Tongue River. It is west from the southwest corner of the Birney schoolhouse 98.5 feet, and the south line of the building passes 26.7 feet to the south from the station. It is about 100 feet from the wagon road, and east from the store building. The station is marked by a red stone, irregular and larger below ground, cut rectangular 5 by 9 inches above ground, projecting 4 inches above the ground, and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Base of leaning tree on hilltop several miles distant (mark)	78 47.6 west of south
Extreme south vertical edge of large bowlder at top of hill about 1 mile east	81 38.9 east of south

Browning, Teton County.—The station is located a little to the west of north from cemetery (cemetery is about 2 miles north and west of town), and is 196.4 feet from the base of H. H. Arthur tombstone and 227.1 feet from the base of Therese Keizer tombstone. The station is marked by a sandstone rock, roughly cylindrical, 10 inches long by 5 inches in diameter. The rock is planted about flush with the surface of the ground and has a hole three-fourths of an inch in diameter and three-fourths of an inch deep drilled into it to mark the exact spot. Rocks are piled around marking stone for protection and to assist in finding it. The following true bearings were determined:

	° ′
Flag pole, W. C. Broadwater's store (mark)	67 29.5 east of south
Flag pole (residence)	71 18.3 east of south
Center of dome, railroad water tank	29 17.3 east of south

Choteau, Teton County.—The station is located in the cemetery, in the first street to the south from entrance, and is nearer the west than the east side. It is 26.9 feet from base of Lizzie Zimmerman tombstone, 34.5 from that of Stephen G. Read, and 23.6 feet from that of Norman P. Bruce. The station is marked by a Montana sandstone post, 6 by 6 by 24 inches, planted flush with the surface of the ground and lettered on top U. S. C. & G. S., 1906. Center is marked by hole in center of stone. The following true bearing was determined:

	° ′
Flag pole district schoolhouse (mark)	85 30.9 west of south

Deer Lodge, Powell County.—The station is located on the grounds of the Montana College, being west of the buildings. It is 320.2 feet from the northwest corner of the step foundation of the girls' dormitory and 279.2 feet from the northwest corner of Taske Hall. The station is marked by a pine post, 2 by 4 by 16 inches, projecting above the surface of the ground about 5 inches, and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	° ′
Penitentiary flag pole (mark)	59 13.0 west of south
Christian Church spire	42 50.0 west of north
Rod on cupola of Taske Hall	59 53.8 east of south

Divide, Silverbow County.—The station is in a pasture belonging to Mr. White, and is about one-half mile a little to the north of west from the depot. It is 171.3 feet from the west gatepost of gate opening into pasture, 45.0 feet from the center of old road leading through pasture, and 85.5 feet from the fence bounding pasture on the east. The station is marked by a rough rock, weight about 40

Descriptions of stations—Continued.

MONTANA—Continued.

pounds, planted flush with the surface of the ground, and having a hole one-half of an inch deep and three-fourths of an inch in diameter drilled into it to mark the exact spot. A pile of small rocks was placed over marking rock for protection. The following true bearing was determined:

	° ′
Depot flag pole (mark)	82 29.8 east of south

Observations were also made at a point about 500 feet to the northeast, but they showed the presence of local disturbance.

Fort Benton, Chouteau County.—The new station is located in the open space northeast of town and down the river and is between Main street and the river. It is 348.9 feet from the northeast corner of large warehouse and 263.1 feet from the northwest corner of the same building. The station is marked by a pine hub, 2 by 4 by 15 inches, and planted a little below the surface of the ground and having a copper tack driven in top to mark the exact spot. Two hickory stakes about 10 inches long are driven in ground along side of marking hub, one on the north and one on the south side, and project above the surface of the ground about one-fourth of an inch. The following true bearings were determined:

	° ′
Flag pole, First National Bank Building northwest corner of Baker and Main streets (mark) (now unoccupied)	43 40.3 west of south
Church spire	67 50.7 west of south

Gateway, Flathead County.—The station of 1905 was reoccupied. It is northwest of the town, 650 feet east of the railroad track, on an open level flat or bench elevated above the town and river. It is 119 feet north of the station of 1903, in a meridian line about 1 150 feet long, each end of which is marked by an iron pipe. The station is 109.1 feet north of the south meridian post and about 700 feet west of the boundary monument. It is marked by a yellow-pine post, 32 by 8 by 8 inches, set 2 feet in the ground, and having a wire nail driven in the center of the top.

Glendive, Dawson County.—The station of 1896 being no longer available for magnetic observations, a new station was located near the edge of a tract of land known as Lloyd square, or in the street closely adjacent to it. The square is in the northern part of the city near the Yellowstone River, and a large portion of it lies in a gully washed out by the water from the hills to the east. The station is in the north line of Kendrick avenue, about 100 feet from the banks of the gully and probably about 20 feet from the south corner of Lloyd square in Allard street, though in absence of landmarks the exact location of street lines is rather uncertain. The station is marked by a limestone post, 5 by 7 by 28 inches, lettered U. S. C. & G. S., 1906, projecting 3 inches above the surface of the ground. The following true bearings were determined:

	° ′
Tip on water tank (mark)	10 43.9 west of south
Tip on east corner court-house tower	34 22.6 west of south
Tower on W. F. Jordan's house	57 33.7 west of south
Judges' stand at fair grounds	19 14.8 east of north

Observations were also made at the 1896 station. It is in a large vacant lot belonging to the Northern Pacific Railway Company, on the south side of the town, between Power street and Nowlan avenue.

Great Falls, Cascade County.—The station is located in Highland (Protestant) Cemetery. It is nearly in the center of a driveway and is 76.0 feet from the corner of William McGurdie monument. This monument is near that of Donald Day. The station is 88.3 feet from the corner of Gladys Walker monument and 99.1 feet from the corner of E. W. Dahlgren monument. The station is marked by a Montana sandstone post, 6 by 6 by 26 inches, planted flush with surface of ground and lettered U. S. C. & G. S., 1906. A hole in center of top of post marks the exact spot. The following true bearings were determined:

	° ′
Large white cross in Catholic Cemetery (mark)	33 21.2 west of south
Smelter brick chimney (center)	2 37.2 east of north

Descriptions of stations—Continued.

MONTANA—Continued.

Havre, Chouteau County.—The station is located in Mount Hope Cemetery, in the north and south driveway leading into cemetery from the south. It is 8.7 feet from the footstone and 15 feet from the headstone of Eva Maddux. These stones are almost directly west from station. It is also 49.2 feet from southeast corner base of Peter G. Gowrie tombstone and 67.2 feet from southeast corner base of Maggie Abernathy tombstone. The station is marked by a rough, irregular-shaped white limestone rock, weight about 20 pounds, and planted just below the surface of the ground. The rock has a hole three-fourths of an inch in diameter and one-half of an inch deep drilled into it to mark the exact spot. The only available mark is the flag pole of the Havre Hotel. The following true bearing was determined:

	° ′
Flag pole of Havre Hotel (mark)	87 37.8 east of south

Jennings, Flathead County.—The station is located on an open space (slightly inclined) north of the Kootenai River. It is across the river from the town and about northwest from depot. The station is about 100 feet from the north edge of the river, though bowlders and fallen tree tops prevented an accurate measurement. It is marked by a hard-wood post, 4 inches in diameter by 30 inches long, projecting above the surface of the ground about a foot and having a copper nail driven in the top to mark the exact spot. The marking post has a U. S. C. & G. S. warning (Form 51) tacked to it on the north side. The following true bearing was determined:

	° ′
Stovepipe of Mr. Baenen's hut (mark)	8 16.5 east of south

Judith, Fergus County.—The station is located in front of Mr. Norris's dwelling house and is 125.2 feet from the northwest corner of the yard fence, 124.0 feet from the southwest corner, and 83.4 feet from the center of the gateway. The station is marked by a pine post, 2 by 4 by 22 inches, planted about an inch below the surface of the ground and having a copper nail driven in top to mark the exact spot. The following true bearing was determined:

	° ′
Northeast corner of Mr. Norris's store (mark)	48 38.1 west of north

Kalispell, Flathead County.—The station is located in the old cemetery, about 3 miles south and east from town, and is near the center of the north and south driveway leading into the cemetery from the south. It is 70.5 feet from the board fence bounding cemetery on the north, 128.5 feet from the base of John R. Ebert tombstone, 104.7 feet from the base of Amanda Johnson tombstone, and 97.2 feet from the base of Harry Connor tombstone. The station is marked by a pine post, 2 by 4 by 16 inches, planted flush with the surface of the ground and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	° ′
Court-house cupola (mark)	24 57.0 west of north
Flag pole on cupola of Mr. Spinoot's barn	27 46.8 east of south

Missoula, Missoula County.—The station of 1905 was reoccupied. It is on the grounds of the State University, north of the eastern part, and about 1 mile southeast of town. It is in the southeast corner of the running track and athletic field and east of University Hall. It is 67.7 feet west of the fence bounding the athletic field on the east and 143.5 feet north of the fence bounding the athletic field on the south. The station is marked by a granite post, 6 by 6 by 24 inches, projecting 1 inch above ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
First Methodist Episcopal Church spire (mark)	31 39.7 west of north
Cupola on University Hall	83 10.4 west of south
Gymnasium flag pole	65 56.4 west of north

Neihart, Cascade County.—The town of Neihart is situated in a narrow valley between two very high and precipitous ridges. Valley is not more than 1 000 feet wide in any place, and has a railroad track and 12-inch water main running down center of it, consequently it was very difficult to find a suitable location for a permanent magnetic station. A station, however, was established in an open

Descriptions of stations—Continued.

MONTANA—Continued.

space to the south and east of town, about 2 000 feet from railroad terminal and about 350 feet from corner of water main. The station is to the east of road leading out of town to the south and east, and is 207 feet from center of bridge where road crosses Belt Creek. It is also 44 feet from the foot of the mountain (incline very pronounced), the two measurements being taken on a straight line running through station. The station is marked by a pine post, 6 inches in diameter and 15 inches long, planted flush with surface of ground and having a copper tack driven in top to mark the exact spot. A large rock, weight about 75 pounds, is placed over post for protection. The following true bearing was determined:

	°	′	
Schoolhouse flag pole (mark)	36	14.6	west of north

Ovando, Powell County.—The station is located on a small rocky knoll about 1 500 feet to the east of town. It is 367.4 feet from the northwest corner of board fence of cemetery and 319.7 feet from the northeast corner of Mr. Hunsecker's dwelling house, both measurements being taken on an incline. The station is marked by an irregular-shaped rock (roughly triangular) weighing about 30 pounds and having a hole three-fourths of an inch in diameter and three-fourths of an inch deep drilled into it to mark the exact spot. The marking rock is planted flush with the surface of the ground and has a pile of smaller rocks placed over it for protection. The following true bearings were determined:

	°	′	
North edge of chimney on Mr. Dixon's house (mark)	81	51.0	west of north
North gable of schoolhouse bell tower	3	44.6	west of south

Poplar, Valley County.—The station is located within the grounds of the Indian school, the Poplar Valley Training School, on an open space southwest of the school buildings. It is 56.5 feet north of the east and west fence limiting the grounds on the south, 64 feet south of the line determined by the south sides of the two dormitories, and in line with the west side of the building used as a hospital. It is marked by an irregular bowlder, projecting 3 inches above the ground, the projecting portion being about 7 inches in diameter. A cross was made in the top with a stone hammer, the branches lying approximately N., S., E., and W. The following true bearings were determined:

	°	′	
Tip on agency water tank (mark)	16	14.3	west of south
Spire on Catholic Church	76	23.3	west of south
Southwest corner, at base, of hospital	5	46.3	west of north
Low peak on horizon, seen over northeast corner of cemetery fence	68	14.4	east of south

Red Lodge, Carbon County.—The station is located west of the cemetery and is 127.5 feet from the base of Annie Reardon's tombstone, 127.4 feet from that of Willie Barry, and 129.3 feet from that of D. J. Nelson. The station is marked by a pine post 4 by 4 by 20 inches, planted flush with the surface of the ground and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	°	′	
South telegraph pole on hill east of town mark)	50	43.6	east of south
North pole	53	44.0	east of south
Middle pole	52	10.0	east of south

Ronan, Missoula County.—The station is located northwest of the Government school building, being 343.0 feet from the southwest corner of the building and 301.6 feet from the northwest corner of wing of building. It is also 133.6 feet from a board fence north of station. The station is marked by a pine post 2 by 4 by 26 inches, projecting about 3 inches above the surface of the ground and having a copper nail driven in top to mark the exact spot. The following true bearings were determined:

	°	′	
West white knob on roof of flour and saw mill mark)	74	07.9	east of south
East white knob on roof of flour and saw mill	74	14.0	east of south

Descriptions of stations—Continued.

MONTANA—Continued.

Shelby, Teton County.—The station is located on a rocky knoll to the north of cemetery. It is 109.6 feet from the northeast corner of cemetery fence and 88.7 feet from the fifth post in fence bounding cemetery on north, posts being counted from northeast corner with corner post as number 1. The station is marked by a Montana sandstone post 6 by 6 by 26 inches, projecting about 3 inches above surface of the ground and lettered on top U. S. C. & G. S., 1906. A hole near center of stone marks the exact spot. The following true bearing was determined:

	° ′
Flag pole on old office of Shelby Independent (newspaper) (mark)	82 02.8 east of north

Sweet Grass, Teton County.—The station is located to the southwest of town, west of the railroad track, and is near two large sandstone rocks. A straight line connecting station and south flag pole of depot passes a little to the west of rocks. The station is 36.8 feet from the west edge of nearer rock and is 41.1 feet from east edge of farther rock. The station is marked by a pine hub 2 by 4 by 20 inches, planted flush with surface of ground and having a copper nail driven in top to mark the exact spot. The following true bearings were determined:

	° ′
South flag pole of depot (mark)	8 35.6 east of north
Cross on church (Canadian side)	21 29.2 west of north

Tokna, Dawson County.—The station is at the ranch of Mr. August Frederickson, across the creek to the southward from his buildings, on a sandy flat within a horse pasture. It is in the line of the telephone poles extended from the south, and about 62 paces westward from the highway bridge across White Clay Creek. It is also nearly in line with the east edge of the log structure now used as an ice house. The station is marked by an irregular blue limestone post, projecting 4 inches above the surface of the ground and marked on top with a cross whose arms extend approximately N., E., S., and W. The following true bearings were determined:

	° ′
Flag pole on schoolhouse (mark)	8 20.5 west of south
Southeast corner of Emmett Dunlap's house	56 41.3 west of north
Peak of ventilator on ice house	32 11.4 east of north

Wisdom, Beaverhead County.—The station is located on the private property of a Mr. Miller, and is to the north and east of the schoolhouse. It is 313.1 feet from the northeast corner of the schoolhouse and 112.1 feet from the south gatepost of gate to north and east of station. The station is marked by a pine post 20 inches long by 9½ inches in diameter, projecting above the surface of the ground about an inch and having a copper nail driven in top to mark the exact spot. The following true bearings were determined:

	° ′
Flag pole rear of J. P. Lossl's store (mark)	5 37.0 west of north
North gable schoolhouse bell tower	29 01.5 west of south

Zortman, Chouteau County.—The station is located on a small ridge to the south and east of town (near some graves that there is talk of moving), and is 81.3 feet from the northwest corner of the board fence surrounding the grave of Tow Head (a suicide), and 79.3 feet from the southwest corner of the same fence. Station is marked by a pine hub 3¾ inches in diameter and 12 inches long, planted an inch below the surface of ground and having a copper nail driven in top to mark the exact spot. A pine stake is placed against hub on the south side and projects above the surface of the ground about 5 inches. Rocks are piled around stake to protect it. The inside edge of the corner facing of the northeast corner of the meat market was used as a mark. The following true bearing was determined:

	° ′
Northeast corner of meat market as above described (mark)	29 03.6 west of north

Descriptions of stations—Continued.

NEBRASKA.

Chadron, Dawes County.—The station of 1896 being no longer available for magnetic observations, a new station was located about five-eighths of a mile south from the old station. It is located on a bench about three-fifths of the way up the hill, which is south from the end of the street that passes by the east side of the county court-house square. The east walk line of this street, if continued up the hill, would pass about 25 feet east of the station. The station is marked by a cement post 7 by 7 by 32 inches, set 8 inches above the surface of the ground and is lettered U. S. C. & G. S., 1906. (A rain on the following night may have defaced the lettering but not the stone set in a box.) The following true bearings were determined:

	° ′
Ball on cupola on Chadron High School (mark)	30 53.6 east of north
Southwest corner of brick work on cupola of court-house	3 53.2 east of north
Lower ball on cupola of Chadron Academy	24 06.2 east of north

Daily, Greeley County.—The triangulation station is on the crest of a prominent hill in NW. ¼ sec. 25, T. 19 N., R. 12 W., 6 miles west and 3.5 miles north of Greeley Center, one-half mile to south of farmhouse of Mr. Jake Everett, and on land owned by Mr. Daily who lives about 1 mile southwest. An old trail passes to southward of station within 100 yards. Triangulation station is marked by a post 8 by 8 inches on top, projecting 4 inches and lettered U. S. C. S. The magnetic station is located 109.4 feet south of triangulation station on south edge of crest of hill and in direct line between triangulation station and a windmill at farmhouse 1½ miles south. It is marked by a wooden stub driven flush with the surface of the ground. A copper nail driven in the top marks the exact spot. The following true bearings were determined:

	° ′
Windmill 1½ miles south (mark)	1 10.5 east of south
Custer triangulation station	62 03.9 east of north
Standpipe at Greeley Center	61 54.4 east of south

O'Neill, Holt County.—The station of 1900 was reoccupied. It is situated on the grounds of the court-house, in line with the west face of the building and 69.1 feet south of the southwest corner of the brick foundation. The following true bearings were determined:

	° ′
Methodist Church spire (mark)	71 40.9 east of south
Cross on Catholic school	53 23.3 west of north
Cross on Catholic Church	35 08.2 west of north

Shelton, Buffalo County.—The station is located in the northeast corner of the high school grounds. It is 124.9 feet from the northeast corner of the high school, 65.3 feet from the city water hydrant located at the northeast corner of the block, and 33.8 feet from the center of the brick sidewalk running along the north side of the block. It is marked by a 4 by 26 inch sewer tile, sunk 1 inch below the surface of the ground, center of top of tile marking the exact spot. The following true bearings were determined:

	° ′
Ball on spire of Methodist Church (mark)	87 59.5 west of north
Northwest corner of high school foundation	61 56.7 west of south
Southeast corner of small house 50 yards distant	8 42.3 west of north
Northwest corner of small house 50 yards distant	89 44.2 east of south

NEVADA.

Amos, Humboldt County.—The station is about 800 feet southeast of the hotel and east of the corrals. It is 13.5 feet southeast of the northeast corner of the corrals, 122 feet east of the north gate-post of the first gate south of the northeast corner of the corrals, and about 350 feet a little east of north of the southeast corner of the corrals. It is marked by a white glass bottle buried about 4 inches

Descriptions of stations—Continued.

NEVADA—Continued.

underground, covered by a piece of slate 3 by 4 by 7 inches set flush with the ground. The neck of the bottle marks the exact spot. The following true bearings were determined.

	°	′	
East gable of hotel (mark)	27	50.9	west of north
Highest point of ridge of hills to the east	86	29.2	east of north

Winnemucca, Humboldt County.—The station is about three-fourths of a mile northwest of the center of town on a hill west of the town cemetery and southwest of the Chinese cemetery. It is 127.5 feet a little south of west from the southwest corner of the fence surrounding the Chinese cemetery, and 324 feet west of the northwest corner of the fence surrounding the town cemetery. The station is marked by a hickory post 4 by 6 by 30 inches, projecting about 4 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	°	′	
Flagstaff on cupola of public school (mark)	39	52.8	east of south
Flagstaff on court-house cupola	51	58.2	east of south
Flagstaff on belfry of engine house	54	42.8	east of south
Flagstaff on Staunton's harness store	56	42.6	east of south
Windmill shaft	76	56.6	east of south

NEW YORK.

Auburn, Cayuga County.—A meridian line was established on the grounds of the City of Auburn Isolation Hospital, about 2 miles northeast from the center of city. Observations were made over the north stone, which is 284.1 feet northwest from the northwest corner of the hospital building, 102.5 feet east from the row of trees on the west, and 75.3 feet south from the north fence. The south stone is 507.6 feet south from it. The stones are building stone, 12 by 12 by 44 inches, projecting 4 inches above the ground, and above surface are 10 by 10 inches, and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	°	′	
Spire on Trinity Methodist Episcopal Church (new) (mark)	23	16.0	west of south
Northwest corner of hospital	48	27.0	east of south

Ithaca, Tompkins County.—A new station was established about 90 rods southeast of the station of 1890. It is on the south knoll southeast from the playground of Alumni Field, known as Kite Hill on university map plans. It is almost due north of the Lehigh Valley Railroad station at East Ithaca and almost due east about 100 rods from the university heating station. The station is on the summit of this knoll and is marked by a cement post 7 by 7 by 30 inches, projecting 4 inches above the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	°	′	
Sphere at base of eagle on State Agricultural College (mark)	14	47.9	west of north
Sage College, main tower tip	68	06.6	west of north
Library tower (approximately)	58	23.5	west of north
North smokestack at heating plant	89	52.6	west of north

NORTH CAROLINA.

Chapel Hill, Orange County.—The station of 1898 was reoccupied. It is located on the campus of the University of North Carolina, about 500 feet east of the geological building, by the side of a ditch parallel to the end of the building. It is 46.9 feet from the small maple tree and 44.3 feet from a sycamore tree. It is marked by the south monument of the meridian line, the other monument being in the rear of Professor Alexander's garden, marked also by a white wooden post. The following true bearings were determined:

	°	′	
Southeast corner of Carr Building (mark)	12	02.5	west of south
Northeast corner of geological building, above water table	68	40.4	west of south
Northeast corner of chemistry building	55	35.0	west of north

Descriptions of stations—Continued.

NORTH CAROLINA—Continued.

Goldsboro, Wayne County.—The station of 1899 was reoccupied. It is in the southeast corner of the court-house grounds, 57.8 feet from a large tree on Chestnut street, and 56.1 feet from a large tree on Williams street. The station is marked by a granite post 6 by 6 by 54 inches, lettered N. C. G. S.—U. S. C. S., and projecting about 8 inches. The following true bearings were determined:

	° ′
Northeast corner of Miss Kendall's house	1 55.7 west of south
Southwest corner registrar's office	2 06.7 west of north
Spire on Judge Allen's residence	74 15.7 west of north
Northeast corner of jail	21 09.6 west of north
Northeast gable of St. Paul's Church	87 21.9 west of south

Halifax, Halifax County.—The station of 1899 was reoccupied. It is in the court-house yard, northeast of the building, 91.9 feet from the northeast corner and 71.2 feet from the southeast corner of same. It is marked by a granite post 6 by 6 by 54 inches, projecting about 1 foot, and lettered N. C. G. S.— U. S. C. S. The following true bearings were determined:

	° ′
Northeast corner of court-house	78 44.4 west of south
Northeast edge of south meridian stone	00 11.3 east of south
Southwest corner of Lawrence house	40 24.5 east of south

Marshall, Madison County.—The station is located northwest of the court-house in the court-house grounds, 76.7 feet from the nearest corner of the court-house, and about 6 feet from a rocky ledge facing the street and French Broad River. It is marked by a stone post 8 inches square, placed firmly in the ground. The other stone marking the meridian line is due south near the jail. The following true bearings were determined:

	° ′
Southwest corner of jail	2 27.1 west of south
Large chimney of Barker's house	12 33.6 west of south
Northeast edge of court-house	32 49.2 east of south
Northeast corner of Nelson's store	54 34.7 west of south

Morganton, Burke County.—The station of 1898 was reoccupied. It is located in the court-house yard, southeast of the court-house, in a very prominent place. (Due north is a stone similar to the station marker, showing the meridian line.) The station is located near the boundary fence, beside the path leading from the front of the court-house to the street. The station is marked by a stone 6 or 8 inches square, lettered N. C. G. S. U. S. C. S., 1898, and projecting about 8 inches. The following true bearings were determined:

	° ′
Second spire east of hospital dome (mark)	37 27.7 east of south
Northeast corner of Anderson's store	64 56 5 west of north
Southeast corner of court-house	11 01.8 west of north

Newbern, Craven County.—The station of 1898 was reoccupied. It is in the northern part of the Cedar Grove Cemetery, 29.0 feet from the southeast corner of the Bryant burial lot, and 21.1 feet from the northeast corner of the Dunn lot. It is also at the southeast corner of the intersection of two driveways. The station is marked by the north stone of a meridian line. The stone is lettered N. C. G. S. U. S. C. S., 1898. The following true bearings were determined:

	° ′
Ridge of Mr. Stuart's house	76 18.7 west of north
Northwest corner of Baker monument	11 15.0 west of south
Northeast corner of base of Seymour monument	12 56.0 east of south

Raleigh, Wake County, 1898.—The station of 1898 was reoccupied. It is about 1½ miles from the center of the city on the grounds of the Agricultural and Mechanical College, southeast of the main

Descriptions of stations—Continued.

NORTH CAROLINA—Continued.

building. It is about 450 feet from a trolley line and 160.8 feet from the corner of the main building and 205.1 feet nearly due south of the flag pole. It is marked by a large stone set firmly in the ground. Due north is another similar stone marking the meridian line. The following true bearings were determined:

	° ′
Southeast edge base of flag pole	8 14.2 east of north
Northeast edge of upright tackling frame by railroad	6 23.6 west of south
Northeast edge of southeast chimney of main building	38 36.6 west of north
Southeast edge base post of summer house	0 41.0 west of north

Raleigh, Wake County.—The station of 1898 being no longer suitable for magnetic observations, a new station was located on the lawn of the experiment farm about one-half mile northwest of the old station. It is about one-quarter of a mile from the nearest trolley line and about 2 miles from the center of Raleigh past the Agricultural and Mechanical College property and fair ground. The station is 78.1 feet from the nearest corner of the house occupied by Mr. Jeffries and 111.5 feet from the nearest corner of a vacant house. It is marked by a marble post 6 inches square, sunk about 2 feet in the ground and lettered C. & G. S. The following true bearings were determined:

	° ′
Northeast edge of cross on Catholic Church	1 21.3 west of south
Northwest edge of chimney end, Catholic Orphanage	13 17.5 east of south
Spire on glass turret of hospital	32 46.7 east of south
West edge base of staff on secretary of fair grounds office	69 29.5 east of south
Southeast corner of Agricultural College	42 01.7 east of south

Roan High Bluff, Mitchell County.—The triangulation station is on a very high bluff about three-fourths of a mile from the Cloudland Hotel. To find the station, leave the railroad at Roan Mountain Depot, 26 miles east of Johnson City, and take the road up the mountain to Cloudland Hotel, 16 miles distant. The station is marked by a cross cut in a very large rock on the edge of the bluff, and lettered U. S. C. S. Magnetic observations were made at a point about 250 paces from the triangulation station in an open, rocky space in the heavy growth of rhododendron brush, about 15 paces north of a clump of balsam trees and about 5 paces south of the foot trail leading to the triangulation station from the hotel. The magnetic station is marked by a small wooden stub and two reference arrows 12 inches long and one-half of an inch deep chiseled in the outcropping rock. One arrow is distant 8.97 feet N. 30° 03′ E., the other 10.04 feet N. 71° 45′ E. from the magnetic station, measurement being from the crossbar on arrow. The following true bearings were determined:

	° ′
Northwest corner Cloudland Hotel	40 37.2 east of north
Roan High Bluff triangulation station	81 39.6 west of south
North edge of Table Mountain	46 26.5 east of south

Southport, Brunswick County.—The station of 1898 was reoccupied. It is on the Government reservation known as Fort Johnson on the bank of the Cape Fear River, between it and the principal street of the town. On the opposite side of the street are the offices of W. H. Pike, real estate agent, Southport Realty and Development Company, and the store of Mr. Ruark. The station is marked by a stone 6 inches square, lettered N. C. G. S. U. S. C. S., 1898, being the south stone of a meridian line. The station is 51.8 feet from a large china berry tree, and 16.4 feet, 27.9 feet, and 49.2 feet from a row of three water-oak trees. The following true bearings were determined:

	° ′
Flagstaff Fort Caswell	0 36.8 west of south
Lookout, Fort Caswell	4 09.8 west of south
Weather tower, Fort Johnson	26 55.2 west of south
Vertex of roof of Ruark's store	51 37.5 west of north

Descriptions of stations—Continued.

NORTH DAKOTA.

Ashley, McIntosh County.—The station is near the northeast corner of the court-house square, the court-house, a frame building, standing in the southwest corner. It is about 4 feet from the north line and about 10 feet from the east line of the block. It is about 350 feet from the northeast corner of the court-house, and about 260 feet east of the small frame building used as a jail. The station is marked by a sandstone post, 5 by 5 by 24 inches, set 2 inches above the surface of the ground and lettered U. S. C. & G. S. 1906. The following true bearings were determined:

	° ′
Cross on Lutheran Church (mark)	14 55.6 west of south
South gable of section house	65 31.8 west of north
Chimney on Martin Lund's house	81 55.4 east of north

Crosby, Williams County.—The station is located in SW. ¼ sec. 30, T. 163, R. 97 W., of the fifth principal meridian on the line running north and south through middle of the quarter and about 400 feet north of the section line. It is 26 paces north of the northeast corner of wire fence inclosure about Miss McGowan's claim shack and to the west of the present site of the Crosby Hotel about two and one-half blocks. The station isleft unmarked. The mark used is the nearest corner of house belonging to Frank Koester on the NW. ¼ sec. 31. The following true bearing was determined:

	° ′
Nearest corner of Frank Koester's house	16 48.6 east of south

Dickinson, Stark County.—The station of 1896 being no longer available for magnetic observations a new station was located within the same inclosure. It is a little more than 100 feet to the eastward of the station of 1896. It is 34.0 feet west and 32.0 feet north of the wooden fences, east and south side of the grounds, respectively. It is about 45 paces from the nearest corner of the schoolhouse. It is marked by a limestone post 5 by 7 by 28 inches projecting 3 inches above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Spire Catholic Church (mark)	24 23.6 east of south
Spire Congregational Church	56 09.3 east of south
Northeast corner of school building (above water table)	27 57.8 west of north

Fargo, Cass County.—The station of 1905 was reoccupied. It is in the Riverside Cemetery, on the river bank along the eastern side and to the north of the pump house. It is on a vacant strip of ground, not plotted for lots or streets but reserved for parking. It is 51.4 feet southeasterly from the southeast corner of the Andrews monument, 79.0 feet northeasterly from the northeast corner of the Morse monument. The station is marked by a sandstone post, 7 by 7 inches on top, set flush with the surface of the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined in 1905:

	° ′
Largest spire on city high school building (mark)	16 59 2 west of north
Pole on large red barn	27 26.6 west of south
South edge of chimney on small farm house	59 35.1 west of south
Spire on main building Fargo College	10 47.9 west of north

Fargo, Cass County.—A new station was selected and occupied because of a suspected local disturbance at the 1905 station at Riverside Cemetery. The station is near the line separating the Fargo College campus from Island Park (being the quarter section line east and west through section 7) and is in the line of the east end of Jones Hall. This region is within a loop of the Fargo and Moorhead street railway, electric. This line is about 900 feet distant to the east, 1 200 to the south, and 900 feet to the west, and 2 000 feet to the north. It is marked by a Kasota limestone post about 5 by 6 by 25 inches and lettered on top U. S. C. & G. S., 1906. This station is about 1⅝ miles north and three-eighths of a mile west of the station of 1905. The following true bearing was determined:

	° ′
Northeast corner of Jones Hall (mark)	1 29.0 west of south

Descriptions of stations—Continued.

NORTH DAKOTA—Continued.

Fayette, Dunn County.—The station is at the ranch of Mr. F. Little, on a stony knoll northwest of the house. It is about 175 paces northwesterly from the northeast corner of the inclosure about the house and about 54 paces west of the southwest corner of the fence around the garden and along the same line about 75 paces from the trench containing the spring water conduit. Observations were made over an irregular stone in place (size unknown), the portion above the ground being roughly triangular in horizontal section, about 10 inches on each side, and rising 8 inches above the ground. The upper edge is sharp, runs north and south, and is marked roughly by a chisel east and west across the edge. The following true bearings were determined:

	° ′
East side of stone pile on high butte	0 17.8 east of south
West side of kitchen chimney on Little's house	33 30.1 east of south
Tip of insulator of telephone pole (northernmost pole visible)	4 29.4 east of north

Garrison, McLean County.—The station is on grounds designed to be used for the public schools, immediately at the north end of Main street, the tract being 300 feet east and west by 150 feet north and south. The station is at the northwest corner of this tract, as nearly as could be determined in the absence of corner stakes. It is about 100 feet north of the small structure temporarily used as a school. The station is marked by a sandstone post 5 by 5 by 24 inches projecting 3 inches above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Gable of Farmers' Elevator (mark)	17 26.5 west of south
Cupola on large red barn (4 miles)	19 12.0 west of north
Spire on Catholic Church	77 51.6 east of south

Haley, Bowman County.—The station is located on sec. 25, T. 129 N., R. 100 W. of the fifth principal meridian, on the SE. ¼, and 120 feet to the west of the section line. It is on the homestead of R. L. Jackson, ranchman. It is about 200 feet north and a little east of the sod structure serving as hotel and post-office and home of Mr. Jackson. It is in the line of a fence along the west side of an inclosure about some small trees and 40 feet north of the northwest corner. It is about 100 feet west of the fence along the lane leading to the northward, and it is marked by a small oak stake. The following true bearings were determined:

	° ′
Stone pile on ridge (3 miles) (mark)	2 01.0 west of south
Stone pile	3 56.2 west of south
Gable of new house	68 21.6 west of north
Northeast corner of Curry's store	65 59.6 east of south

Hankinson, Richland County.—The triangulation station is on a very prominent ridge in SE. ¼ SE. ¼ sec. 28, T. 130 N., R. 50 W., on land owned by Mr. Harrison, living in West Concord, Minn. It is close to the south line of the section, 10 paces north of center of section line road, about 89 paces south of west from the northwest corner of an old deserted barn and one-quarter of a mile south-southwest of the schoolhouse of the Independent school district. The hills are 4 miles northwest of Hankinson. It is marked with sewer tile and concrete. The magnetic station is 102.7 feet from the triangulation station, on a line 22° 06′ 05″ to right of line to center of high school spire, and is marked by a 2 by 2 inch wooden stub set flush with the ground with copper nail driven in the top. The following true bearings were determined:

	° ′
Center of schoolhouse chimney (mark)	22 31.4 east of north
Spire on Andrew Mourer's house	79 35.8 east of north
Spire of Hankinson high school	48 06.4 east of north
Triangulation station	70 21.6 west of south

Kenmare, Ward County.—The station is in Lakeview Cemetery, lying southwesterly across the lake from the city. It is in the middle of a street running north and south, about 240 feet from the

Descriptions of stations—Continued.

NORTH DAKOTA—Continued.

fence bounding the cemetery on the west and 120 feet from the fence along the north. It is marked by a limestone post 5 by 6 by 20 inches set 1 inch above the ground and lettered U. S. C. & G. S. 1906. The following true bearings were determined:

	° ′
Tip on Kenmare water tank (mark)	54 43.2 east of north
Flag pole on Kenmare school	41 56.9 east of north
Northeast corner of Mr. Jacobson's farmhouse (1 mile)	45 52.5 west of north
North gable Mr. Hjort's house	43 31.1 west of south

Linton, Emmons County.—The station is within the county block, directly in line with the north edge of the new schoolhouse, and also with the west edge of the old schoolhouse. It is 161.2 feet west of the northwest corner of the new schoolhouse, about 135 feet from the old schoolhouse, and 150 feet to the northeast of the northeast corner of the court-house. The station is marked by a sandstone post 5 by 5 by 22 inches projecting 2 inches above the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Tip on north gable passenger depot (mark)	40 47.4 east of south
Cupola on E. A. Crane's house	75 50.0 west of south
Cross on Catholic Church	35 36.2 east of north
Spire on Methodist Episcopal Church	67 36.7 east of north

Medora, Billings County.—The station is located in the extension of the street passing between the court-house and the Rough Riders' Hotel, near the east side of the street and two blocks north of the hotel. It is about 250 paces north of the southwest corner of the hotel and about 10 paces from the bank of a dry creek. It is marked by a limestone post 5 by 7 by 28 inches set 4 inches above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Cross on Catholic Church (mark)	27 06.2 east of south
North gable old court-house	3 48.0 west of south
East gable Little Missouri section house	70 44.6 west of north

Napoleon, Logan County.—The station is near the southeast corner of the tract of ground upon which the court-house stands, this being about one-half of a mile east of the village. It is in line with the east side of the jail (produced) and about 15 feet from the fire guard on the east and about 18 feet from the fire guard on the south of the grounds. It is 228.4 feet from the southeast corner of the court-house and 174.0 feet from the southeast corner of the jail. The station is marked by a square oak stake. The following true bearings were determined:

	° ′
Cupola on Mr. McAlmont's barn (mark)	13 30.2 west of south
Schoolhouse flagstaff	81 19.8 west of north
South gable on J. H. Fitch's barn	13 04.5 west of north

New England, Hettinger County.—The station is situated on a high bank overlooking the north fork of the Cannon Ball River, west of the center of the NE. ¼ sec. 4, T. 135 N., R. 97 W. of the fifth principal meridian, on land belonging to Asa Gardner. It is on a narrow point lying between two ravines and is about 400 feet from the northwest corner of Asa Gardner's store. The station is marked by an irregular piece of native stone about 18 inches long, the portion above ground being wedge-shaped with the edge lying approximately north and south, the base being about 7 by 9 inches and the edge rising about 8 inches above the surface of the ground. The precise point is a break about midway of the edge. The following true bearings were determined:

	° ′
North gable of W. C. McKenzie's barn (mark)	5 35.9 east of south
Flag pole on W. C. McKenzie's store	41 38.7 east of south
East gable Asa Gardner's house	49 39.7 west of north

Descriptions of stations—Continued.

NORTH DAKOTA—Continued.

Portal, Ward County.—The station is near the intersection of the south line of Boundary avenue and the east line of Second street. It is 63 feet easterly from the fence that marks the west side of Second street and 65 feet south of a shallow trench which is said to lie on the International Boundary. The station is marked by a limestone post 5 by 6 by 20 inches, set flush with the ground and marked U. S. C. & G. S., 1906. The mark used was the spire of a church seen nearly in line with the schoolhouse. The following true bearings were determined:

	° ′
Spire of Presbyterian Church (mark)	42 18.9 east of south
Flag pole United States Detention house U. S. I. S.	76 35.3 east of south
Flag pole Canadian custom-house	58 21.7 east of north
East gable of farmhouse (half a mile distant)	33 01.9 west of south

Schafer, McKenzie County.—The village of Schafer has been recently plotted and the station is chosen on a piece of ground bordering Cherry Creek and reserved as a park. This point is about 20 rods north and 175 feet east of the center of sec. 23, T. 150 N., R. 98 W., of the fifth principal meridian. It is 121 paces south and 48 paces east of the southwest corner of the blacksmith shop. The station was left unmarked except by small pine stakes under arrangement with the County Surveyor, William Jansen, and the proprietor, Charles Schafer, to set a suitable stone. The following true bearings were determined:

	° ′
Southeast corner at base of Schafer's claim shack (mark)	13 19.6 west of south
South gable of Frank Gonon's house (one-half of a mile north)	5 38.1 east of north

White Earth, Ward County.—The station is situated on a high point in the southwest part of town, being on tract of land designed for site of schoolhouse. The point is east about 10 feet of the section line bounding this tract on the west and about 50 rods south of the quarter corner between secs. 35 and 36, T. 157, R. 94 W. of the fifth principal meridian. It lies about 40 feet north of the highest point on this ridge and is marked by a limestone post 5 by 6 by 28 inches and lettered U. S. C. & G. S., 1906, on top, and set with the top about 3 inches above the surface of the ground. The following true bearings were determined:

	° ′
Tip on G. N. water tank (mark)	56 21.5 east of north.
Cupola barn of Shepard Bros. Lumber Co.	28 59.9 east of north
Highest post section-line fence on hill	0 07.2 east of north
Nearest corner farmhouse (one-half of a mile south)	15 29.4 east of south

Williston, Williams County.—The station of 1896 was not occupied owing to the fact that a large brick schoolhouse had been erected within about 50 feet. A new location was therefore taken about four blocks (1 500 feet) north and two blocks (700 feet) east, approximately, the new location being on a tract of land belonging to Bruegger Mercantile Company, and now used as a driving track and ball ground. The station is in line with the south edge of a brick structure now used as a powder storehouse and distant about 200 feet to the eastward. It is a little to the north of the quarter-section line running through the section. The station is marked by a limestone post 5 by 6 by 30 inches and set 3 inches above ground and top lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Flag pole on schoolhouse (mark)	21 45.6 west of south
Staff vane on weather bureau	35 16.4 west of south
Northeast corner of truss, Muddy River Highway Bridge	64 40.0 east of south
South edge house on distant hill	37 56.4 west of north

OHIO.

Cincinnati, Hamilton County.—The station of 1903 was reoccupied. The station is in the grounds of the Cincinnati University, in the Burnett Wood Park. It is south of the athletic field, on high ground

Descriptions of stations—Continued.

OHIO—Continued.

overlooking the same, being 58.2 feet from a tree to the southeast and 48 feet from a second tree to the west. It is marked by a limestone monument 3 feet long and 6 inches square. The top of stone has been chipped off since 1903. The following true bearings were determined in 1903:

	° ′
Main tower of McMicken Hall (mark)	42 07.2 west of north
Spire on the fire house	50 53.8 west of south
Southwest spire on St. George's Church	60 50.9 east of south

Cleveland, Cuyahoga County.—The station of 1900 being no longer suitable for magnetic observations, a new station was established at about the central part of Woodland Hill Park, about 5½ miles southeast of the center of town. It is north of the park pavilion or shelter and near the south edge of a shallow ravine. It is 115.6 feet northwest of the northwest corner of a row of fence posts surrounding the athletic field and 172.8 feet north of the northwest corner of the steps surrounding the pavilion. It is marked by a sandstone post 8 by 8 by 30 inches, set 6 inches above the ground, and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Base of lamp-post at east end upper fence of reservoir (mark)	37 10.8 east of south
South edge of tallest smokestack in Newburg	82 42.1 west of south
Southern of two tall church steeples close together	82 08.4 west of north
The northern of above steeples	81 59.5 west of north

Marietta, Washington County.—Observations were made near the station of 1898 and 1904. The station of 1898 was in the grounds of the Marietta College Observatory, about 75 feet to the northwest of the small equatorial. It is marked by a sandstone post with copper station mark. Fifty-four feet due south of this station a stone was set by the professor of mathematics for his own use. This is the point occupied in 1907. The south stone of the meridian line established in 1898 having become displaced, it was reset about 30 feet north of its former location. The following true bearings were determined:

	° ′
Drainpipe on the east side of Mr. Perry's house	40 33.4 west of north
Drainpipe on white house	62 26.5 west of south

Toledo, Lucas County.—Observations were made near the station of 1903 on the farm of Mr. Shepard, near the boundary line separating it from the Case farm. It is on the shore of Maumee Bay, about 5½ miles northeast of the center of the city. It is 53 feet south of the flagstaff on triangulation station Case and in line with a tall red post in the bay. It is marked by a piece of driftwood 5 by 10 by 30 inches, projecting 6 inches above ground. The following true bearings were determined:

	° ′
Top of north gable window in roof of Mrs. Shepard's house (mark)	7 08.5 east of south
Smokestack to south	47 17.4 east of south
North gable of Mr. Case's house	19 05.9 west of south
South gable of house to the north across bay	21 44.2 east of north

Youngstown, Mahoning County.—The station is in an open piece of ground in Mill Creek Park, about 3 miles south of the center of town. This open space is between an iron bridge over Mill Creek and the pavilions, refreshment booths, etc., in the park. The iron bridge is between Laterman's Falls and the old pavilion. The station is in the southern part of this open space about 500 feet south of the above iron bridge. It is 79.5 feet southwest of the southwestern of two trees, 24.6 feet apart and about 2 feet in diameter. It is also 76 feet a little south of east from a lone tree about 1.8 feet in diameter. It is marked by a marble post 4 by 4 by 20 inches, about 2 inches above ground. The following true bearing was determined:

	° ′
Top of south post of iron bridge (mark)	31 46.3 east of north

Descriptions of stations—Continued.

OKLAHOMA.

Guthrie, Logan County.—The station of 1905 was reoccupied. It is situated in the northwestern part of Highland Park, about 354 feet north-northwest of a small square wooden house. It is 67.3 feet south of the northern bend of new boulevard, and 44.3 feet and 23.0 feet, respectively, from two oak trees on south side of the boulevard. It is about 390 feet east of a small ravine and about 600 feet north of the eastern terminus of Warner avenue car line, about 1 mile northeast of business portion of the town. It is marked by a limestone post 6 by 6 by 24 inches, showing 2 inches above the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	°	′	
Cross on Catholic Church (mark)	52	28.3	west of south
Flag pole Logan County high school	72	46.5	west of north
Windmill 1 mile distant	41	24.1	east of north
Center of chimney on square house	38	59.8	east of south
Center of standpipe	19	00.0	east of south

Pond Creek, Grant County.—The station is located in the northeast corner of the public school grounds. It is marked by a 4 by 26 inch sewer tile, buried flange down and top of tile 1 inch below the ground, center of top of tile marking station. The station is 146.0 feet from the northeast corner of the north wing of the schoolhouse and 96.8 feet from the city water hydrant at the northeast corner of the block. It is 61.9 feet from the east fence (wooden) and 48.6 feet from east row of trees; 50.2 feet from the north fence and 35.4 feet from the north row of trees. The following true bearings were determined:

	°	′	
Ball on top of city water tower mark)	1	42.5	east of south
Spire of schoolhouse	44	41.7	west of south
Northeast corner of north wing of schoolhouse	56	25.8	west of south
Center of south gable of small house about 130 feet distant	3	29.5	west of north
Flag pole on the Pond Creek Mill and Elevator Co.'s building	66	13.1	west of south

OREGON.

Alba, Umatilla County.—The station is in the southwest corner of the ground surrounding the schoolhouse, almost exactly in the magnetic meridian with the cupola on the church. It is 121 feet west of the southwest corner of the school building and 135.6 feet southwest of the northwest corner of the same building. It is also about 28 feet east of the line of the school ground on the west and about 105 feet north of the line of the school ground on the south. It is marked by a white glass bottle filled with earth and buried about 3 inches underground. The following true bearings were determined:

	°	′	
Base of rod at top of cupola on the church mark)	21	10.8	west of south
East point at top of roof of post-office	18	53.2	west of south
East point at top of roof of hotel	24	07.8	west of south

Andrews, Harney County.—Observations were taken out in the sage brush at a distance of about 180 feet west of the general store and post-office.

Bly, Klamath County.—The station is in the southwest corner of the pasture due north of Mrs. Kasebeer's hotel, and on the north side of the road running east and west about 200 feet north of this hotel. It is three-fourths of a mile east of the post-office. It is 98 feet north of the worm fence bounding the pasture on the south and 164 feet east of the fence bounding the pasture on the west. It is marked by a cedar post of irregular cross section, about 5½ by 8½ by 28 inches, projecting about 6 inches above ground and having a cross sawed in the top to mark the exact spot. The following true bearings were determined:

	°	′	
Top of east side of Kasebeer's hotel just under roof	00	53.9	west of south
East gable of John W. Well's house	70	54.4	west of south

Descriptions of stations—Continued.

OREGON—Continued.

Burns, Harney County.—The station is in the southeast corner of the Burns fair grounds, about 1 mile southwest of the center of town. It is 48.2 feet north of the fence bounding the fair grounds on the south, 46.5 feet south of the southeast corner of the fence on the outside edge of the race track, and 91.5 feet west of the fence bounding the fair grounds on the east. It is marked by an oak stake 3½ by 5 inches, showing about 2½ inches above ground, with a cross cut in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Flagstaff on court-house mark)	10 12.0 east of north
Spire of Presbyterian Church	7 04.7 east of north
Flag pole on county high school	15 54.3 east of north

Canyon City, Grant County.—The station is about 300 feet east of the Methodist Church, on the slope of the hill, about one-fourth of a mile east of the center of town. It is on the east edge of a shallow dry gully, which is about 250 feet east of the Methodist Church. It is 118 feet north of a fence running east and west, about 15 feet south of the church. It is marked by one-half of an oak wagon axle, painted red, and 30 by 3 by 3½ inches in size, showing 1 foot above ground. A cross sawed in the top marks the exact spot. The following true bearings were determined:

	° ′
West point at top of roof of county court-house	26 27.8 west of south
Top of northeastern corner I. O. O. F. Hall	13 11.4 west of south

Condon, Gilliam County.—The station is in the southern part of the ground surrounding the public school, about 300 feet south of the schoolhouse, and about one-half of a mile southeast of the center of town. It is 90 feet west of the fence bounding the school ground on the east, 96.4 feet north of the fence bounding the school grounds on the south, and 104.7 feet east of the fence bounding the school ground on the west. It is marked by an oak stake 3½ by 3½ by 30 inches, showing 4 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Rod on cupola, county court-house (mark)	58 47.6 west of north
Spire, Congregational Church	81 46.7 west of north
Spire, Baptist Church	57 58.2 west of north

The Dalles, Wasco County.—The station is in the southeastern corner of the ground surrounding the old academy and the high school, about three-fourths of a mile from the center of the town. It is 74.3 feet north of the fence bounding this ground on the south and 76.8 feet west of the fence bounding this ground on the east. It is marked by a dark glass bottle buried about 3 inches under ground. A stone is to be placed in position by the county surveyor. The following true bearings were determined:

	° ′
Western point at top of roof of old planing mill across river (mark)	54 35.4 east of north
Windmill about 4 miles to the east	88 18.0 east of south
Cupola of Mr. Belt's stable	62 56.9 east of north

Denio, Harney County.—The station is about 700 feet southeast of the post-office and east of the county road. It is 150 feet south of the southwest corner of Mr. Peterman's corral and 170.5 feet east of the southeast corner of the general store. It is marked by a rough field stone about 2 by 7 by 24 inches, coming to an edge at the top and showing about 5 inches above ground. A notch cut in this top edge indicates the exact spot. The following true bearings were determined:

	° ′
Upper west corner of front of saloon (mark)	17 11.6 west of south
Flagstaff on Pueblo Hotel	24 31.4 west of south
Western gable of Mr. Denio's house	40 46.7 east of south

Descriptions of stations—Continued.

OREGON—Continued.

Diamond, Harney County.—The station is in the southeast corner of a hayfield belonging to Mr. Smith. It is across the first fence west of the post-office and general store. It is 84 feet west of the fence bounding this field on the east and 81 feet north of the fence bounding the field on the south. It is marked by an oak stake (one-half of a wagon axle) 3 by 4 by 30 inches, projecting about 3½ inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′	
Corner at top of extreme west edge of low ridge to the north	51 24.8	west of north
North edge at top of front of general store	87 09.6	east of north

Fort Klamath, Klamath County.—The station is in the pasture west of the Jackson Hotel, and about one-half of a mile north of the post-office. It is 97.5 feet south of the fence running east and west on the north side of the hotel, and 205.5 feet west of the southwest corner of the fence surrounding the hotel. It is also 197.9 feet south of a granite monument situated in Mr. Skeen's yard and marked W. S. on four sides. This stone was probably at one corner of an old reservation. The station is marked by a log 6 by 28 inches, projecting almost 1 inch above the surface of the ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′	
Highest point on peak forming west wall of Crater Lake (mark)	21 41.9	west of north
Base of flagstaff on schoolhouse	35 01.3	west of north
Most westerly point at extreme top of Mount Scott	4 02.0	west of north

Heppner, Morrow County.—The station is in the northwestern part of the ground surrounding the Heppner School, and northwest of the front entrance to schoolhouse. It is about one-fourth of a mile northeast of the center of town. It is 158 feet west of northwest corner of the school building, 55 feet south of a stone marking the northwest corner of the school ground, and 7.2 feet east of stone marking next lot corner south of the above corner stone. It is marked by a rough bowlder about 1.6 feet by 1.7 feet, sunk flush with the ground. A cross cut in the top of this bowlder marks the exact spot. The following true bearings were determined:

	° ′	
Top of steeple on South Methodist Church (mark)	75 05.8	west of north
Top of steeple, Baptist Church	83 12.7	west of south
Steeple, North Methodist Church	18 02.6	west of south
Cross on steeple of Catholic Church	15 45.0	west of south
Cupola on county court-house	2 21.6	west of south

Klamath Falls, Klamath County.—The station is in the southwestern part of the oval within the race track at the fair grounds, about 1 mile northeast of the center of town. It is about 9 feet southwest of a line between the flag pole and the judges' stand. It is 123 feet northwest of the flag pole and 225.5 feet southeast of the southeast corner of the judges' stand. It is marked by an oak stake 2½ by 3 by 30 inches, projecting 5 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′	
Rod at top of front tower of public school (mark)	41 57.3	west of north
Cupola of high school	62 57.7	west of north
Spire on church steeple with red top	80 01.9	west of north
Flagstaff on cupola of old public school	37 58.7	west of north

Lakeview, Lake County.—The station is in the southeastern part of the fair grounds, about three-fourths of a mile southwest of the center of town, and northwest of a windmill near the southeast corner of the fair grounds. It is 198 feet north of the fence bounding the fair grounds on the south, and 200 feet west of the fence bounding the fair grounds on the east. It is also 100 feet south of a

Descriptions of stations—Continued.

OREGON—Continued.

ditch. It is marked by an ash stake 4 by 4 by 30 inches, projecting about 4 inches above the ground with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Rod at top of high-school cupola (mark)	43 45.1 east of north
Baptist Church spire	56 15.3 east of north
Methodist Church steeple	58 38.9 east of north
Base of water gauge on reservoir	69 36.0 east of north

McDermitte, Malheur County.—The station is about 200 or 300 feet north of the Oregon-Nevada line, and about 300 feet northwest of the post-office. It is 142 feet east of the east fence of the first field across the county road west of the post-office, measured in a line perpendicular to the fence, 191 feet northeast of the southeast corner of the fence surrounding the same field, and about 84 feet west of the county road. It is marked by an oak stake 2 by 4 by 24 inches, projecting about 2 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined.

	° ′
Flagstaff on public hall on State line (mark)	72 01.0 east of south
Highest point on peak to the south immediately west of Coyote Pass	21 50.2 west of south

Mitchell, Wheeler County.—The station is in the northern part of the ground surrounding the public school, about one-fourth of a mile southeast of the center of town. It is 42 feet south of the fence bounding the school ground on the north, 47.8 feet west of the fence bounding the school ground on the east, 62 feet east of the fence bounding the school ground on the west, and 122 feet a little east of north from the center of the steps at the front entrance to the school. It is marked by a white glass bottle filled with earth and buried about 3 inches under ground. The following true bearings were determined:

	° ′
Highest point on Bailey Butte (mark)	65 58.0 west of north
Center of the top of a rock to the northwest in north side of canyon	53 52.8 west of north

Moro, Sherman County.—The station is in the southwest corner of section No. 8, and about one-fourth of a mile northeast of the county court-house. It is 130 feet north of the fence along the section line to the south and 158 feet east of the fence along the section line to the west. It is marked by an oak stake painted red, 3 by 3½ by 30 inches, showing 5 inches above ground and having a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Top of cupola, county court-house (mark)	37 31.2 west of south
Spire, Methodist Church	25 31.9 west of south
Spire, Presbyterian Church	20 32.7 west of south

Paisley, Lake County.—The station is in the southeastern corner of the ground surrounding the public school, about 800 or 900 feet southeast of the center of town. It is 21 feet west of the fence bounding the school grounds on the east, 51 feet north of the fence bounding the grounds on the south, and 147.6 feet southeast of the southeast corner of the school building. It is marked by a mahogany log 7 by 28 inches, projecting about 1 inch above the ground, and having a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Church spire (mark)	49 17.9 west of north
Extreme south edge of top board on front of livery stable	79 58.5 west of north

Paulina, Crook County.—The station is on a stony piece of ground, rising slightly, on the north side of the main road, and northwest of the house of Mr. John Faulkner. It is 201 feet west of the northwest corner of John Faulkner's house, and 153 feet northwest of an iron staple at the northeast corner of Faulkner's barn, and marking the northeast corner of lot 1, block 1. It is marked by a burnt

Descriptions of stations—Continued.

OREGON—Continued.

clay volcanic rock 9½ by 2½ inches at the top and projecting about 6 inches above ground. A one-fourth inch hole at the top marks the exact spot. The following true bearings were determined:

	° ′
Northwest point at top of roof of Miller & Morgan's ranch house (mark)	40 19.8 west of south
Geological Survey bench mark at corner of general store	85 09.4 east of north
North point at top of roof of general store	77 45.6 east of north

Pendleton, Umatilla County.—The station of 1905 was reoccupied. It is about one-fourth of a mile southeast of the center of the town, in the grounds surrounding the high school, southeast of the main brick building. It is 37.9 feet from a wooden fence to the south, 47.1 feet from a wooden fence to the east, and 204 feet southeast of the southeast corner of the main high school building. The station is marked by a lava post 5 by 8 by 24 inches, set flush with the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Christian Church spire (mark)	28 13.2 west of north
Methodist Church spire	19 45.8 west of north
Baptist Church spire	12 25.6 west of north
Flagstaff on large central cupola of court-house	11 25.5 west of north

Plush, Lake County.—The station is in the sagebrush northwest of the general store and post-office and southwest of the schoolhouse. It is 300 feet southwest of the southwest corner of the schoolhouse and 336 feet northwest of the northwest corner of the general store and post-office. It is marked by an ash stake 2½ by 5 by 24 inches, projecting about 7 inches above the ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
North edge of ornament at top of roof of station or hotel (mark)	29 39.6 east of south
Extreme south edge of top of general store and post-office	65 07.5 east of south

Prineville, Crook County.—The station is in the southeast corner of the baseball grounds, about 500 feet east of the planing mill and about 700 feet northeast of the Crook County High School. It is about one-fourth of a mile east of the center of town. It is 84 feet west of the fence line on the east side of the baseball ground and 171.5 feet south of the southeast corner of the grand stand. It is marked by one-half of an oak wagon axle 30 by 4 by 3 inches, showing about 5 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Ball at top of steeple of Methodist Church (mark)	80 20.6 west of north
Base of flag pole on cupola of public school	78 39.4 west of south
Presbyterian Church spire	80 13.5 west of south
Extreme western point at top of butte to the south	21 56.6 east of south
Top of water tank of the Light and Water Company	33 00.1 west of north

Rosland, Crook County.—The station is on the edge of a steep bank about 20 feet high, about 1 000 feet northwest of the general store and post-office. It is near the southwest corner of block No. 1. It is 13.1 feet northeast of the stake marking the southwest corner of block No. 1 and 36.3 feet southeast of a large yellow pine tree about 3 feet in diameter and on the edge of the above bank. It is also about 15 feet south of a worm fence along the edge of this bank. It is marked by an oak stake 3 by 4 by 30 inches, projecting about 1 inch above the ground and having a cross sawed in the top to indicate the exact spot. The following true bearings were determined

	° ′
Northeast point of roof of stable northwest of post-office (mark)	79 53.6 east of south
Tree in pasture	27 51.5 west of north

Descriptions of stations—Continued.

OREGON—Continued.

Shaniko, Wasco County.—The station is on the eastern edge of the baseball ground, about 600 feet east of the largest warehouse. It is about 297 feet east of the eastern end of the grand stand and about 291 feet west of the fence running north and south, east of the baseball ground. It is marked by an oak stake 30 by 3½ by 4½ inches, showing about 5 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Base of flagstaff on tower of schoolhouse (mark)	52 05.2 west of north
Northeast edge of railroad station, under roof	54 27.8 west of north
Highest point on Mount Jefferson	66 40.2 west of south
Rod on top of railroad water tank	51 22.2 west of south

Silver Lake, Lake County.—The station is in the sagebrush at the southeast corner of the town, about 1 000 feet southeast of the Hotel Chrisman, which is nearly at the center of town. It is west of a fenced-in acre of ground belonging to Mr. Heffer. It is 144 feet south of the most southern fence running east and west at the southern side of the town, and 166 feet west of the fence bounding the above acre of ground on the west. It is marked by a juniper log, about 8 by 36 inches, projecting about 16 inches above the ground, with a pile of sand built around. A cross sawed in the top of this log indicates the exact spot. The following true bearings were determined:

	° ′
Cleft in the extreme top of Mount Hagar	5 31.5 east of south
Rod on power house tower at Hotel Chrisman	44 41.1 west of north
South point at top of roof of Chrisman's general store	60 10.6 west of north

Sisters, Crook County.—The station is about 1 000 feet east of the center of town, and probably in the northwestern part of the ground surrounding the public school. Lines of this ground could not be determined.) It is 63.4 feet north of the nearest point of a rock about 12 feet in diameter and about 7 feet high. It is also 150.8 feet west of the northwestern corner of the public schoolhouse. It is marked by a brown glass bottle filled with earth and sunk about 3 inches underground. The following true bearing was determined:

	° ′
Center of top of Squaw Mountain	79 06.6 west of north

Three Mile Creek, Wasco County.—Observations were made as near as possible to the station occupied by Mr. Lawson in 1881, probably within 100 feet. The station of 1881 was 85 paces north of the top of the north bank, measured in line to the academy building, and 63 paces west of the railroad track, measured in line to the northeast corner of the slaughterhouse corral, where it strikes the steep, rocky bluff. The following true bearing was determined:

	° ′
White church steeple in "The Dalles" (mark)	85 39.1 west of south

Tygh Valley, Wasco County.—The station is on the hill on which the schoolhouse stands, about 1 200 feet southeast of the center of town. It is 160 feet west of the fence immediately east of the schoolhouse, and 133.7 feet northwest of the northwest corner of the school building. It is marked by an oak stake 4 by 5½ by 30 inches, showing about 5 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Top of cupola on blacksmith shop (mark)	52 40.2 west of north
East gable Tygh Valley Hotel	58 07.3 west of north
East point of roof of post-office	41 49.6 west of north

Umatilla, Umatilla County.—The station is about 90 feet southeast of the site of the old observatory, which was the probable location of Mr. Lawson's station of 1881. It is about 180 feet west of an old frame house which is directly east of the site of the old observatory. It is marked by an oak

Descriptions of stations—Continued

OREGON—Continued.

stake, 3 by 4 by 30 inches, showing about 5 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Rod at top of oil tank of Oregon Railroad and Navigation Co. (mark)	11 53.6 west of south
Southwest corner of Duncan Hotel	63 20.6 east of south
West gable of main building of Oregon Railroad and Navigation Co.	44 35.1 east of south

PENNSYLVANIA.

Allegheny, Allegheny County.—The station of 1902 was reoccupied as nearly as could be determined. The station is in the public park south of the new Allegheny Observatory. It is marked by a stone 6 inches square on top and 2 feet long, set flush with the surface of the ground. It is 229.4 feet south of the south wall of the front stairway to the main entrance of the observatory. A cupola about 2½ miles away bears 31° 35′.2 west of true south.

As the station of 1902 was not likely to again be available for magnetic observations, a new station was established about 500 feet west of the Allegheny Observatory, in Riverview Park. It is near a low mound of earth about 15 by 21 feet and about 3 feet high. It is about 32 feet southeast of the edge of a bank down to the road and about 42 feet northeast of the above low mound. It is also about 36 feet north of a path running east and west on the south side of the observatory. It is marked by a glazed earthen pipe 6 by 30 inches, projecting about 3 inches above the ground. The following true bearing was determined:

	° ′
Cross on southern steeple of a church to the southwest (mark)	59 14.9 west of south

Harrisburg, Dauphin County.—The station of 1901 being no longer suitable for magnetic observations, a new station was established about 1 800 to 2 000 feet east of that of 1901. The new station is at the south side of the playground on the eastern end of Island Park, about halfway between the bridge of the Cumberland Valley Railroad and the bridge of the Harrisburg Bridge Company. The station can at any time be found by referring to the Island Park authorities. The station is marked by a marble post 5½ by 5½ by 24 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1907. The following true bearings were determined:

	° ′
Raised hand on statue at State Capitol (mark)	10 05.5 east of north
Base of spire on post-office	18 16.5 east of north
Lutheran Church steeple	33 39.5 east of north
Presbyterian Church spire	34 14.0 east of north

PORTO RICO.

Obispo Cayo.—The station of 1906 was reoccupied. It is on the northeast shore of Obispo Cayo, about 10 paces from the water and 12 feet from high-water mark. It is about the middle of an opening in the mangroves, which extends for about 60 feet along the beach. The horizon from Cape San Juan Light-house to Palominos Island is visible from the station. The station is marked by an oak stake driven flush with the ground and covered with sand. The following true bearings were determined:

	° ′
Cape San Juan Light-house (mark)	1 57.0 east of north
Hydrographic signal Nob	49 58.1 east of north
Hydrographic signal Palominos	81 58.2 east of north

Porto Rico Magnetic Observatory, Vieques Island.—In connection with the establishment of a temporary magnetic observatory at Fort Isabel a station for absolute observations was established on the hill east of the fort, about halfway up.

In 1906 two tracts, the so-called Cofi and Le Brun tracts, were examined as to their suitability as a site for a magnetic observatory, and declination observations were made at a number of places

Descriptions of stations—Continued.

PORTO RICO—Continued.

on each. The Cofi tract was finally selected and the absolute observatory was moved to it in the spring of 1907. The variation building was completed and the variometers started in the new location in April, 1907.

RHODE ISLAND.

Newport, Newport County.—As the station of 1904 could not be located exactly from the description, a new station was established 8.5 feet south of the line of the south face of the barracks building, and 200.5 feet east from the southeast corner of the same. This building is the large one just north of the War College. The station is marked by a white marble post 6 by 6 by 15 inches, set flush with the surface of the ground and lettered U. S. C. S. A hole drilled in the top marks the exact spot. The following true bearings were determined:

	° ′
Rod on central tower of headquarters (mark)	9 47.8 east of south
St. Mary's Catholic Church, Newport	30 31.0 east of south
Weather vane on central tower of War College	30 40.2 west of south
Thorndike Hotel flag pole, Jamestown	65 11.4 west of south

SOUTH DAKOTA.

Bellefourche, Butte County.—The station of 1905 was reoccupied. It is in the meridian line established by the United States Geological Survey, about 100 feet south from the north monument. The south meridian monument is in the yard of the court-house near the south fence along the street and about 30 feet from the east fence. The north monument is on the highest point across the Bellefourche River and about 20 rods back from the bank. The magnetic station is marked by a sandstone post 9 by 9 by 27 inches, lettered U. S. C. & G. S., 1905, and set 6 inches above the ground. The following true bearings were determined:

	° ′
Chimney on farmhouse	69 57.5 east of south
Pole on schoolhouse	13 44.3 east of south
Tip on water tank	2 53.5 west of south

Bixby, Butte County.—The station is south of the buildings on Hudgin's ranch, in sec. 29, T. 14 N., R. 13 E., B. H. M. It is on open, unoccupied ground about 10 rods south, and in line with the east edge of the unfinished stone house, south of the log house occupied as road ranch and post-office. The following true bearing was determined:

	° ′
Junction of brace with corner post in fence to southward (mark)	23 57.4 west of south

Chance, Butte County.—The station is at Tom Veal's ranch near the center of NW. ¼ sec. 28, T. 17 N., R. 15 E., B. H. M. It is at the rear of Mr. Veal's sod house, on a bank above Thunder Butte Creek. It is about 10 feet from the bank and about 300 feet northwest from the northwest corner of the sod house. The station is marked by a piece of native limestone, about 20 inches long, with the part above ground wedge-shaped, its base being about 3 by 6 inches, and about 4 inches high, the edge lying approximately north and south. The following true bearing was determined:

	° ′
Fence post one-half of a mile south, on farther side of field (mark)	5 29.6 west of south

Creston, Pennington County.—The station is located on the grounds of the district schoolhouse, about 30 rods west of Robert Lee's store and post-office. It is directly in the line with the east side of the schoolhouse and about 75 feet to the rear. The mark used was a certain fence post on the hill on the south bank of the Cheyenne River, and seen close by the northwest corner of the schoolhouse.

	° ′
Bearing of mark	17 30.0 west of south

Custer, Custer County.—The station is located at the foot of a hill about 40 rods south from the county court-house. It was placed in what was thought to be the meridian line established by the

Descriptions of stations—Continued.

SOUTH DAKOTA—Continued.

United States Geological Survey. It is north from a U. S. G. S. bench mark, which is embedded in a large rock at the foot of the hill, 48 feet measured on the slope. The north monument of the meridian line, by the sidewalk south of the court-house entrance, was used as mark. The south monument is on the top of a large rock next west from the highest rock due south of the court-house. The line to magnetic station from north monument bears 2° 21′.9 east from the meridian line. The station is marked by a granite post 6 by 9 by 24 inches, set 6 inches above ground. The top is dated 1906 and the east face is lettered U. S. C. & G. S. The following true bearings were determined:

	° ′
North monument (mark)	2 21.3 west of north
Flag pole on schoolhouse	15 00.0 east of north
South gable on county court-house	2 38.1 west of north
Deepest depression in rock several miles northwest	70 02.0 west of north

Freeman, Hutchinson County.—The Freeman triangulation station is in the NE. ¼ NW. ¼ sec. 15, T. 98 N., R. 56 W., on the highest point of land in pasture belonging to John Stahl, of Freeman, S. Dak. It is marked by a marble post 8 inches square and projecting 4 inches above the surface of the ground, and lettered U. S. C. S. The magnetic station is 104.1 feet a little east of north of the triangulation station, in direct line between triangulation station and the spire on the high school in Freeman, which is five-eighths of a mile east and 3 miles north. It is marked by a wooden stub with a tack in the top. The following true bearings were determined:

	° ′
Spire on high school (mark)	13 50.1 east of north
Center of chimney of Mr. Gross's house	61 42.8 east of north
Chimney of white house to southeast	44 16.1 east of south

Harding, Butte County.—The station is located on an open piece of ground lying in front of the store and Woodman hall and used as a common, though privately owned by L. W. Shevling, a ranger on the forest reserve. It is in line to the north with the east edge of J. S. Cook's house (used as a hotel) and 67 paces distant. It is 17 paces west of the north and south fence bounding the tract on the east. It is in the NW. ¼ sec. 36, T. 17 N., R. 2 E. of B. H. M. (Black Hills meridian), and is marked by an irregular piece of native sandstone about 20 inches long and 4 inches square at the top, set with the top projecting about 3 inches above the surface of the ground, and is lettered U. S. '06. The following true bearings were determined:

	° ′
Northeast corner of J. S. Cook's house (mark)	00 38.1 west of south
Middle point in front of Woodman hall	87 49.4 west of north
The south gable on L. W. Shevling's house	70 19.8 east of north

Highmore, Hyde County.—The station is on the extension of Fourth street (south) to the east of Maple avenue, within a tract now belonging to Mr. Van Camp (postmaster). The observations were made over a prairie boulder of unknown dimensions, in place, and located about 20 feet south of the north line of Fourth street and about 75 feet east of the east line of the alley lying parallel with Maple avenue. The portion of the stone above ground is roughly pyramidal, about 12 inches square at base and 8 inches high. The following true bearings were determined:

	° ′
Pole on Merchant's Hotel (mark)	47 44.7 west of north
Pole on schoolhouse	81 11.3 west of north
Urn-topped monument in cemetery	55 11.6 east of south

Howard, Miner County.—The station is in the southeast quarter of the high school grounds, across the street to westward of Congregational Church. It is 93.0 feet from the southeast corner of the high school building and 79.2 feet from west edge of the concrete walk on east side of square. The sta-

Descriptions of stations—Continued.

SOUTH DAKOTA—Continued.

tion is marked by a 4 by 26 inch sewer tile, inverted, with top flush with the surface of the ground. Center of top marks the exact spot. The following true bearings were determined:

	° '
Spire of court-house (mark)	34 10.0 east of north
West spire on cupola of Congregational Church	85 53.5 east of north
Spire of Methodist Church	19 28.3 east of south

Interior, Stanley County.—The station is in sec. 9, T. 4 S., R. 18 E., B. H. M., about 40 rods north and 25 rods west of the southeast corner of said section, on an elevated point, bounded on all sides except the north by bare clay cliffs of the Bad Lands. The station is precisely marked by an oak stake. The ground upon which the station lies is unoccupied public land and is immediately to the west of the Johnson ranch and Johnson Brothers' store. The following true bearings were determined:

	° '
East gatepost of Indian reservation fence on south side of White River (mark)	11 49.6 east of south
Southeast corner of Johnson Brothers' store	60 10.7 east of north

Murdo, Lyman County.—Observations were made over an oak stake marking the northeast corner of a block in the newly plotted town of Murdo. This corner is one block south and two blocks west of the Crosbie Hotel, or three blocks south of the Chicago, Milwaukee and St. Paul Railway tracks and two blocks west of Main street. The following true bearings were determined:

	° '
Northwest corner Crosbie Hotel (mark)	61 24.0 east of north
Switch stand at stock yards	16 02.8 west of north
East gable homestead shack	84 11.5 west of north

Pierre, Hughes County.—The station of 1896 being no longer suitable for magnetic observations, a new station was located in the Riverside Park, east of the central part of the city, about 115 feet east of the drive entering the park at the northwest corner and 82.2 feet south of the fence bordering the highway on the north. It is near the edge of the bank bordering the timbered tract along the lower bottom. The station is marked by a Bedford limestone post 5 by 5 by 27 inches projecting 2 inches above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° '
Cross on Catholic Church (mark)	5 05.4 west of north
Spire on court-house tower	19 04.0 west of north
Base of flag pole on hospital	77 25.0 east of south

Observations were also made at the station of 1896. It is in the court-house grounds, 195.2 feet northeast of the northeast corner of the court-house, 198.1 feet east of the east side of North Main street, and 47.1 feet south of the east and west plank walk.

Preacher Hill, Roberts County.—The triangulation station is in Sisseton Reservation, Roberts County, S. Dak. It is on a high hill, known in the vicinity as Preacher's Hill, in the NE. corner NE. ¼ sec. 1, T. 123 N., R. 52 W., upon dead Indian land. It is 5 miles south and 2 miles west of Sisseton Agency village. It is marked with sewer tile and concrete with inverted nail to mark the exact spot. The magnetic station is 235.5 feet west of the triangulation station and about 8 feet lower in elevation. Distance measured along slope with no correction for grade. It is in direct line between triangulation station and center of chimney of Kinsman's house, three-fourths of a mile west. The station is marked by a 2 by 4 inch stub set flush with the ground and having a copper nail driven in the top to mark the exact spot. The following true bearings were determined:

	° '
Chimney on John German's house (mark)	14 25.8 east of north
Chimney of Kinsmans house	88 41.0 west of south
East gable of barn 2 miles southwest	50 21.9 west of south
Chimney of house (1½ miles)	8 54.6 east of south

Descriptions of stations—Continued.

SOUTH DAKOTA—Continued.

Presho, Lyman County.—Observations were made at a point near the center of First street (west of Main street) produced to the east and west highway on section line south of the village. It is about 76 feet north from the wire fence bounding the highway along the south and about 10 feet from the north line of said highway, and approximately 5 blocks south of the Chicago, Milwaukee and St. Paul Railway. From the station the southeast corner of the Arcade Hotel shows in line with the west gable end of the freight house of the railway company. The following true bearings were determined:

	° ′
Chimney on Mr. Vought's house (mark)	32 54.6 east of north
West gable of freight house	16 24.6 east of north
West gable of Mr. Delaney's house	74 26.4 east of south
Tip on railroad water tank	77 12.6 east of north

Rapid City, Pennington County.—The station of 1905 was reoccupied. It is located on the grounds of the South Dakota State School of Mines. It is 267.5 feet from the nearest corner of the metallurgical building and 260.3 feet from the nearest corner of the heating plant. The station is marked by a native sandstone post 9 by 9 by 27 inches projecting 4 inches above the surface of the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Tower on abandoned college (mark)	11 56.4 west of north
East gable of old dormitory	53 56.5 west of north
North edge of brick flue on chlorination plant	29 55.0 east of south
Wood's monument, old cemetery	88 41.0 east of south

Reva, Butte County.—The station is at Mitchell's ranch in the E. ½ sec. 8, T. 18 N., R. 8 E., of B. H. M. and a little to the west of the quarter corner between sections 8 and 9. Observations were made on a narrow ridge between two draws running to the creek in front of Mr. Mitchell's house and about 10 rods away to the eastward. The following true bearing was determined.

	° ′
Sharp projection on the top of a clay butte	18 34.8 west of south

Roscoe, Edmunds County.—The station is located at the rear of the grounds of the public school, about 132 feet east of the east line of Main street, and about 30 feet east of the east line of the schoolhouse (produced). It is 217.5 feet from the northeast corner of the schoolhouse The station is marked by a sandstone post 5 by 5 by 24 inches, and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Tip over east gable of Chicago, Milwaukee and Saint Paul Railway depot (mark)	23 27.1 west of south
Spire, Presbyterian Church	8 34.0 east of south
South gable of farmhouse (1 mile)	63 20.0 east of north
Chimney on house (1½ miles)	49 04.8 west of north

Seim, Butte County.—The station is located on an unoccupied piece of ground on the bank of the Grand River, at the junction of the north and south forks. It is 65 rods southeast from Wilson's ranch (hotel and post-office) along the trail on the north bank. It is 17 paces from the southwest corner of a fenced field, and 10 paces from the fence in line with the mark, and 22 paces from the river bank in the same line. It is near the center of the SW. ¼ sec. 26, T. 21 N., R. 15 E., of B. H. M. The following true bearings were determined:

	° ′
Pole stood upright in pile of stones on south bank of river (mark)	2 19.9 west of south
South gable of schoolhouse	51 13.0 east of north

Selby, Walworth County.—The station is located in the northwestern part of the village on a square designed to be the location of the county court-house. It is within 20 feet of the street line along the

Descriptions of stations—Continued.

SOUTH DAKOTA—Continued.

north side of the square. It is 193.4 feet from the northwest corner of a frame building once used as a court-house, and about 250 feet from the northeast corner of the frame schoolhouse. The following true bearings were determined:

	° ′	
North gable elevator (No. 1) (mark)	36 47.3	east of south
Spire of Episcopal Church	89 47.4	east of north
Northeast corner of house near schoolhouse	88 45.0	west of south
Spire of Methodist Episcopal Church	7 33.9	west of south

Stearns, Stanley County.—The station is at a point on the range line between ranges 23 and 24 E. in T. 2 S., about 400 feet south of the center of the proposed extension of the Chicago, Milwaukee and Saint Paul Railway, and about 650 feet from the northeast corner of sec. 36, T. 2 S., R. 23 E. of B. H. M. It is also in the line with the south side of Thode Brothers' store, at which the Stearns post-office is at present located. This will be moved elsewhere on the completion of the railroad. The following true bearings were determined:

	° ′	
Fence post on quarter line east and west through section 36	27 08.0	west of south
East gable of Thode Brothers' store	89 53.7	west of south
Southwest corner of shack on SW. ¼ sec. 30, etc	13 44.3	east of north

Vale, Butte County.—The station is situated on the tract of ground upon which the schoolhouse is located, being about 100 rods west of the post-office and hotel, and on sec. 28, T. 8 N., R. 6 E. of B. H. M. 10 rods north of the quarter corner between sections 28 and 33. It is in line with the north edge of the schoolhouse (a small frame structure 16 by 26 feet) and 57 feet distant to the eastward, and 20.5 feet from the north and south fence bounding the tract on the east, being also the one-quarter section line through section 28. The station is marked by a small black bowlder, the projecting portion being roughly 6 by 6 inches, and projecting 2 inches above the surface of the ground. A cross was made in the top, though not deep enough to be conspicuous. The following true bearings were determined:

	° ′	
U. S. R. S. signal on north bank of river (mark)	13 30.9	east of north
South gable of Mr. Richard's house (2 miles)	43 21.4	west of north
Southeast corner of schoolhouse	67 48.5	west of south
Chimney on Mr. Perry's house	88 14.6	east of south
South gable of John R. Curtiss's house	17 35.5	east of north

Watertown, Coddington County.—The station of 1900 being no longer suitable for magnetic observations, a new station was established southeast of the old one in the southwest quarter of the grounds of the high school. It is 105.2 feet south of the south side of the walk running westward from the high school, 37.1 feet east from the east side of walk along west side of square, and 73.2 feet southeast from the southwest corner of the high school building. It is marked by a 6 by 6 by 26 inch stone post, set flush with the surface of the ground and lettered U. S. C. & G. S., with drill hole to mark the exact spot. The following true bearings were determined:

	° ′	
Spire on court-house (mark)	15 37.4	west of north
Magnetic station of 1900	9 38.9	west of north
Spire of church east of court-house	14 18.5	east of north
Spire of high school	64 35.4	east of north
Southwest corner of high school	85 23.3	east of north
Spire of church south of court-house	50 24.4	west of north

TENNESSEE.

Knoxville, Knox County.—The station is located on private property, known as Fort Sanders, in the western part of the city. The station of 1903 could not be absolutely determined, as the marking stone had been removed, but observations were made over the hole left by the stone. It is in the property line of the west side of Tenth street, and 380 feet, approximately, from W. W. Carson's house,

Descriptions of stations—Continued.

TENNESSEE--Continued.

in line with the north side of same. The station is no longer desirable, owing to the proximity of water mains, trolley lines, etc. The following true bearings were determined:

	° ′
Old college flagstaff	85 14.6 east of south
Northwest corner of Professor Carson's house	64 14.9 east of north
Southwest edge of west of two white chimneys on dark house	33 38.3 east of south

Knoxville, Knox County.—The station of 1903 being no longer well adapted for magnetic observations, a new station was established on the University of Tennessee experiment farm, about 1½ miles from the court-house in a southwesterly direction. It is about 3 feet from the eastern edge of the lawn east of the dwelling house, 42.7 feet from the northeast corner of the house, and 62.7 feet from the east post of the south piazza. It is marked by a square marble post, projecting about 2 inches above the lawn and lettered U. S. C. S. The following true bearings were determined:

	° ′
Spire on Daniel Briscoe's residence (mark)	44 47.5 east of north
Cupola of public school	75 32.6 east of north
Southeast corner of dormitory	64 24.8 west of south
Center of south gable of gray house	18 19.5 west of north
Center of east chimney of same house	17 53.4 west of north

Sparta, White County.—The station is in the northeast corner of the grounds of the public school. It is on the highest part of the grounds and to the rear of the building, 32.2 feet south of the north fence and 38.8 feet west of the east fence. The station is marked by a sewer tile 19 by 4 inches, placed flange down, the top being about 1 inch below surface of ground. The following true bearings were determined:

	° ′
Christian Church spire (mark)	74 50.6 west of south
Methodist Church spire	82 48.5 west of south
Center of tower of Judge Smith's house	6 33.4 west of south
Center of tower of schoolhouse	53 08.1 west of south

Waldensia, Cumberland County.—The station is located in the open space northeast of the dam and reservoir and between the post-office and the residence of the superintendent of the Chicago and Tennessee Coal Company's mines. The southwest corner of the foundation of the superintendent's house is distant 116.1 feet, the southeast corner of the office of the coal company is distant 79.7 feet. The station is marked by a rough native stone about 18 inches long and about 5 by 9 inches on top, which is placed flush with the surface of the ground. The following true bearings were determined:

	° ′
Southeast edge of chimney of house distant one-eighth of a mile (mark)	28 09.2 west of south
Southeast corner of coal company's office	82 48.0 west of south
Southwest corner of superintendent's house	23 45.8 west of north
Northwest corner of chimney of roundhouse	1 39.7 west of south

TEXAS.

Bowie Northwest Base, Clay County.—The magnetic station is near the triangulation station, which is on a prominent rise about 1 mile southeast of Bellevue, on land of Mr. J. D. Orton, who lives about 150 yards east of the station. The magnetic station is marked by a copper nail in a small hub, 163.4 feet from the triangulation station in exact line to Bowie Southeast Base. The following true bearings were determined:

	° ′
Center of tower of Bowie Southeast Base triangulation station (mark)	37 15.7 east of south
Center of chimney on white house	0 21.2 west of south
Center of cupola on Mr. Webb's house, distant 1 mile	66 45.2 west of north
Northwest corner of chimney on Mr. Orton's house	59 01.4 east of north

Descriptions of stations—Continued.

TEXAS—Continued.

Weatherford, Parker County.—The station is in the northeast corner of the grounds of the Fourth Ward public school, which faces South Main street and is in the fifth block south of the court-house square. The station is 81.8 feet northeast from the northeast corner of the schoolhouse, 45.9 feet from the north fence of the grounds, and 76.3 feet from the east fence of the alley of the block. The station is marked by a piece of 4-inch sewer tile about 14 inches long, the top of which is about 2 inches below the surface of the ground. The center of top of tile marks the exact spot. The following true bearings were determined:

	° ′
High school spire (mark)	31 53.4 west of north
Court-house spire	5 52.4 west of north
Spire of the Woman's Seminary	2 50.8 west of south

UTAH.

Beaver, Beaver County.—The station is situated on the public school property, 69 feet east of the west fence, 63 feet south of the north fence, and 147 feet northwest of the northwest corner of the school building. The station is marked by a green granite post, 7 by 7 by 28 inches set flush with the surface of the ground, and lettered U. S. C. & G. S., 1906. The following true bearing was determined:

	° ′
Chimney on Ray Barton's house (mark)	13 50.0 east of south

Dragon, Uintah County.—The station is situated on the side of the mountain, about 450 paces due east from the hotel porch, and about 350 paces from the Uintah Railroad tracks. It is on a line with the board sidewalk running from the hotel porch to the street. The station is marked by a small stake driven into the ground and stones piled over it. The following true bearing was determined:

	° ′
Top of hotel water tank (mark)	86 25.7 west of north

Green River, Emery County.—The station of 1905 was reoccupied. It is on land owned by the Denver and Rio Grande Railroad, about one-fourth of a mile southwest of the center of the town, and about 700 feet south of the railroad station. It is about 600 feet southeast of the longitude station of 1898 and south of the Palmer Hotel. It is 348.2 feet south of the southeast corner of the fence surrounding the Palmer Hotel and 389 feet southeast of the southwest corner of the same fence. The station is marked by a redwood post 7 by 5 by 30 inches, projecting 6 inches above the ground. The following true bearings were determined:

	° ′
Western water tank (mark)	5 44.2 east of north
Flagstaff on Palmer Hotel cupola	26 34.6 east of north
Eastern water tank	89 14.8 east of north

Junction, Piute County.—The station is situated on the block where the public school building and the Mormon meetinghouse stand. It is almost on a line with the southeast corner of the schoolhouse and the northeast corner of the meetinghouse. It is 91.5 feet from the east fence, 70.4 feet from the schoolhouse, and 114.3 feet from the meetinghouse. The station is marked by a rough limestone 16 inches long, 10 inches in diameter at the base and 4 inches in diameter at the top, sunk flush with the surface of the ground. The following true bearing was determined:

	° ′
Chimney on Mrs. Hale's house (mark)	76 05.8 east of south

Kanab, Kane County.—The station is in the yard around the Mormon Church. It is 242.8 feet from the northeast corner of the Mormon Church and 161.9 feet south of the north fence. The station is marked by a red sandstone, 6 by 6 by 24 inches, set flush with the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Flag pole of Bower & Co.'s store building (mark)	87 48.5 west of north
Cupola on school building	5 48.7 west of north
Northeast corner of north chimney on church	89 02.3 west of north

Descriptions of stations—Continued.

UTAH—Continued.

Manti, Sanpete County.—The station is situated on the square with the Mormon meetinghouse and the public and high school buildings. It is 100.7 feet west of the east fence and 136.4 feet south of the north fence. The station is marked by a brown sandstone post, 6 by 6 by 24 inches, lettered on top U. S. C. & G. S., 1906, projecting 2 inches above the surface of the ground. The following true bearing was determined:

	° ′
South corner of the Scandinavian Store (mark)	37 24.5 east of south

Modena, Iron County.—The station is situated on public land, about 425 yards southeast of the San Pedro, Los Angeles and Salt Lake Railroad tracks, at a point near the east end of depot. It is 59.0 feet south of the St. George road. It is marked by a rough limestone set 18 inches in the ground and extending 6 inches above ground. The following true bearing was determined:

	° ′
Flag pole on United States Weather Bureau station (mark)	73 55.5 west of north

Panguitch, Garfield County.—The station is situated on the school playground. It is 165.8 feet south of the southeast corner of the schoolhouse and 157.4 feet southeast of the pump near the west edge of the school ground. It is marked by a limestone post, 8 by 8 by 24 inches, projecting 4 inches above the surface of the ground, and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Weather vane on church steeple (mark)	61 29.2 west of north
West chimney on J. W. Imely's house	44 30.3 east of south

Parowan, Iron County.—The station is situated near the middle of the fourth street north of the schoolhouse. It is 24 paces west of the middle of the street running north and south. It is 57.4 feet south of the north fence and 51.4 feet north of the south fence. The station is marked by a cedar post, 2 feet long, 4 inches in diameter, and set flush with the surface of the ground. The following true bearings were determined:

	° ′
Gable on Mr. Albert Orton's barn (mark)	20 31.7 west of north
Gable on Mr. Michaelson's barn	15 00.3 west of south

Richfield, Sevier County.—The station is situated on the ball grounds in the north part of the town. It is 37.8 feet west of the east board fence and 131.9 feet south of the southeast corner of the grand stand. The station is marked by a stone 3 by 8 by 8 inches, set 1½ inches below the surface of the ground. The following true bearing was determined:

	° ′
South corner of south chimney on Mr. Ed. Clark's house (mark)	74 29.2 west of south

St. George, Washington County.—The station is on the public square, 109.3 feet west of the east fence and 103.5 feet south of the north fence. It is marked by a red sandstone, lettered on top U. S. C. & G. S., 1906, set 24 inches deep and projecting 2 inches above the surface of the ground. The following true bearings were determined:

	° ′
Southwest corner of cornice of schoolhouse (mark)	56 36.9 west of north
Gable of small stable near northwest corner of square	78 11.6 west of north
Gable of small stone building in northeast corner of square	37 16.8 east of north

VIRGINIA.

Big Knob, Scott County.—The triangulation station Big Knob is in the Clinch Mountain range, about 5½ miles northeast of Gate City and about 2½ miles by road from Hilton's station on the Virginia

Descriptions of stations—Continued.

VIRGINIA—Continued.

and Southwestern Railroad. It is marked by a large rock, level with the surface of the ground, with grooves cut north and south and east and west, with a drill hole 2 inches deep at their intersection, and lettered U. S. C. S.

The magnetic station was placed 81.3 feet from the triangulation station in direct line to the center of the top of a tall pole-like tree on a spur of the mountain about three-eighths of a mile distant across a deep gap in the ridge. This tree was used as mark in the magnetic work and bears 53° 38'.3 east of true north. The magnetic station was marked by an oak stub driven flush with the ground.

Boydton, Mecklenburg County.—The station is on the east side of the public school grounds, 56.6 feet from the northeast and 44.6 feet from the southeast corner of the frame schoolhouse. It is 40.0 feet from the east fence, 60.0 feet from a small oak tree in the middle of board walk to the south; and 46.3 feet from another small oak tree to the southwest. The station is marked by a cedar post with a cross cut in the top. The following true bearings were determined:

	°	'
Cupola on E. Overby's house (mark)	70	41.6 east of south
Methodist Episcopal Church tower	64	31.6 east of south
Lone tree	36	20.1 east of south
Northeast corner of shanty	9	36.9 east of south
South gable C. Ricks's house	36	43.8 west of south

Bristol, Washington County.—The station of 1898 on the grounds of the Southwestern Virginia Institute was reoccupied. It is 107 feet from the front line of the grounds and 60 feet to the right from the center of the walk leading to the main entrance of the building. It is marked by a limestone post projecting 3 or 4 inches and lettered U. S. C. & G. S., 1898. A similar but unlettered stone 120.5 feet to the south determines a meridian line. One hundred and twenty-six feet to the north is a hole in the granite step of the institute, also in the meridian. The following true bearings were determined:

	°	'
Flagstaff public school	34	39.7 west of south
Spire First Baptist Church	6	53.0 west of south
Spire First Christian Church	8	21.1 west of south
Spire Mary Street Church	3	27.0 west of south
Southeast side smokestack Columbian Paper Company	59	03.3 east of south

Cahas, Franklin County.—The station is located in a pasture on the farm of Mr. Daniel Bowman, 6 miles southwest from Boone Mill, about five-eighths of a mile north of road between Boone's Mill and Dillons Mill post-office. The station is about one-fourth of a mile north-northwest from Mr. Bowman's house, near the southwest corner of pasture on the crown of the south spur from Cahas Knob extending into the valley, which terminates just west of the house. It is 145 paces south of the lower of two large rock piles which lie at the head of the gully just east of the station and 17 paces north of the south rail fence of the pasture. It is marked by a small wooden stub and is in exact line between 1-inch drill holes on large outcropping granite rocks. The south hole is distant 33.1 feet, S. 8° 17'.0 W., and the north hole is distant 14.2 feet, N. 8° 19.1 E. Grooves from both holes point to station. The following true bearings were determined:

	°	'
Center of north gable of Mr. Bowman's house (mark)	35	09.8 east of south
Southeast corner of house, distant about 1 mile (Mr. Nunley's)	30	09.0 west of south
Deep gap in Grassy Hill, distant about 8 miles	48	52.9 east of south

Cape Henry, Princess Anne County.—As the station of 1895 could not be recovered, observations were taken at a point to the north of the board walk leading to the wireless telegraph station from the east brick pavement along the street between Casino and depot. It is 56.5 feet from the eastern edge of the pavement and 23.3 feet from the northern side of board walk. The station is unmarked, as

Descriptions of stations—Continued.

VIRGINIA—Continued.

the proximity of the electric-car line makes its future occupation inadvisable. The following true bearings were determined:

	° ′
Windmill rod at Casino	15 05.6 west of north
Windmill rod at depot	23 45.1 west of south
Old light-house	27 25.3 east of south
New light-house	60 34.1 east of south
Flagstaff Hygeia Hotel	69 51.3 east of south
Wireless telegraph pole	75 33.0 east of south
Anemometer staff	86 09.3 east of south

Charlottesville, Albemarle County.—The station of 1901 was occupied as nearly as could be determined. It is on the tennis courts of the Y. M. C. A. of the University of Virginia, to the rear of Madison Hall. It is 88.6 feet south from the north monument of a meridian line, which is in the fourth backstop. The station is not marked. The following true bearings were determined:

	° ′
Northeast vane on museum	6 31.8 east of south
Southeast vane on museum	6 59.6 east of south
Spire on Y. M. C. A	17 44.5 west of south
Northeast corner of Booker dwelling	13 31.0 east of south
East edge of flagstaff on gymnasium	81 52.9 west of north
Northeast corner of Anthony's Hall	88 16.8 east of south

King George, King George County.—The station is 22 miles from Fredericksburg, the nearest railroad station. It is on the grounds surrounding the court-house, near the public road. It is 78.7 feet from the northwest corner of the base of the Confederate monument, 108.3 feet from the northwest corner of the court-house, and 65.6 feet from a wire fence on the opposite side of the road. It is marked by a locust post 3 feet long and about 6 inches in diameter, sunk into the sandy soil to within about 4 inches of its top. A cross cut on the post marks the exact point. The following true bearings were determined:

	° ′
Northwest corner base of Confederate monument	42 09.2 east of south
Northeast corner of chimney Junior Hall	49 32.6 east of south
Northwest corner of chimney on Hunter's office	26 42.5 west of south
Northeast corner clerk's office	62 49.7 east of north
Northwest corner of court-house	18 25.0 east of north

Little Creek Inlet, Princess Anne County.—The station is on an elevated sand dune about 200 feet from Little Creek inlet, on the peninsula formed by the inlet and the ocean, about 40 feet from the shore line. Three poles about 4 inches in diameter and about 12 feet long were set up, forming a triangle about the station, to aid in recovering it. The station is marked by a marble post 6 by 6 by 28 inches, projecting about 8 inches above the sand. The precise point is 10.1, 9.7, and 11.5 feet from the pole to the northwest, northeast, and south, respectively. The following true bearings were determined:

	° ′
Flagstaff at Ocean View (mark)	65 44.9 west of north
Chimney at Fortress Monroe	56 52.1 west of north
Steel seesaw support at Ocean View	66 18.3 west of north
Tree	16 11.2 west of south

Mount Weather, Loudoun County.—Observations were made over pier E in the absolute building of the Mount Weather magnetic observatory and also at a station outside, 218.4 feet from pier E in line with the mark used in magnetic observations. This mark bears 59° 06′.6 west of true south.

Princess Anne, Princess Anne County.—The station is in the yard in front of the dwelling of Mr. Charles Brock, about 1 mile southwest of the court-house. It is 102.7 feet from the highway

Descriptions of stations—Continued.

VIRGINIA—Continued.

fence, 36.1 feet from the garden fence, 104.3 feet from a large tree at the intersection of the two fences, 20.8 feet from a large cedar, and 42.7 feet from a small cedar. The station is marked by a stone post 5 by 5 by 7 inches, lettered U. S. and set flush with the ground. The following true bearing was determined:

	° ′
Lower southeast corner of chimney on the Woodhouse dwelling	43 21.7 east of north

White Rock, Lee County.—The magnetic station is in exact line between White Rock triangulation station and a tall, pole-like tree growing on the crest of the large rock cliff about three-fourths of a mile to the eastward and bearing 78° 50′.5 east of north. It is close to the ridge of the mountain, being about 30 or 40 feet northward from the edge of a small rock cliff and 309.4 feet distant from the triangulation station. It is marked by a wooden stub 8 inches long driven nearly flush with the surface of the ground. The mark used was the top of the above-mentioned tree.

WASHINGTON.

Colville, Stevens County.—The station is located on the crest of a hill to the west of the southwest corner of the fence inclosing the fair grounds. It is 88.0 feet from the fence, the measurement being taken from a point in fence where the bottom board is placed horizontal instead of upright. The station is marked by a pine post 2 by 4 by 32 inches projecting above surface of ground about 5 inches and having a copper nail driven in top to mark the exact spot. The following true bearings were determined:

	° ′
Flag pole Richey building (mark)	78 01.0 west of north
Court-house flag pole	77 24.1 west of north

Port Orchard, Kitsap County.—The station established in February, 1906, was reoccupied. It is on a knoll in the southwest corner of the court-house square, 52 feet from the southwest corner stake, about 14 feet from the west line of the square, and 280 feet from the northwest corner of the court-house. The station is marked by a 6-inch sandstone monument, lettered U. S. C. & G. S., 1906, set about 33 inches deep, and with about 4 inches projecting. The county authorities kindly placed a load of gravel around the station. The following true bearings were determined:

	° ′
Navy-yard flagstaff (mark)	6 59.0 east of north
West tangent to administration building	8 13.2 east of north
Southeast corner main building	11 14.1 east of north
East edge of base of power-house chimney	13 08.2 east of north
Northwest corner of court-house	50 19.0 east of north

Spokane, Spokane County.—The station of 1881 being no longer suitable as a magnetic station, a new station was established on an unused portion of ground in the northwest part of Fairmount Cemetery, and 315.6 feet from the board fence bounding the cemetery on the north. The station is marked by a sandstone post 4 by 6 by 26 inches, projecting about a foot above the surface of the ground. (Rocks prevented post being planted deeper.) The post is lettered on top U. S. C. &. G. S., 1906, and has a hole in the center to mark the exact spot. The following true bearings were determined:

	° ′
Pinnacle of east water tank (mark)	5 46.6 west of south
South corner smelter brick chimney	45 38.9 west of north
North corner smelter brick chimney	45 13.3 west of north

Stevenson, Skamania County.—The station is in the northeastern part of the ground surrounding the public school, about one-fourth of a mile north of the center of town, and on the north edge of the clearing. It is 130.8 feet north of the northeast corner of the public school building and 142 feet

Descriptions of stations—Continued.

WASHINGTON—Continued.

east of the fence bounding the school grounds on the west. It is marked by a stake of native oak 2½ feet by 6 inches, showing about 6 inches above ground, with a cross sawed in the top to indicate the exact spot. The following true bearings were determined:

	° ′
Top of north gable on roof of yellow house with dark shingle roof in Cascade Locks	0 01.5 east of south
Cupola court-house	33 59.2 east of south
Point on peak of mountain to the west	78 35.9 west of south
North gable postmaster's house	0 16.5 west of south

WYOMING.

Arvada, Sheridan County.—The station is located on a knoll about 80 rods north from the B. and M. R. R. depot. It is about 175 yards west from the railroad, measuring from the point where the railroad enters the cut in the southeast side of the sandstone bluff. The knoll is skirted on the east, south, and west by three gulches, the one on the south being quite deep through seamy sand rock. About 40 feet south from the station the knoll breaks off abruptly toward the larger gulch. About 250 yards south from the station are three storage water tanks, the east one of which bears a wooden center staff, used as a secondary mark. The station is marked by a sandstone 10 by 17 by 24 inches, wedge shaped, in the ground. It projects 6 inches above the surface of the ground and is marked U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Point on B. & M. railroad tank by track (mark)	15 37.6 east of south
Point on east one of three water tanks on hill	8 29.4 east of south.

Basin, Big Horn County.—The station is on the southwest corner of the Big Horn County court-house square (four blocks). It is nearly on a line from the southwest corner of the grounds to the court-house and is 115 paces from the court-house and county jail at the center of the square. It is 35 paces from the southwest corner of the grounds. The station is marked by an irregular shaped gray sandstone 10 by 16 by 24 inches, cut down to circular form 6 inches in diameter at the top, and projecting 5 inches above the surface of the ground, and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Staff on Baptist Church steeple (mark)	2 38.7 west of north
Center of notch in top of north point of rock at Clouds Peak (35 to 50 miles away)	87 38.4 east of north

Buffalo, Johnson County.—The station is located on the southwest corner of the public school block. To the fence which surrounds the block it is 70.8 feet south and 64.0 feet west. A line of sight along the south wall of school building, which stands at the southeast corner of the block, passes 2 feet north of the station, and, measured along this line, the station is 327.0 feet from the southwest corner of this same building. It is marked by a cement post 7 by 7 by 27 inches, set 2 inches above the ground, and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Base of steel rod on court-house (mark)	63 31.2 east of north
Tip on Congregational Church	67 06.8 east of south
Southwest corner (sill) of schoolhouse	80 02.1 east of north

Casper, Natrona County.—The station is on the south side of a block of land reserved for city park, lying in the south part of town, on the east side of the main street. It is in the east alley line, 2.4 feet north of the street line, which is marked by a corner stake. A line of trees in the park to the west, if produced, would pass about 6 feet to the north of the station. A small barn in the block to the south, on the same alley line, is 116.5 feet distant. To the northwest corner of a dwelling house to the eastward is about 79 paces. The southeast corner of a brick schoolhouse is about 122 paces

Descriptions of stations—Continued.

WYOMING—Continued.

to the southwest. The station is marked by a sandstone post 6 by 6 by 36 inches, the top dressed (hexagonal) and marked U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Base of pole on city hall belfry mark)	7 09.5 west of north
Southeast corner of brick schoolhouse	49 03.9 west of south
Flag pole on North Side schoolhouse	2 34.5 east of north
Northwest corner of house at southwest corner of park	80 18.7 east of north

Cheyenne, Laramie County.—The magnetic station is on the reservation belonging to Fort D. A. Russell. It is approximately 1 800 feet eastward from the barracks and 200 feet to the south of the road running direct from the fort to the Capitol building. It is on a small knoll 226 paces from the northwest corner of the fence, 82 paces to the eastward along a line drawn perpendicularly from the west fence, 52 paces to the southwestward along a line drawn perpendicularly from the north fence, and about 77 paces southward from the seventeenth pole in the electric-light line, counting eastward from the first pole on the north side of the road; it is also 77 paces to the southwest from the eighteenth pole. The station is marked by a cement post 9 by 9 by 26 inches, set 3 inches above ground, centered by a five-eighths inch hole on top and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Spire on dome of State Capitol building (mark)	68 06.9 east of south
Steel windmill several miles away	4 14.0 west of north
Top south edge of chimney at Fort Russell crematory	85 17.4 west of south
Spire on Catholic convent	69 59.2 east of south

Cody, Bighorn County.—The station is on the northwest corner of the public school block. It is 217 feet from the northwest corner of the school building, 53.7 feet from the north fence, and 45.3 feet from the west fence. A good board fence surrounds the block. The station is marked by a cement post 8 by 8 by 30 inches, projecting 4 inches above the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Cross on Episcopal Church (mark)	35 15.0 east of north
Ball on schoolhouse belfry	69 25.0 east of south
Wooden staff at center of south tank of city waterworks	86 17.1 east of south
Sharp round top mountain (35 or 40 miles southwest)	26 26.0 west of south

Lander, Fremont County.—The station is on the northwest brow of a hill which overlooks the city from the southeast. It is on the NW. ¼ of the NW. ¼ of sec. 20, T 33 N., R. 99 W. The property is known as the J. E. Baldwin estate. If the east and west section line were opened over the hill, it would pass about 40 feet north of the station. A line to the southeast from the northeast corner of the county court-house and jail, through the smokestack at the electric-light plant, would pass 25 feet west of the station. A line due south from the fork of the road (the one fork going up the hill north of the Odd Fellows' Cemetery, the other fork going through the gap toward Myersville) would pass a few feet to the east of the station. It is marked by a cement post 8 by 8 by 26 inches, projecting 4 inches above ground, centered by a one-half inch hole and marked U. S. C. & G. S., 1906. The following true bearings were determined:

	° ′
Short staff on schoolhouse belfry (mark)	54 47.8 west of north
Smokestack on electric-light plant	19 32.9 west of north
Fork in roads	1 17.7 east of north
Short spire on Methodist Episcopal Church	32 32.7 west of north

Lovell, Bighorn County.—The station is on the northeast corner of the southwest quarter of a block upon which the public school building stands. On the northeast quarter of this same block

Descriptions of stations—Continued.

WYOMING—Continued.

is the Mormon tithing house and yard. A strong board fence surrounds the quarter block of tithing yard, and the station is 22 feet west and 22 feet south from the southwest corner of this fence. The southeast corner of the school building is 40 paces distant. The station is marked by a hard gray sandstone 9 by 16 by 20 inches, set 3 inches above the surface of the ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	°	′	
Highest point on chimney-like rock on top of castle-shaped rock, a little east from mountain 14 miles north of station (mark)	13	52.8	east of north
Flagstaff on school building	52	16.2	west of south
North gable of Mormon meetinghouse	6	35.2	west of south

Mayoworth, Johnson County.—The station is not far from the southeast corner of sec. 26, T. 45 N., R. 83 W. It is on a small plot (one-fourth of an acre) of land lying between the county road and the North Fork of Powder River about 200 feet in front of the road ranch house at the Mayoworth post-office kept by Mr. Manus. The Sullivan Brothers' ranch lies across the river from station. It is 60 feet north from the bank of the river, midway between the river and the county road; it is also 30 feet east from a gulch 25 feet wide and 10 feet deep opening into the river. The station is marked by a cement post 8 by 8 by 32 inches, set 8 inches above the ground and lettered U. S. C. & G. S., 1906. As no permanent mark of easy description was available, the highest point in row of fence posts in line of sight over a hill 2 miles to the north was used. The following true bearings were determined:

	°	′	
Fence post (mark)	11	42.4	east of north
Southwest corner of road ranch house (near sill)	36	08.4	west of north

Meeteetsee, Bighorn County.—The station is about 90 rods south of the town hall and public school building adjoining it. It is on a westward slope from the base of a yellow sandstone bank which faces to the west. The bare sandstone crops out at the top from north to south, 110 paces north from the station and 55 paces to the south from the station, which is west from the upper edge of the sandstone about 200 feet. The wash directly above the station to the east is composed of rounded and worn granite stones of small size. A wagon road passes 75 feet below the station, and a small irrigation ditch crosses this road a few rods north from the station. It is marked by a yellow sandstone projecting 10 inches above ground and lettered U. S. C. & G. S., 1906. The following true bearings were determined:

	°	′	
Short staff on brick schoolhouse (mark)	13	23.5	east of north
Highest point seen through gap to south	34	41.0	west of south
Highest point on Shoshone Mountains to southwest	56	38.4	west of south

Myersville, Fremont County.—The station is about 225 paces south from the road ranch house, in the north and south section line. The station is over the stone that marks the corners between quarters and is at the southeast corner of the NE. ¼ sec. 19, T. 30 N., R. 94 W. The mark used is a small round-topped hill in the same line with the road leading to the bridge over Sweetwater River and is 8 miles in a direction south of west. The following true bearings were determined:

	°	′	
Small round-topped hill (mark)	70	56.5	west of south
South gable on road ranch house	1	27.5	west of north
Highest point in Longs Creek Mountain	36	32.6	east of north

Powder River, Natrona County.—The station is on a small ridge which runs back from the railway depot, gently rising to the northeast. It is located on a line of sight which passes directly through the central north and central south windows of the depot, and is 204 paces northward along this line from the depot. The station is marked by a sandstone slab 4 by 16 by 24 inches, set 5 inches above

Descriptions of stations—Continued.

WYOMING—Continued.

ground, face east, and is marked on face U. S. C. & G. S., 1906. A cross at the center of the top end marks the exact point. The following true bearings were determined:

	° ′
Knob on top of railroad water tank	1 24.6 east of south
Center of chimney on section house	49 24.5 east of south

Sheridan, Sheridan County.—The station of 1905 was reoccupied. It is on the military reservation at Fort McKenzie, 602 feet nearly south of the building now used as noncommissioned officers' residence, about 100 feet south of the main drive entering the grounds, and a little to the west of the point of junction with the road to the quartermaster's storehouse. The eastern corner of noncommissioned officers' residence appears in line with the gable of the bakery, and the western corner of the first of the barracks is in line with the commanding officer's residence (a new barracks is planned which may obscure this line). The station is marked by a sandstone post 7 by 7 by 27 inches, projecting 4 inches above the ground and lettered U. S. C. & G. S., 1905. The following true bearings were determined:

	° ′
Pole on county court-house (mark)	32 29.6 east of south
East vertical edge of notch in Cloud Peak	18 03.9 west of south

Shoshoni, Fremont County.—The station is located on a low hill about 100 rods east from the water tank of the Northwestern Railway. It is on the north and south section line about 24 paces south from a corner (not well marked). About 100 feet to the southeast from the station is the homestead cottage of Miss Davis (county superintendent of public instruction). The railroad runs 225 paces to the north from the station. The station is marked by a rough gray sandstone 8 by 10 by 30 inches, set 6 inches above ground, having a cross on the top, and on the north face marked U. S. C. & G. S.; on the east face it is marked 1906. The following true bearings were determined:

	° ′
Knob on top of center of railroad water tank (mark)	80 31.5 west of north
Northwest corner post of shipping pens	60 38.2 east of north
Southwest corner of Miss Davis's house	45 44.5 east of south

South Pass, Fremont County.—The station is about 75 rods from the mills operated by the Carissa Mines. It is also about one-half of a mile north from the city of South Pass. It is at a section corner, which is marked by a granite stone 5 by 10 inches standing 1 foot above ground. The east face of the stone has four marks, thus: IIII, and the south edge has three, thus: III. The stone marks the northeast corner of sec. 20, T. 29 N., R. 100 W. A small pile of granite and blue stones are strewn about the stone. The following true bearings were determined:

	° ′
Highest point on Continental Peak (mark)	15 23.8 east of south
Smokestack on Carissa Mines mill	6 16.0 east of south
East top edge of largest of the Oregon Buttes	9 55.4 west of south

Sundance, Cook County.—The station is located on the half block of the public school ground in the southeast part of town. It is near the center of the east half of the half block and is 112 feet east from the corner of the school building and directly in line with the north wall of same. The station is marked by a native marble block 7 by 12 by 18 inches, set 4 inches above the ground. The north face is polished and on it is roughly marked U. S. C. S.; on the top of the stone is chiseled a half-inch hole to mark the center, and also the date 1906. The following true bearings were determined:

	° ′
Point of lightning rod on belfry of county court-house (mark)	37 49.3 west of north
Rod above ball on Methodist Episcopal Church steeple	89 04.9 west of north

Thermopolis, Fremont County.—The station is 1 mile north of the town. Observations were made over the center of the stone which marks the northwest corner of the 1-mile square reservation,

Descriptions of stations—Continued.

WYOMING—Continued.

set apart in connection with the Big Horn Hot Springs. The stone is a rough brownish one about 5 by 15 inches, broken off at the surface of the ground. There is a 4 by 4 foot pit 5 feet east from it and a similar pit 5 feet south from it. It is on the flat north of the hill and east from the wagon road 150 paces. The following true bearings were determined:

	° ′
Top of Joseph Connet monument in cemetery (mark)	62 44.0 west of south
South edge of top of big red hill one-half of a mile west	85 02.1 west of south

Valley, Bighorn County.—The station is on the ranch of Oliver D. Marx. It is on the north bank of the south fork of the Shoshone River, about 40 rods from the current of the river. It is about halfway between Deer Creek and Mr. Marx's house, i. e. about 35 rods each way. It is 20 feet from the edge of the bank, where it drops down about 20 feet to the wash and gravel of the river's old bed. The station is marked by a concrete block, 10 by 10 by 30 inches, set 8 inches above the ground and lettered U. S. C. & G. S., 1906. 436.6 feet north from the station is a blue granite stone 8 by 10 by 30 inches, set 10 inches above the ground and lettered C. S., which marks the north end of the meridian line. The following true bearings were determined:

	° ′
Highest point on mountain to north (mark)	19 15.5 west of north
Highest point on mountain to west	76 52.0 west of south
Highest point on mountain southwest	38 23.4 west of south

Worland, Bighorn County.—The station is located on the southeast corner of the block proposed for public school grounds. The two streets adjoining this corner are Robertson avenue and Stine street. The station is about 60 feet from the east sidewalk line (to be) and 70 feet from the south sidewalk line (to be) of the block. The station is marked by a cement post 8 by 8 by 40 inches, set 32 inches in the ground (and may become drifted over with sand), and lettered U. S. C. & G. S., 1906. The following true bearing was determined:

	° ′
Iron ball on southeast corner of Rupp's store	56 13.1 west of south

APPENDIX 6

REPORT 1907

MANUAL OF TIDES—PART V

CURRENTS, SHALLOW-WATER TIDES, METEOROLOGICAL TIDES, AND MISCELLANEOUS MATTERS

By ROLLIN A. HARRIS

PREFACE.

This paper, constituting the concluding chapters of a manual of tides, treats of a variety of matters more or less connected with the main subject. The other parts appeared in the reports of the Survey for the years 1894, 1897, 1900, and 1904.

Chapter I treats of the motion of liquids, with special reference to the possible modes of flow and the nature of the resistance experienced.

Chapter II considers in some detail the kind of resistance (dissipation) which practically controls the principal ocean tides.

Chapter III is devoted to the discussion of shallow-water or river tides. Airy's treatment of this subject is slightly extended and is compared with more recent work. The peculiarities of many tide curves are accounted for in this chapter, but others defy explanation. A conclusion is drawn as to the forms of estuaries from the known laws of friction.

Chapter IV treats of the combinations of motions such as occur in connection with currents and tides. Special points styled "circular points," or points where the tidal current never slackens, are described.

Chapter V treats of the observation of currents and modes of reducing the observed data.

Chapter VI with the included maps, tables, and quotations contains most of the available information concerning tidal currents which seems likely to throw light upon the oscillations in oceanic basins. Observational data for the coasts of the United States are given in considerable detail. The greater portion of this matter has been worked up during the past two years. The connection between the observed tides and currents is, in many cases, pointed out and briefly explained.

A few matters relating to marine engineering comprise Chapter VII.

One of the principal aims of Chapter VIII is to point out the causes which produce the annual meteorological tides, and to briefly consider the causes of ocean currents.

In Chapter IX the question of seiche oscillations is considered for both open and closed bodies. It appears from this discussion that regular oscillations observed even in small partially-inclosed harbors depend, as a rule, directly upon the dimensions of such harbors rather than upon the dimensions of the sea with which they are connected.

Chapter X treats of lake tides, and shows from observations that Lake Superior very nearly obeys the equilibrium theory.

Chapter XI is to some extent supplementary to the other parts of the manual, particularly to Part III.

As usual, the author has received assistance from other members of the Tidal Division of the Survey in the preparation of the tables contained in and following the text.

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CHAPTER I.—*Flow and resistance.*

CHAPTER II.—*Consideration of dimension and resistance in tidal waves.*

CHAPTER III.—*Shallow-water and river tides.*

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MANUAL OF TIDES—PART V. CURRENTS, SHALLOW-WATER TIDES, METEOROLOGICAL TIDES, AND MISCELLANEOUS MATTERS.

By ROLLIN A. HARRIS.

CHAPTER I.

FLOW AND RESISTANCE.

1. *The flow of water in uniform canals and pipes.*

Before about the middle of the last century it was commonly assumed that the greatest velocity of a stream should, except for the effect of winds, be found at the surface. Various assumptions were made as to the law of velocity decrease in going downward. Among the curves taken to represent the velocities were: A parabola with vertical axis, the vertex being placed beneath the bed of the stream; a sloping straight line; an ellipse; and a logarithmic curve.

Raucourt (b. 1779, d. 1841) from observations upon the Neva, believed that the velocities could be represented by the ordinates of a vertical ellipse whose minor axis lies a little below the surface and the lower extremity of whose major axis lies a little below the bottom of the river. When the river was frozen over, the maximum velocity was found to be a little below middle depth.

Boileau, about 1850, obtained from his measurements of the Mosel, at Metz, a parabola with horizontal axis along the surface, whose equation could be written

$$u = A - Bz^2,$$

z denoting depth below the surface, the measurements being taken in the main current. However, this equation does not apply to the part of the velocity curve above the line of maximum velocity where the velocities are assumed to follow another curve. For a small canal in which he experimented, he found the maximum velocity to occur below the surface from one-fourth to one-fifth of the water's depth.

From observations made on the Irrawaddy, Gordon found the line of greatest velocity to lie as a rule at one-tenth of the depth, and in a few cases at from two-tenths to four-tenths.

The velocities change rapidly in going from the shore to the center of a stream. Humphreys and Abbot found that at Columbus, Ky., the velocities of the Mississippi River 5 feet below the surface vary according to the law of a parabola; also that—

> The parameter of the curve of velocities 5 feet below the surface at any stage is proportional to the square root of the corresponding mean velocity of the river.

From their measurements of the velocities of the lower Mississippi, Humphreys and Abbot drew the following conclusions:

The velocities at different depths below the surface, in a vertical plane, vary as the abscissæ of a parabola whose axis is the axis of X and parallel to the water surface.

The position of the axis in calm weather is about three-tenths of the depth below the surface, whatever be the mean velocity of the river.

The effect of the wind, whether blowing up or down stream, is directly proportional to its force, in the former case lowering and in the latter raising the axis. Also, the amount of such lowering or raising is independent of the mean velocity of the river.*

From their work it is evident that even if the wind had the velocity and direction of the stream the maximum velocity would still be found below the surface and at nearly three-tenths of the entire depth. This fact seems to oppose the theory that the resistance of the atmosphere is necessary for causing the position of greatest velocity to lie below the surface.

Bazin assumes the velocity curve for a regular canal to be an ordinary parabola with its axis horizontal; he finds this to lie from 0 to 0.2 of the total depth below the surface for natural channels, and as deep as 0.35 for some artificial channels.†

The relative velocities for different parts of the cross section of rectangular conduits and open canals; also of open canals of trapezoidal, triangular, and semicircular section, are given by Darcy and Bazin on Plates XVIII–XXIII of their Recherches Hydrauliques. The velocity curves for a canal of rectangular cross section are roughly parabolic in both horizontal and vertical planes. When the canal is open, the parabolic velocity curve of the vertical plane has its vertex somewhat below the surface. Their experiments show that the air-resistance is not the most important factor in depressing the thread of maximum velocity.

That considerable transverse motion occurs in a stream flowing along an open channel is obvious from the most casual observations made upon floating objects. That vertical motion also occurs is not so evident because of the difficulty in following water particles below the surface.

In 1867 Mr. James B. Francis, at Lowell, Mass., experimented upon the cross flow of water currents in uniform canals by discharging whitewash at points near the bottom and noting when and how far downstream it would appear at the surface.‡ He says:

From these experiments it appears that the water at the bottom of the streams came to the surface at distances varying from about ten to thirty times the depth, the shorter distances being in the canal of the least depth and most uneven bed.

But he also states that the whitewash continued to come to the surface for a considerable portion of the time which the part first appearing required in ascending from the bottom to the surface.

Observation curves showing the manner in which the velocity diminishes from the center to the sides of canals with vertical sides are given by James B. Francis, on Plate XVII of his Lowell Hydraulic Experiments, and described in sections 207 and 208 of that

*Report upon the Physics and Hydraulics of the Mississippi River, Philadelphia, 1861, pp. 234, 243, 257, 262, Pl. XI. Velocity curves are given on Pl. XI.

† Encyclopædia Britannica, Vol. XII, p. 498.

‡ Transactions of the American Society of Civil Engineers, Vol. VII (1878), pp. 109–113. See also remarks upon this paper, pp. 122–130.

work. He notes that the velocity at any given point, or rather at any given part of the section, varies continually, although the mean velocity for the whole section remains sensibly constant. This he attributes to an interchange of the currents. In a general way the velocity curves are parabolic.

According to measurements made by W. E. Spear, the tidal currents in Boston Harbor have maximum velocities at considerable depths below the surface.* The velocity curves resemble parabolas.

If a stream be covered with ice, the maximum velocity lies one-third or more of the way down from the surface. For broken and tilted ice, this fraction may be increased to one-half or more.†

Dr. E. C. Murphy draws the following conclusions from observations made at the hydraulic laboratory at Cornell University. The canal is 16 feet wide, 10 feet deep, and 415 feet in length.

> The thread of the maximum velocities is at the surface for depths less than 2 feet and unobstructed flow at the lower end of the canal. For depths of 5 feet or more and discharge checked at the lower end of the canal this thread is from 0.2 to 0.4 depth below the surface, the mean for 21 experiments being 0.31 depth.
>
> The position of the thread of mean velocity varies from 0.5 depth for small depths to 0.73 depth for larger depths. For the 31 experiments by the ordinary method of series C and D it is 0.64 depth below the surface.
>
> In ordinary streams where the depth varies from about 1 to 6 feet, the thread of mean velocity is about 0.6 [of the entire depth] below the surface.‡

For historical notices of the movement of water in canals, see Rühlmann's Hydromechanik (2d ed., 1879), section 121, and Chapter III of Humphrey's and Abbot's Report.

2. *Cross-sectional velocity variation connected with the constant of resistance.*

Observation shows that the velocity is greatest along the axis of a canal and least near the sides and bottom.

For simplicity, first suppose the canal so deep that the effect of the bottom may be neglected. Every elementary mass may be supposed to cross the canal while traveling downstream or onward a distance equal to q, on the average; the mass may not actually cross the stream while traveling this distance, but its transverse motions are such that so far as affecting the onward flow is concerned they may be supposed to give way to this hypothetical uniform crossing. For, the cross-sectional variation in velocity being a continuous and uniform function of the distance from the axis of the stream, all transverse motions of the particles will imply determinate losses of energy. As an element leaves the axis of the stream it loses a portion of its energy. In this way each element takes away (periodically on the average) energy from the energy of the

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*Report of the Committee on Charles River Dam (1903), pp. 387–466, Appendix by J. R. Freeman.

†See Water Supply and Irrigation Paper No. 76, U. S. Geological Survey, "Observations on the Flow of Rivers in the Vicinity of New York City," by H. A. Pressey, Washington, 1903; also Paper No. 187, "Determination of Stream Flow during the Frozen Season" (1907), by H. K. Barrows and Robt. E. Horton.

‡Water Supply and Irrigation Paper No. 95, U. S. Geological Survey, "Accuracy of Stream Measurements," by E. C. Murphy, Washington, 1904.

stream. The impacts of the elements set up rotations and other cross motions. These rotations and cross motions are diffused throughout the liquid, and their maintenance against viscosity requires the expenditure of considerable energy, which is eventually converted into heat. They become apparent when lime water or other colored liquid is mixed with the water.

The diminution in velocity shows how much energy per element is lost to the stream during an excursion of an element from the axis to one side and back again. If v_c denotes the velocity at the center and v_s at the side or bank, the energy which must be supplied to each unit mass while the latter travels a distance q in order to maintain the flow is

$$\frac{1}{2}\left(v_c^2-v_s^2\right), \tag{1}$$

and so the average resisting force per unit mass is

$$\frac{1}{2q}\left(v_c^2-v_s^2\right). \tag{2}$$

Now, it is found from observation that for moderately smooth walls q is about $60b$ where b denotes the breadth of the stream. The resisting force per unit mass is therefore about

$$\frac{1}{120\,b}\left(v_c^2-v_s^2\right). \quad ($$

The side resistances upon a slice of water one unit long, one unit deep, and of a width b, may (§ 7) be written

$$2\zeta' v_m^2 \frac{\gamma}{2g},$$

v_m denoting the mean velocity over the section.

This slice contains b cubic units and the mass is $b\frac{\gamma}{g}$; ∴ the resistance per unit mass

is $\zeta' \frac{v_m^2}{b}$, and so

$$\zeta' = \frac{1}{120} \frac{v_c^2-v_s^2}{v_m^2}. \tag{4}$$

Assuming, for the moment that the velocity of a stream is greatest at the surface, and that the resistance due to the bottom is similar to that due to one side in the case just considered, it follows that b can be replaced by $2h$ and that $2h/q$ is the average upward slope of an ascending element, $\frac{1}{2}q$ being the x-distance over which a particle placed at the bottom travels before reaching the surface.

In Francis's experiments $2h/q$ varies from one-tenth to one-thirtieth or less. This rapid ascension is in part due to transverse or upward motions of the particles in addition to the motion of the element as a whole. Moreover, for some of the particles $2h/q$ is considerable less than one-thirtieth.

3. *Wave motion and flow in a vertical plane, the depth being uniform or nearly so.*

Suppose the horizontal displacement be assumed to be of the form

$$\mathbf{x}=\left[A+B\frac{h-z}{h}+C\left(\frac{h-z}{h}\right)^2+\ .\ .\ .\right]F(x,t)+\phi(z,t). \tag{5}$$

Then because of the equation of continuity,

$$\frac{\partial \mathbf{x}}{\partial x}+\frac{\partial \mathbf{z}}{\partial z}=0,$$

the vertical displacement will be

$$\mathbf{z}=\left[-Az+B\frac{h}{2}\left(\frac{h-z}{h}\right)^2+C\,\frac{h}{3}\left(\frac{h-z}{h}\right)^3+\ .\ .\ .\right]\frac{\partial F(x,t)}{\partial x}+\psi(x,t), \tag{6}$$

A similar expression could have been assumed for the horizontal velocity and by making use of the equation of continuity,

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0,$$

an expression similar to (6) would have been obtained for the vertical velocity.

Now, it seems reasonable, and in accordance with common observation, to assume that the horizontal displacement or velocity has a factor independent of time and distance. This amounts to assuming that the displacement or velocity has a factor depending upon the depths alone; $\therefore\ \phi\ (z,\ t)$ should be zero. In a somewhat similar manner it can be shown that $\psi\ (x,\ t)$ should be zero. Along the bottom of the sheet of water $z=0$. $\mathbf{z}$(or w) will there be zero, provided that either

$$B=0,\ \text{or}\ \frac{B}{2}+\frac{C}{3}=0\ \text{or}\ \frac{B}{2}+\frac{C}{3}+\frac{D}{4}=0 \tag{7}$$

etc., according as 2, 3, 4, etc., terms are assumed to occur in the brackets.

In case u does not contain x—that is, in case the velocity of a particular thread or depth is the same at all cross sections of a uniform canal—then w (the x-axis coinciding with the nearly horizontal bottom) will be zero at all depths regardless of the nature of the z-function in the brackets. Hence it is kinematically possible to have at a given time and depth any constant velocity for all points situated at the given depth. But the constant velocities belonging to the other depths may differ in any manner whatever amongst themselves, or from the velocity belonging to the depth to which attention is directed. In reality the manner in which uniform flow can take place is limited or defined by the nature of the external and internal resistances. According to statements made in section 1 concerning the motions of the particles, the velocity in a broad canal should be a parabola whose vertex lies somewhat below the surface, unless the bottom is rough; in which case the maximum velocity may be at the surface.

When F contains x, the simplest mode of flow is that where $B=0$, and where no further terms occur in the coefficients. This means that water moves in vertical slices, all of whose particles travel the same horizontal distance. This is evidently an impossible case on account of the resistance at the bottom. The next mode in order of simplicity is that where $\frac{B}{2}+\frac{C}{3}=0$, and where no terms beyond the C-term occur in the coefficient. This may be styled the parabolic flow for reasons which will soon appear.

It is the simplest possible mode of flow consistent with a bottom resistance, and independently of the considerations of section 1, it would be the natural assumption to take. The case where $\frac{B}{2}+\frac{C}{3}+\frac{D}{4}=0$, and where no terms beyond the D-term occur in the coefficient, may be styled parabolic flow of order three.

Let $\frac{h-z}{h}=r$, and omit the terms beyond C; then

$$A+Br+Cr^2 \tag{8}$$

is the coefficient of the displacement. This may be written in either of the two forms

$$A+Br-\frac{3}{2}Br^2 \tag{9}$$

or

$$A-\frac{2}{3}Cr+Cr^2. \tag{10}$$

From $\frac{\partial \mathbf{x}}{\partial r}=0$, it follows that the maximum value of $\mathbf{x}$ corresponds to $r=\frac{1}{3}$. The values of the coefficient of the displacement at the surface, one-third of the way down, and at the bottom are, respectively,

$$\begin{aligned} &A, \\ &A+\frac{B}{3}+\frac{C}{9}=A+\frac{B}{6}=A-\frac{C}{9}, \\ &A+B+C=A-\frac{B}{2}=A+\frac{C}{3}. \end{aligned} \tag{11}$$

Consequently the maximum displacement or velocity exceeds the displacement or velocity at the bottom by four times the amount it exceeds that at the surface.

For $r=\frac{1}{2}$, the coefficient$=A+\frac{B}{2}+\frac{C}{4}=A+\frac{B}{8}=A-\frac{C}{12}$. (12)

For $r=\frac{2}{3}$, the coefficient$=A+\frac{2}{3}B+\frac{4}{9}C=A$. (13)

The average value of the coefficient $=A+\frac{B}{2}+\frac{C}{3}=A$, the surface value, or the value two-thirds of the way down.

In case of the tides

$$F(x,t)=\sin\,(at-lx+\alpha),$$

$$\frac{\partial F(x,t)}{\partial x}=-l\cos\,(at-lx+\alpha),$$

for a progressive wave: and

$$F(x,t)=\sin\,[l\,(L-x)]\cos\,(at+\alpha),$$

$$\frac{\partial F(x,t)}{\partial x}=-l\cos\,[l\,(L-x)]\cos\,(at+\alpha),$$

for a stationary wave in a canal whose length is L, the origin being taken at its mouth.

If u contains x, because the depth is subject to small gradual changes, it can be shown that the simplest possible type of steady motion is that in which the velocity curve is a parabola with vertex one-third of the depth of the stream below its surface.

Let u and w be written thus,

$$u=\left[a+b\frac{h-z}{h}+c\left(\frac{h-z}{h}\right)^2\right]f(x), \tag{14}$$

$$w=\left[-az+\frac{bh}{2}\left(\frac{h-z}{h}\right)^2+\frac{ch}{3}\left(\frac{h-z}{h}\right)^3\right]\frac{\partial f(x)}{\partial x}. \tag{15}$$

These satisfy the equation of continuity; w will vanish at the bottom if $\frac{b}{2}+\frac{c}{3}=0$. Let h denote the average depth for a distance over which the depth changes by only a small fraction of itself. z is supposed to be reckoned from the nearly horizontal bottom. The expressions in the brackets have nearly constant values at each cross-section of the reach considered. For another reach, h may have a sensibly different value. But in each case the simplest possible mode of flow is the parabolic kind referred to above. This will apply to reach after reach whose depth variations are everywhere gradual. Even if a stream in an earlier part of its course flowed over a bed not of the kind here supposed, the effects upon its flow will, later on, practically disappear and the parabolic mode of flow be finally established if the length of the stream over tolerably even bed be sufficiently great. As the observed velocity curve approaches in form a parabola of the second order, the depth of maximum velocity will approach $\frac{1}{3}h$.

As already noted, roughness of the bed, or a shallowing of the stream, throws the line of maximum velocity nearer to the surface. A channel broader at the top than at the bottom has its line of maximum velocity raised, and vice versâ for one narrow at the top and broad at the bottom.

See Darcy and Bazin: Recherches Hydrauliques, Plates 18–23.

4. *Kinds of resistance.*

If a solid be held in a fixed position while the adjacent liquid has a steady flow, or if the solid move while the liquid remains at rest, three kinds of resistance will generally be experienced: skin friction, resistance due to impact, implying discontinuous motion, and generally some wave resistance.

Viscosity proper—i. e., the force required to overcome the shear of the elements as one lamina moves over a neighboring lamina—will not be considered here, as it is probably of little consequence. But its indirect effect is of great importance, as will presently be seen. A resistance (dissipation) described in the next chapter is a species of wave resistance.

5. *Skin friction as varying on account of the velocity.*

If an elementary mass of water move through or into a larger mass of water having less velocity than the given element has, the latter experiences a retarding force; some of the original energy will be retained in the element, some will be utilized in directly helping along the neighboring particles, and some will be consumed, i. e., turned into heat. The change of motion experienced is quite analogous to that resulting from the impact of inelastic bodies.

For, imagine a long pipe or canal filled with very small elastic balls. Let the whole collection of them move forward because of gravity or pressure. If they impinge against an object, or if the size of the pipe suddenly change, the chance is very small that important rebounds, like those belonging to a single ball, will take place for a considerable portion of the mass of balls, because the forces resulting from the impacts are largely consumed in moving and rotating the particles among themselves and in urging forward any balls which may lag behind in the rebound. Thus the aggregate of these assumed elastic balls behaves nearly like an aggregate of inelastic balls. With greater reason a liquid will so behave because the particles are indefinitely small.

For perfectly inelastic bodies, M', M'', moving with velocities v', v'' in the same direction, the velocity after their impact is

$$\frac{M'\,v'+M''\,v''}{M'+M''},$$

because the quantity of motion remains unaltered. Now, if v' and v'' before impact be each increased n-fold, so will be the velocity after impact. Since the diminutions in the velocities of a large portion of the liquid, especially near a solid or solid boundary, may be considered as depending upon impacts, it follows that such diminutions in velocities probably bear nearly fixed ratios to the general velocity of the stream, whatever be the actual value of the latter, within tolerably wide limits.

The average force imparted to the boundary walls when the velocity of an element of unit mass is reduced from its maximum value, v_1, to its minimum value, v_2, is $\frac{1}{2}(v_1^2-v_2^2)\div s$, where s denotes the distance along the stream between successive points of minimum velocity of the element as it pursues its slightly undulating or sinuous path. Assume that all motions are geometrically similar. Because of this assumption, when v_1 becomes nv_1, v_2 will become nv_2, while s remains the same as before. The energy in either case divided by the length of the path s is the average value of the resisting force acting upon the element. These forces are therefore to each other as 1 is to n^2. Hence the resisting force when two scales of velocities are employed is proportional to the square of the velocity, i. e. to the square of the initial velocity of the element, or velocity at a certain point in the cross section.

Consider now a rigid body immersed in a uniformly flowing stream. Observations indicate that there is a film of water adhering to the body, otherwise there would be a slipping along the surface of the body. The influence of this film extends outward to a considerable distance in accordance with some law not well understood. A moving element enters the zone of retarded flow which forms a sort of cushion around the rigid body. For any symmetrical surface the impinging particles produce a dragging force upon the body, whose resultant effect acts in approximately the direction of flow. As has just been seen, this portion of the force of impact is proportional to the square of the velocity of the stream. But nothing here stated contemplates a comparison between bodies of different shapes or sizes. All that it is intended to show is, assuming the flows are geometrically alike for different scales of velocity, that what is commonly known as the skin friction upon a body is proportional to the square of the velocity.

This resistance arises from changes in the velocities of the moving liquid elements as they enter the field of influence of the rigid body.

For the resistance due to impact and which does not imply changes in the magnitudes of the velocities, see section 12.

6. *Skin friction as varying on account of the areas of the rigid boundaries.*

Suppose that we compare the resistance found in a given long pipe or canal with the resistance experienced in a pipe or canal whose cross section is similar to that of the former, but whose length and diameter or width are not the same as before.

As already intimated, the resistance to a moving liquid involves what may be termed a misdirection of the particles, and that this in turn is primarily due to the adhesion of a liquid film to the rigid boundary, to viscosity, and to sensible irregularities of the boundary. That is, because of the adhesion and viscosity, however small they may be, a deflecting force must exist (particularly near the boundaries), which sooner or later will cause the rapidly moving particles to enter regions of less onward motion and even to arrive so near the boundary that the motion becomes much diminished.

It may be laid down as the fundamental property of liquid flow in long pipes or canals that each particle will in time occupy all cross-sectional positions of the stream from the axis to the boundary. For short pipes or canals the same tendency to exchange positions is going on, but particles may leave these conduits before experiencing great transverse displacements.

The question as to how viscosity and the presence of rigid boundaries can cause deflections of the particles need not be discussed. It may, however, be noted that since the side of a particle toward the axis of the stream is urged forward by the adjacent liquid while the side toward the rigid boundary is retarded, there must be a couple tending to produce rotation, such that the forward part of the particle is crowded toward the boundary. But the result when all particles are considered is sinuous flow.

In a uniform pipe or canal the impacts of the forward-directed elements against those moving slower produce a traction which is ultimately exerted along the boundary. The continuity of the liquid in a pipe or canal does, in a sense, prescribe the paths of the particles, and these paths may, in the long run, all be considered as alike in all respects. Now, whatever element is followed, it attains the maximum velocity near the axis of the pipe and later on loses this velocity and attains a minimum velocity near the bounding walls.

If two long pipes have the same diameter but differ only in length, then, by what has just been said, the geometrical character of the flow in each is identical. For, the number of minimum velocities experienced by the elements in the two cases will be directly proportional to the lengths; and the forces required to impart a given motion to the particles, which at intervals, regular in the long run, lose a certain part of their maximum velocity, must be proportional to the number of elements concerned.

If the pipes have the same length but differ only in diameter, it is reasonable to assume that the number of minima experienced by the particles in the two cases will be inversely proportional to the diameter. This will evidently be so if the motions are geometrically similar.

The amount of matter to which the forces must impart velocities is directly proportional to the area of the cross section of the pipe. But the number of minimum velocities experienced by the moving particle is inversely proportional to the diameter. Consequently the required force is directly proportional to the diameter.

Hence it is reasonable to conclude that the resisting force or drag upon the pipe (or bed of the canal) is directly proportional to the length of the pipe (or canal) and directly proportional to the diameter (or wetted perimeter); but the average resistance per unit of cross-sectional area is consequently inversely proportional to the diameter (or hydraulic mean depth). From what was shown in section 5 the resisting force is directly proportional to the square of the velocity (i. e., scale of the velocities).

Since the direct effect of viscosity is assumed to be negligible, and since the flow in the same body under different conditions is assumed to be geometrically similar, it follows that the diminution in velocity, or the loss of head, is independent of the pressure under which all motions take place. For, the differential pressure required to produce a certain scale of velocities is the same, whatever the general or atmospheric pressure, because it is consumed in the same way (i. e., to the same advantage) in accelerating the water particles. Experiments made with water pipes buried at various depths, and Coulomb's experiments with an immersed pendulum disc, the apparatus being under the receiver of an air pump, all indicate that the general pressure has no effect upon the resistance. From what has just been said, this indicates that the motions of the water particles are geometrically similar.

It is here convenient to regard as a fundamental type of skin-frictional resistance that which occurs when a thin board of considerable length is placed lengthwise in a large, uniformly-flowing stream. Moreover, for a given fluid, only velocities falling within certain limits will be considered.

It may be postulated as a law derived from observation that in some unknown manner a very thin fluid film clings to the solid with such tenacity that moving adjacent particles can not impart motion to it, and that this stationary film influences the motion of the fluid to considerable distances from the solid. This conception in part explains the fact that for most rigid and tolerably rigid surfaces the amount of resistance for like velocities and dimensions is approximately the same per square unit. But it increases somewhat with the roughness of the boundary surface.

The amount of this resistance (force) can be approximately represented by

$$\zeta' v^2 \frac{\gamma}{2g} A,$$

where $A =$ resisting area, γ the heaviness of a cubic foot of the fluid, and so $\gamma/g =$ the density. ζ' is an abstract number, supposed to be constant for a body of given shape, and to remain nearly the same where the size of the body varies.

7. *Numerical values for skin-frictional resistance.*

Let $F =$ resistance per square unit; then

$$F = \zeta' v^2 \frac{\gamma}{2g} \text{ or } \zeta' v^n \frac{\gamma}{2g}. \tag{16}$$

Using the foot as unit, this becomes

$$F = \zeta' v^2 \frac{\gamma}{64.3444} \text{ or } \zeta' v^n \frac{\gamma}{64.3444}. \tag{17}$$

For pure water, sea water, and air, γ may be taken as 62.4 pounds, 64 pounds, and 0.08 pounds, respectively; then

$$\begin{aligned} F&=0.9698\ \zeta' v^2,\ 0.9946\ \zeta' v^2,\ 0.00124\ \zeta' v^2 \\ \zeta'&=1.0312\ F/v^2,\ 1.0054\ F/v^2,\ 804.305\ F/v^2 \end{aligned} \tag{18}$$

The value of ζ' for a smooth surface is approximately 0.004 in all three fluids. Since F is a force per unit area, it follows that the dimensions of ζ' are zero in time, length, and mass, provided the exponent equals 2; but if the exponent 2 be replaced by n, then the dimensions of ζ' become

$$M^0 T^{n-2} L^{2-n}.$$

It will be noted that the dimensions of F must be

$$ML^{-1}T^{-2}$$

for all the values of n.

If we are dealing with only one liquid or fluid, as water, the resisting force per unit area may, for convenience, be written

$$F=\zeta''\ v^n, \tag{19}$$

where $\zeta''=\zeta' \dfrac{\gamma}{2\,g}$. For water, $\gamma/(2\,g)=0.9698$; or $\zeta''=0.9698\ \zeta'$.

The values of ζ' and ζ'', from various authorities, for several kinds of resisting surface, are given below, together with values of F for a velocity of 10 feet per second according to Froude:*

Varnished surface	$\zeta'=0.00258$	$\zeta''=0.00250$	$F=0.25$ lb.
Painted or planed plank	$\zeta'=0.00350$	$\zeta''=0.00339$	
Surface of iron ships	$\zeta'=0.00362$	$\zeta''=0.00351$	
Fine sand surface	$\zeta'=0.00418$	$\zeta''=0.00405$	$F=0.40$ lb.
New well-painted iron plate	$\zeta'=0.00489$	$\zeta''=0.00473$	
Coarse sand surface	$\zeta'=0.00503$	$\zeta''=0.00488$	
Beds of streams	$\zeta'=0.007565$	Depends on size and form of cross section.	
Iron pipes	$\zeta'=0.0075$	Depends on diameter of pipe and velocity of flow.	
For air	$\zeta''=0.00124\ \zeta'$.		

According to experiments made by Prof. A. F. Zahm,

$$F=0.000\ 006\ 71\ v^{1.86}.$$

Since the dimensions of γ are $ML^{-2}T^{-2}$ and of g, M^0LT^{-2}, it follows that the dimensions of ζ'' are $ML^{-1-n}T^{n-2}$.

* Weisbach: Mechanics of Engineering, Vol. I, pp. 867, 965. Unwin: Encyclopædia Britannica, Vol. XII, pp. 482, 483. Bovey: Hydraulics (1901), p. 124.

8. *Uniform flow impeded by skin-frictional resistance.*

To find the relation between velocity and slope of an indefinitely long pipe or channel of uniform cross section.

If the slope is uniform, the pressure at the two ends of a moving elementary slice will be equal; i. e., $dp = 0$. A resisting surface of unit area exerts a retarding force equal to F. If m units of volume stand upon this area, or rather have this area as lateral boundaries, the force of gravity will drive the slice of water forward with the force $\gamma m \frac{h}{l}$, h here denoting fall and l length. ∴ for uniform motion

$$F = \gamma m \frac{h}{l} = \zeta' \frac{v^n \gamma}{2g}, \tag{20}$$

or

$$\zeta' \frac{v^n}{2gm} = \frac{h}{l} = \text{slope} = i, \tag{21}$$

and

$$v^n = \frac{2gm}{\zeta'} \frac{h}{l}. \tag{22}$$

In a pipe, $m = \frac{1}{2} r$, (23)

$$\text{slope} = \zeta' \frac{v^n}{gr}, \tag{24}$$

$$= v^n \frac{gr}{\zeta'} \frac{h}{l}. \tag{25}$$

In a broad channel, m = the depth; also

$$\text{slope} = \zeta' \frac{v^n}{2gm}, \tag{26}$$

$$v^n = \frac{2gm}{\zeta'} \frac{h}{l}. \tag{27}$$

In general m denotes the hydraulic mean depth.

As ζ' is known to depend in a measure upon the velocity, it has sometimes been replaced by $g\left(a + \frac{b}{v}\right)$. Hence the dimensions of a are $M^\circ L^{-1} T^2$ and of b, $M^\circ L^\circ T$. Consequently, to turn a, expressed in meters, into values expressed in feet, we must divide by 3.28083; b remains the same in both systems.

$$F = \left(a + \frac{b}{v}\right) v^2 \frac{\gamma}{2} = \gamma m \frac{h}{l}. \tag{28}$$

the height corresponding to the loss through friction may be written,

$$h = (\alpha' v^2 + \beta' v) \frac{l}{m}, \tag{29}$$

if ζ' be replaced by $2g\left(\alpha' + \frac{\beta'}{v}\right)$, where $\alpha' = \frac{a}{2}$, $\beta' = \frac{b}{2}$.

In case of a pipe, d = diameter $= 4m$.

The formulas of Prony, Eytelwein, and d'Aubuisson, for long tubes are

$$h=(0.0013932v^2+0.0000693v)\frac{l}{d},$$

$$h=(0.0011213v^2+0.0000894v)\frac{l}{d}, \tag{30}$$

$$h=(0.001370v^2\ +0.0000753v)\frac{l}{d},$$

if the meter is the unit of length, or

$$h=(0.00042465v^2+0.0000693v)\frac{l}{d},$$

$$h=(0.00034177v^2+0.0000894v)\frac{l}{d},$$

$$h=(0.00041758v^2+0.0000753v)\frac{l}{d}, \tag{31}$$

the mean being $$(0.00039467v^2+0.0000780v)\frac{l}{d},$$

if the foot is the unit. These coefficients divided by 4 give α', β', and by 2, a, b. ζ' is of the form $g\ (a+\frac{b}{v})$.

It is to be especially noted that the ζ used by Weisbach in pipe formulæ is by definition four times ζ' used throughout this paper, and so the numerical values in Vol. I, § 429, of his Mechanics must be divided by 4 in order to make them comparable with the above ζ''s or with his own ζ when used in connection with streams.

The relations

$$F=\zeta' v^2\frac{\gamma}{2\,g}=(a+\frac{b}{v})v^2\frac{\gamma}{2}=\gamma m\frac{h}{l}, \tag{32}$$

when applied to long tubes, give

$$F=\frac{\gamma m}{l}\ (0.000\ 394\ 67v^2+0.000\ 0780v)\frac{l}{d}$$

$$=\gamma\ (0.000\ 098\ 67\ v^2+0.000\ 019\ 5\ v),$$

$$=\quad 0.006\ 157\ v^2\quad +0.001\ 217\ v, \tag{33}$$

if $\gamma=62.4$, and

$$F=\quad 0.006\ 315\ v^2\quad +0.001\ 248\ v, \tag{34}$$

if $\gamma=64$.

Weisbach proposes as the value of ζ, $\alpha+\frac{\beta}{\sqrt{v}}$, where h is of the form

$$\left(\alpha+\frac{\beta}{\sqrt{v}}\right)\frac{l}{d}\,\frac{v^2}{2g},$$

which implies that ζ' takes the value $\frac{1}{4}\left(\alpha+\frac{\beta}{\sqrt{v}}\right)$ if h has the form

$$\left(\alpha+\frac{\beta}{\sqrt{v}}\right)\frac{l}{m}\frac{v^2}{2g}.$$

Here $\alpha=0.0143$ and $\beta=\begin{cases}0.010\\0.018\end{cases}$ according as the unit is the meter or the foot.

For an open channel Prony and Eytelwein respectively find

$$h=(0.000\,094\,277\,v^2+0.000\,044\,50\,v)\frac{l}{m}, \tag{35}$$

$$h=(0.000\,111\,415\,v^2+0.000\,024\,265\,v)\frac{l}{m}, \tag{36}$$

the foot being the unit of length. These coefficients are α' and β'. They are somewhat greater than the α' and β' connected with pipes because of the considerable irregularities in stream beds.

These values substituted in $F=\gamma mh/l$ give

$$F=0.005\,883\,v^2+0.002\,777\,v, \tag{37}$$
$$F=0.006\,952\,v^2+0.001\,514\,v,$$

if $\gamma=62.4$, and

$$F=0.006\,034\,v^2+0.002\,848\,v,$$
$$F=0.007\,131\,v^2+0.001\,553\,v, \tag{38}$$

if $\gamma=64$.

Omitting the term in v to the first power in (35), (36),

$$\sqrt{mi}=0.009\,710\,v,$$
$$\sqrt{mi}=0.010\,56\,v;$$
$$v=102.99\sqrt{mi}, \tag{39}$$
$$v=94.74\sqrt{mi}. \tag{40}$$

If ζ' is assumed to so depend upon the hydraulic mean depth, m, that $\zeta'=2g\,(\alpha+\frac{\beta}{m})$, the equation

$$\gamma\, mi=F=\zeta' v^2\,\frac{\gamma}{2\,g}$$

gives

$$v^2=\frac{mi}{\alpha+\frac{\beta}{m}}, \tag{41}$$

the formula deduced by Darcy and Bazin for a channel of rectangular or trapezoidal section. For a channel through earth, $\alpha=0.000\,085$ when the foot unit is used and $0.000\,28$ when the meter; in either case $\beta=0.000\,35$.

Bazin's formula (1897) is

$$v=\frac{157.6}{1+\frac{\gamma'}{\sqrt{m}}}\sqrt{mi} \tag{42}$$

for feet, and

$$v=\frac{87}{1+\frac{\gamma'}{\sqrt{m}}}\sqrt{mi} \tag{43}$$

for meters, γ' is a coefficient, being about 0.1 for a smooth artificial surface, about 1.5 for earth, and 3 or more for exceptionally rough channels. The corresponding values when the meter is used are 0.06, 0.85, and 1.7.

In Ganguillet and Kutter's formula ζ' is taken to be a function of the roughness of the channel, of the slope, and of the mean depth.

Tadini's formula is

$$v=91\sqrt{mi} \tag{44}$$

when the foot is the unit and

$$v=50\sqrt{mi} \tag{45}$$

when the meter is the unit.

The following are a few references to formulæ relating to the flow of water in pipes and canals:

Julius Weisbach: Mechanics of Engineering, Vol. I, secs. 420–479.

Humphreys and Abbot: Report on the Physics and Hydraulics of the Mississippi River (1861), Chap. V.

Darcy and Bazin: Recherches Hydrauliques (1865).

Greenhill and Unwin: Encyclopædia Britannica, Article, Hydromechanics (1881).

James B. Francis: Lowell Hydraulic Experiments, 4th ed. (1883), secs. 177–246.

Hamilton Smith, jr.: Hydraulics (1886), pp. 17–24, 195–198, 271–276.

Ganguillet and Kutter: A General Formula for the Uniform Flow of Water in Rivers and Other Channels, translation (1889), pp. 1–76.

Bovey: Hydraulics, 2d ed. (1901), pp. 123–144, 246–253.

9. *Bernoulli's theorem when friction is taken into account.*

Equation (52), Part IV A, expresses that the energy of all kinds possessed by an element which passes a cross section in unit time is constant for any cross section. If to the second member be added the energy which this unit-time mass loses in going from the first cross section to the second, the equation becomes

$$p_1 v_1 \Omega_1 + \frac{\gamma}{g} v_1 \Omega_1 \left(\frac{1}{2} v_1^2 + V_1\right) = p_2 v_2 \Omega_2 + \frac{\gamma}{g} v_2 \Omega_2 \left(\frac{1}{2} v_2^2 + V_2\right) + \int_{s=s_1}^{s=s_2} FPvds, \tag{46}$$

where ds means $\frac{\partial s}{\partial t}dt$, $V=gh$, and P denotes the wetted perimeter. This equation reduces to

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + \int \frac{FPvds}{\gamma\ \Omega v}. \tag{47}$$

The last terms may be written $\zeta' v^n \frac{P}{\Omega} \frac{s}{2g}$ if F be put equal to $\frac{\zeta' v^n}{2} \frac{\gamma}{g}$, and v denote average velocity.

The same result can be established in connection with section 8, Part IV A.

Effective force = acceleration × mass of element = impressed force

$$= -\Omega dp - \Omega\gamma dz - \zeta' P ds \frac{v^n}{2g}\gamma.$$

$$\therefore\ vdv = -g\frac{dp}{\gamma} - gdz - \zeta'\frac{Pv^n}{2\Omega}ds;$$

$$\frac{v_1^2 - v_2^2}{2} = -\frac{g}{\gamma}[p_1 - p_2 + \gamma(z_1 - z_2)] + \zeta' \int_{s=s_1}^{s=s_2} \frac{P}{\Omega}\frac{v^n}{2}\, ds. \tag{48}$$

The last term becomes $\zeta'\frac{P}{\Omega}\frac{v^n}{2}s$ if v is the constant average value.

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + \zeta'\frac{P}{\Omega}\frac{v^n}{2g}s \tag{49}$$

If n equal 2, and the initial velocity be zero, as when a pipe leads from a large tank, then

$$v^2 = \frac{2gh}{(1 + \zeta'\frac{P}{\Omega}l)}, \tag{50}$$

This equation is of fundamental importance both for the flow of water through pipes and in open channels.

In neither of the foregoing modes of establishing Bernoulli's theorem with friction added is it supposed that the velocity is alike from axis to boundary. It may vary according to any law. The velocity used in the formula may be the mean cross-sectional velocity, the axial velocity, or any other specified with reference to the cross section; for each case ζ' will have a different value. Unless otherwise indicated, the mean cross-sectional velocity is understood to be the one associated with ζ'.

If the pipe or channel consist of several parts which have different cross-sectional areas, a resistance term can be added in the denominator of (50) for each length. Moreover, for each bend or sudden change of cross section, a resistance term, depending in a measure upon the slope and size of the stream, will occur.

10. *Nonuniform flow impeded by skin-frictional resistance.*

If the cross section changes slowly, and if we assume the flow to be without frictional resistance, the case comes under Bernoulli's theorem without resistance terms.

If resistance exists, a modification of the work just given will become necessary, because there the pipe or channel was assumed to have a uniform cross section for a considerable distance. This can be readily accomplished for a pipe of continually varying diameter. For it would only be necessary to divide the pipe into elements so short that the resistance for each could be easily ascertained, the relative velocities being known through the condition of continuity. If water flows in an open channel, it would still generally be possible to make an estimate of the velocities in a similar manner, provided we somewhere know the depth and velocity, and especially if we know the depth at two points a considerable distance apart and the velocity at one of them, or know the velocities at the two points and the depth at one of them.

If any filament of water in an open channel be considered, it is readily seen that the forces which drive along an elementary mass, gravity directly and pressure (gravity indirectly), are the same as the force along the surface, directly above the element and which is direct gravity alone, viz., $g \cos \phi$ per unit mass, where ϕ is the angle between the surface and the nadir. Consequently, in the motion of an element, the pressure at each end of the element may be regarded as one and the same; and so the pressure terms may be omitted from Bernoulli's theorem.

The differential equation thus becomes

$$vdv = -gdz - \zeta' \frac{P\,v^n}{2\Omega} ds, \tag{51}$$

and the same integrated between the limits $s=s_1$, $s=s_2$, becomes

$$\frac{v_1^2 - v_2^2}{2} = -g\ (z_1 - z_2) + \zeta' \frac{P}{2\Omega} v^n s. \tag{52}$$

Or by equation (87) Part IV A

$$v \cdot \frac{\partial v}{\partial s} = -g \frac{\partial z}{\partial s} - kv^n,$$

$$\tfrac{1}{2}(v_1^2 - v_2^2) = -g(z_1 - z_2) + k \int v^n ds \tag{53}$$

where v is a function of s.

For any cross section the quantity of water passing in unit time must be constant.

$$\therefore \Omega v = \text{constant}$$

$$\therefore \frac{d}{ds}(\Omega\, v) = v \frac{d\Omega}{ds} + \Omega \frac{dv}{ds} = 0. \tag{54}$$

If b denotes the constant breadth of the surface of the stream and h its variable depth, then

$$\frac{d\Omega}{ds} = b \frac{dh}{ds}, \tag{55}$$

and so

$$\Omega dv + vbdh = 0.$$

Let $-dz$ denote the fall of the surface in the distance ds, dh the increase in depth in the same distance, i the inclination of the bed, radian measure, taken as positive if the bed slope downward in the direction of the motion; then

$$ids = dh - dz,$$

and so the differential equation becomes

$$vdv = g(ids - dh) - \zeta' \frac{Pv^n}{2\Omega} ds,$$

or

$$-v \frac{vbdh}{\Omega} = g(ids - dh) - \zeta' \frac{Pv^n}{2\Omega} ds; \tag{56}$$

$$\frac{dh}{ds} = i \cdot \frac{1 - \zeta' \dfrac{Pv^n}{2\Omega g i}}{1 - \dfrac{v^2 b}{\Omega g}}. \tag{57}$$

Putting $n=2$,

$$v^2=\frac{i-\dfrac{dh}{ds}}{\zeta'\dfrac{P}{2\Omega g}-\dfrac{b}{\Omega g}\dfrac{dh}{ds}}. \tag{58}$$

If the channel be of uniform depth as well as breadth

$$\frac{dh}{ds}=0,$$

and so

$$i=\zeta'\frac{Pv^n}{2\Omega g} \tag{59}$$

is the equation for steady flow along a uniform channel.

Let H and V refer to the principal portion of the stream where the course is uniform. Suppose the stream to be very wide in comparison with its depth. Then

$$v^2=\frac{H^2}{h^2}V^2$$

and from (59), putting $n=2$,

$$V^2=\frac{2\Omega ig}{\zeta' P}=\frac{2Hig}{\zeta'}; \tag{60}$$

$$\therefore\ v^2=\frac{H^3}{h^2}\ \frac{2gi}{\zeta'};$$

$$\therefore\ \frac{dh}{ds}=i\frac{1-\left(\dfrac{H}{h}\right)^3}{1-\dfrac{2i}{\zeta'}\left(\dfrac{H}{h}\right)^3}.$$

By integration s can be expressed in terms of h and $\frac{h}{H}$. The expression involves what has been styled the backwater function.

When i is assumed to be very small, the sign of $\frac{dh}{ds}$ will depend upon that of the numerator. Consequently, if $h>H$ the depth increases in going downstream from where the depth approximates H to where it equals h, and according to the law involved in the above equation. Similarly for $h<H$, the depth decreases in going downstream.*

11. *Resistance of impact.*

That portion of the force of impact which depends on the component of the centrifugal force of the moving particles can be easily seen to vary as the square of the velocity if two different scales of velocity are compared.

*The following are a few references to the backwater or rémou: Bennett's translation of D'Aubuisson de Voisius' Treatise on Hydraulics (Boston, 1852), secs. 161–174; Rühlmann, Hydromechanik, 2d ed., under "Stauweite," secs. 155–159; Merriman, A Treatise on Hydraulics, under "Backwater;" Bovey, A Treatise on Hydraulics, 2d ed., secs. 13–17.

In computing this force, the velocity of a particle is supposed to be unaltered by the presence of the submerged object, although eventually it will be reduced in value, because after leaving the front surface of the object the particle moves obliquely to the general direction of the stream.

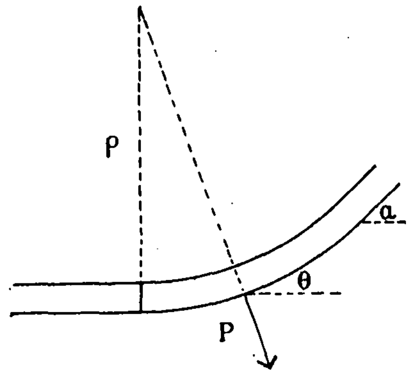
12. *To find the dynamical pressure in the original direction of motion upon a curved pipe.*

The centrifugal force of a body of mass M moving with velocity v is

$$\frac{Mv^2}{\rho},$$

where ρ denotes the radius of curvature of the path.

No. 1.



At a point P the centrifugal force of an elementary mass is $dM\frac{v^2}{\rho}$; and the component directed along the x-axis is

$$dM\frac{v^2}{\rho}\sin\theta.$$

$$\text{Total force} = \int_{s=s_1}^{s=s_2} \frac{v^2}{\rho}\sin\theta dM, \tag{61}$$

$$s_2 - s_1 = l,\ dM = \frac{M}{l}ds,\ ds = \rho d\theta.$$

$$\therefore \text{total force} = \int_{\theta=0}^{\theta=\alpha} \frac{v^2}{\rho}\sin\theta\,\frac{M}{l}\rho d\theta, \tag{62}$$

$$= \frac{v^2M}{l}(1-\cos\alpha).$$

If the pipe had the velocity v', the total force would become

$$\frac{(v-v')^2M}{l}(1-\cos\alpha).$$

because the water during its time of exerting pressure has an x-velocity of $v-v'$ relatively to the pipe.

$$M=l\cdot\text{area}\cdot\text{density}=l\cdot\text{area}\,\frac{\gamma}{g};$$

$$\therefore\ \text{total force}=(v-v')^2\cdot\text{area}\cdot\frac{\gamma}{g}(1-\cos\alpha). \tag{63}$$

Hence the total longitudinal pressure is independent of the length or law of curvature of the curved pipe.

This evidently applies to a jet impinging upon a surface of revolution, either stationary or moving in the direction of the line of motion of the jet. For, the jet in the region where curvature takes place can be divided into tubes of flow.

Applying equation (63) to a stationary plate whose direction is perpendicular to the direction of the stream, the force of resistance is

$$v^2\frac{\gamma}{g}\cdot\text{area of jet.}$$

If the area of the jet be the same as that of the plate, this formula becomes

$$v^2\frac{\gamma}{g}\Omega,$$

a value much in excess of the true resistance, because only a small portion of the approaching column of water whose cross-sectional area is Ω is turned or deflected through the angle of 90°. If the average angle of deflection were 60°, the factor $(1-\cos\alpha)$ of (63) would equal $\frac{1}{2}$.

If a column of water of cross-section Ω moving with velocity v could have this velocity entirely destroyed, and without interfering with neighboring stream lines, the energy consumed per unit time would be

$$\Omega v\frac{\gamma}{g}\frac{v^2}{2}.$$

If the pressure $\Omega\,p$ could act through the distance traveled in one time unit it would do, per unit time, work represented by $\Omega\,pv$;

$$\therefore\Omega\,pv=\Omega\,v\frac{\gamma}{g}\frac{v^2}{2},$$

$$p=\frac{\gamma}{g}\frac{v^2}{2}.$$

This being the resistance per unit area the total resistance will, upon the above hypothesis, be

$$\Omega\,\frac{\gamma}{g}\frac{v^2}{2}. \tag{64}$$

Or, if h denote the height a body must fall to acquire the velocity v, this expression is the statical pressure of a column of water whose height is h.

Kirchoff has calculated this resistance upon an immersed plate for stream-line two-dimensional flow, and found it to be

$$\frac{\pi}{4+\pi} \cdot \Omega \frac{\gamma}{g} v^2. \tag{65}$$

If the plate is inclined to the stream at an angle α, $\frac{\pi}{4+\pi}$ is replaced by $\frac{\pi \sin \alpha}{4+\pi \sin \alpha}$.*

The dynamical pressure of a jet striking against a plane perpendicular to its direction is by (63)

$$v^2 \cdot \text{area of jet} \cdot \frac{\gamma}{g}, \tag{66}$$

and this must be in excess of the true value when the plane is no larger than the cross section of the jet, because the threads of the liquid are deflected, as a rule, much less than 90°. In case of a plane immersed in a stream of indefinite extent, the normal impulse must be less than the above expression, for reasons just stated. The experiments of du Buat and Thibault gave $\zeta = 1.86$ in the formula

$$\zeta \frac{v^2}{2} \frac{\gamma}{g} \cdot \Omega. \tag{67}$$

Comparatively recent determinations give to ζ values between 1.25 and 1.75.

It is generally assumed that the resistance or force of impact is the same whether the body moves through the water or the water impinges upon the body held stationary. In case of a plate wholly submerged and held perpendicular to the lines of motion, it is evident that the greater resistance will occur in the case where the plate is stationary. For, in this case, on account of the discontinuous motion and the inertia of the impinging water, a considerable amount of dead water will lie behind the plate; the stream lines will be prevented from so closing in behind as to somewhat resemble their appearance in front of the plate; that is, the impinging force due to the curvature of an elementary stream in front of the plate may not to any considerable extent be offset by a similar force in the rear. But if the plate moves through the water, the streams around its edges continually turn inward, thus preventing the occurrence of a void, and later give rise to a force urging the plate forward.

Wherever discontinuous motion occurs, it is not probable that the resistance determined by moving the body will be equivalent to that obtained by assuming it fixed and the water in motion.

13. *Resistance for cylindrical bodies.*

Experiments made by myself for the force of impact upon steel wire and rods varying in diameter from 0.036 to 0.5 inch, and with the velocity of the water ranging from 1 to 1½ feet per second, showed that the force is well represented by the expression

$$\zeta \frac{v^2}{2} \frac{\gamma}{g} ld \text{ or } \zeta \frac{v^2}{2} \frac{\gamma}{g} \Omega \tag{68}$$

where the abstract number $\zeta = 0.95$.

* Rayleigh: Collected Works, Vol. 1, pp. 287–296; or Phil. Mag., Vol. II (1876), pp. 430–441. Lamb: Hydrodynamics, 2d ed., article 77.

If

$$Z=cz+a^2\frac{c}{z},$$

then

$$X=c\left(r+\frac{a^2}{r}\right)\cos\theta, \qquad (69)$$

$$Y=c\left(r-\frac{a^2}{r}\right)\sin\theta.$$

Y=constant, denotes the stream lines for steady two-dimensional flow past a circular cylinder placed transversely to the stream. For, if $Y=0$, either $\theta=0$ or $r=a$. This is the case where the stream line breaks up into a straight line and circle. If Y=a large constant, r becomes large in comparison with $\frac{a^2}{r}$, and we eventually have

$$r\sin\theta=\text{the large constant}$$

which gives the equation of a straight line parallel to x-axis.*

By assuming only statical pressure on approximately the rear half of the cylinder, it is possible to make some estimate of the pressure due to motion on the remaining surface. For this purpose consider the greatest deflection experienced by each tube of flow.

The central one is deflected 90°; the one originally in front of the extreme edge of the cylinder is deflected about 21½°.

The longitudinal force of each tube of flow is

$$v^2\cdot\text{ cross section of tube}\cdot\frac{\gamma}{g}(1-\cos\alpha) \qquad (70)$$

The longitudinal thrust of all tubes of flow thus computed divided by the area of the diametrical plane of the cylinder gives $\zeta\frac{v^2}{2}\frac{\gamma}{g}$, from which ζ can be determined, v now denoting the general velocity of the stream before being influenced by the presence of the cylinder.

Since the resistance of impact concerns the front half of the cylinder, it is of interest to note that the resistance upon planes whose traces form a half hexagon inscribed in a semicircle is, when computed by Kirchoff's formula (65) nearly equal to the observed resistance of the cylinder.

A similar method is roughly applicable to a sphere. The observed value of ζ for a sphere lies, according to Weisbach, between 0.5 and 0.6, the resistance being

$$\zeta\frac{v^2}{2}\frac{\gamma}{g}\Omega, \qquad (71)$$

Ω denoting the area of a great-circle section.

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*See Lamb: Hydrodynamics, 2d ed., sec. 68.

14. *The transporting power of water.*

If water impinges upon two solids of like densities and geometrically similar, the forces just sufficient to move them along the horizontal bed of a stream are proportional to their weights, and so to the cubes of their homologous linear dimensions, l_1, l_2.

$$\therefore \frac{(\text{Force required})_1}{(\text{Force required})_2} = \frac{l_1^3}{l_2^3}.$$

By sections 12 and 13 the ratio of the forces of impact is

$$\frac{(\text{Force of impact})_1}{(\text{Force of impact})_2} = \frac{v_1^2\, l_1^2}{v_2^2\, l_2^2} = \frac{v_1^2}{v_2^2}\, \frac{(\text{Force required})_1^{\frac{2}{3}}}{(\text{Force required})_2^{\frac{2}{3}}}. \tag{72}$$

If the solids just move, the force of impact must equal the required force, and so

$$\frac{(\text{Force})_1}{(\text{Force})_2} = \frac{v_1^6}{v_2^6}. \tag{73}$$

15. *Obstruction caused by sudden enlargement.*

The momentum possessed by a mass of water which passes a fixed point near the mouth of a small pipe in unit time is $\Omega_1 v_1 \frac{\gamma}{g} \cdot v_1$; the momentum of a mass passing a fixed point of the large pipe in the same time is $\Omega_2 v_2 \frac{\gamma}{g} . v_2$. Since the motion is steady, the momentum between the two elementary masses considered remains constant in time.

The loss of momentum per unit-time mass occasioned by the sudden increase in the size of the pipe is therefore

$$\Omega_1 v_1^2 \frac{\gamma}{g} - \Omega_2 v_2^2 \frac{\gamma}{g},\ = \Omega_1 \frac{\gamma}{g} v_1 (v_1 - v_2),\ = \Omega_2 v_2 \frac{\gamma}{g} (v_1 - v_2), \tag{74}$$

since by the condition of continuity $\Omega_1 v_1 = \Omega_2 v_2$. The pressure in the small pipe is p_1, that in the large one, not too near the mouth of the small pipe, is p_2. Since increase of pressure does not appear until the velocity of the stream becomes diminished (because $\frac{p}{\gamma} + \frac{v^2}{2g} = \text{constant}$), and since the pressure in dead water can not differ much from that in the neighboring stream, it may be assumed that for the upper end of the large pipe the pressure equals p_1 rather than p_2. The accelerating resultant pressure is

$$p_1 \Omega_1 + p'(\Omega_2 - \Omega_1) - p_2 \Omega_2,$$

or

$$(p_1 - p_2)\Omega_2,$$

where p' is put equal to p_1.

This resultant force acting upon the water of this region does, during each unit of time, increase the momentum of a unit-time mass from what it possessed upon entering to what it possesses upon leaving.

$$\therefore (p_1 - p_2)\Omega_2 = -\Omega_2 v_2 \frac{\gamma}{g} (v_1 - v_2). \tag{75}$$

The energy after the shock is therefore, per unit mass,

$$\frac{p_2-p_1}{\gamma}=\frac{v_2(v_1-v_2)}{g}.$$

For motion without loss of energy

$$\frac{p_2''-p_1}{\gamma}=\frac{v_1^2-v_2^2}{2g}$$

since the pressure head (p_1/γ) is assumed to be the same in both cases. The second member of this equation exceeds that of the preceding by

$$\frac{(v_1-v_2)^2}{2g},$$

or since $\Omega_2 v_2=\Omega_1 v_1$,

$$\frac{v_1^2}{2g}\left(1-\frac{\Omega_1}{\Omega_2}\right)^2$$

is the loss of energy per unit mass, and this is equal to the loss of pressure head at the lower cross section $\left(\text{i. e. } \frac{p_2}{\gamma}-\frac{p''}{\gamma}\right)$ because of shock. The factor $\left(1-\frac{\Omega_1}{\Omega_2}\right)^2$ is Borda's coefficient of resistance.

16. *Hydraulic coefficients.*

Through orifices the amount of the theoretical discharge is diminished by a factor styled the coefficient of discharge. This is the product of the coefficient of velocity times the coefficient of contraction or *vena contracta*. For orifices, the coefficient of velocity is nearly equal to unity, especially for high velocities, and the coefficient of discharge about 0.6. The value diminishes slightly as the size of the orifice is increased and shows that the motion is nearly but not exactly geometrically similar for various velocity scales.

As noted in section 20, Part IV A, the coefficient of contraction for a two-dimensional stream is $\pi/(2+\pi)=0.611$.

Bovey considers the coefficient of contraction to be approximately 0.64 for sharp-edged orifices of any form and nearly unity for those perfectly rounded.*

At the mouth of a projecting tube or mouthpiece the velocity is theoretically that due to height. Consequently if the mouthpiece be divergent the velocity at a narrow section will exceed that due to height.

This has been shown by Bernoulli, Venturi, Eytelwein, and Francis. The increased velocity will not be realized in vacuo, nor if an open channel take the place of the tube or mouthpiece. Hence the flow along an open short channel connecting two bodies of water can never from this cause exceed the velocity due to difference between the surface levels even at the most contracted part of the channel.

17. *A compound vessel.*

A vessel is supposed to be divided into several compartments by means of vertical partitions through each of which is a small opening. At one end of the vessel and near the bottom is an opening through which the liquid escapes into the air. The sur-

* Bovey; A Treatise on Hydraulics, 2d ed., rewritten, sec. 12.

face of the first compartment is maintained at a fixed height by continually supplying the liquid, and all other surfaces will eventually assume certain heights. Let these heights be h_1, h_2, h_3, ... , h_l reckoned from the center of the lowest orifice. Let A_1, A_2, A_3, ... , A_l denote areas of the free liquid surfaces in the several compartments and Ω_1, Ω_2, Ω_3, ... , Ω_l the effective areas of the several small openings in the partitions.

Given the $n+1$ quantities h_1, Ω_1, Ω_2, Ω_3, ... , Ω_l to find the $2n-1$ quantities v_1, v_2, v_3, ... , v_l; h_2, h_3, ... , h_l. The relations between the v's and h's of the form

$$v_1^2=2\,g(h_1-h_2),\ v_2^2=2\,g(h_2-h_3),\ v_3^2=2\,g(h_3-h_4),\ \ldots\ldots,\ v_l^2=2\,gh_l \tag{76}$$

are n in number; and between the v's and Ω's

$$v_1^2\,\Omega_1^2=v_2^2\,\Omega_2^2=v_3^2\,\Omega_3^2=\ldots\ldots\ldots=v_{l-1}^2\,\Omega_{l-1}^2=v_l^2\,\Omega_l^2$$

are $n-1$: all relations thus number $2n-1$.

From the first set we have

$$v_1^2+v_2^2+v_3^2+\quad\ldots\quad+v_l^2=2\,gh_1;$$

and from the second set

$$\frac{v_1^2}{v_l^2}=\frac{\Omega_l^2}{\Omega_1^2},\ \frac{v_2^2}{v_l^2}=\frac{\Omega_l^2}{\Omega_2^2},\ \frac{v_3^2}{v_l^2}=\frac{\Omega_l^2}{\Omega_3^2},\ \ldots\ldots\ldots\ldots\ \frac{v_{l-1}^2}{v_l^2}=\frac{\Omega_l^2}{\Omega_{l-1}^2}.$$

Substituting these values of v_1, v_2, v_3, ... , v_{l-1}, we have

$$v_l=\frac{\sqrt{2\,gh_1}}{\sqrt{1+\frac{\Omega_l^2}{\Omega_1^2}+\frac{\Omega_l^2}{\Omega_2^2}+\frac{\Omega_l^2}{\Omega_3^2}+\ \ldots\ +\frac{\Omega_l^2}{\Omega_{l-1}^2}}} \tag{77}$$

From v_l any other v follows from the equations just written, and two adjacent v's will by aid of (76) determine any required h.

The coefficient

$$\frac{1}{\sqrt{1+\frac{\Omega_l^2}{\Omega_1^2}+\ \ldots}} \tag{78}$$

depends only on the ratios Ω_l/Ω_1, etc., and is independent of the velocity, agreeing in this respect with the other coefficients of resistance. The energy lost is converted into heat in the several compartments and the body into which the final discharge takes place.

If the constrictions consist of well-rounded capes, so that no energy is lost, we have

$$v_1^2-v_0^2=2g(h_1-h_2),\ v_2^2-v_1^2=2g(h_2-h_3),\ v_3^2-v_2^2=2g(h_3-h_4),\ \ldots\ldots\ldots,$$

$$v_l^2-v_{l-1}^2=2gh_l;$$

$$\therefore\ v_l^2-v_0^2=2gh_1;$$

or

$$v_l=\sqrt{2gh_1},$$

if

$$v_0=0.$$

18. *The principle of similitude.**

It is assumed that two configurations of matter, or two mechanisms, are to be geometrically similar at certain times; also that the masses of the corresponding moving parts have a constant ratio to one another; also the motion is sustained or governed by forces which have a constant ratio to one another in the two cases.

Let the size of the second configuration be l times that of the first; the times in passing from one position to a similar position be τ times as great in the second as in the first; the corresponding masses μ times as great; and the corresponding impressed forces F times as great.

In the indeterminate equation of motion

$$\sum\left\{(X-m\frac{d^2x}{dt^2})\delta x+(Y-m\frac{d^2y}{dt^2})\delta y+(Z-m\frac{d^2z}{dt^2})\delta z\right\}=0 \tag{79}$$

we can suppose that X, Y, Z are the components of the impressed moving forces on the element or particle because that portion of the impressed forces which is balanced by the reactions can be associated with no displacements other than zero which are compatible with the connections of the system.

Substitute for X, Y, Z, x, y, z, m, and t, the quantities FX, FY, FZ, lx, ly, lz, μm, τt in the indeterminate equation.

The equation will be identical with (79), provided

$$\mu l=F\tau^2. \tag{80}$$

Kepler's third law.—For the motions of two planets the equation

$$F\tau^2=\mu l$$

becomes, because $F=\mu/l^2$, or $F=\frac{\mu M}{l^2}$ if the planets have different central bodies whose mass ratio is M,

$$\frac{\tau^2\mu M}{l^2}=\mu l. \tag{81}$$

Resistances of model and ship.—Assuming that the resistance is proportional to the area and the square of the velocity; also, that the density of both bodies is the same. The first question is, what velocity will satisfy the requirement

$$F\tau^2=\mu l?$$

Let v denote velocity ratio; then, by hypothesis,

$$F=v^2 l^2,\ \mu=l^3;$$

$$\therefore\ v^2 l^2 \tau^2=l^4.$$

This gives $$v\tau=l.$$

Now assume $$v=\sqrt{l}.$$

$$\therefore\ F=\frac{\mu l}{\tau^2}=\frac{l^4}{l^2}v^2=l^2 v^2=l^3. \tag{82}$$

* See Routh; Elementary Rigid Dynamics, sec. 367.

That is, if we use a velocity for the model such that the ship's shall be $\sqrt{l}$ times as great, the total resistance of the ship will be l^3 times that of the model.

This is known as Froude's theorem.

Torricelli's theorem.—Imagine two vessels of like form (orifice included) to contain a like portion of their total volumes of liquid. Then

$$F\tau^2 = \mu l$$

becomes, since the ratio of the impressed force is $g'\ l^3$, g' denoting the ratio of gravity in the two cases,

$$g' l^3 \tau^2 = l^3 l,$$

$$\tau = \sqrt{\frac{l}{g'}}; \tag{83}$$

∴ the times of discharging the nth part of the vessels varies directly as the square root of their linear dimensions. Cf. § 9, Part IV A. Under ordinary circumstances g' is very nearly unity. If one liquid were more dense than the other, τ would not be altered, because F and μ would both be altered by the same factor for density.

Long wave motion.—Consider the case of the free oscillation of two shallow sheets of water having the horizontal dimensions proportional, but with any uniform depths whose ratio is d.

Assume amplitudes proportional to depths, which we may do on the principle that the periods of small oscillations are independent of amplitudes. This makes it easy to compare (accelerating) impressed forces.

By section 11, Part IV A, the force of restitution is $g \times$ slope $\times$ density $\times$ volume; the mass is density $\times$ volume.

$$F\tau^2 = \mu l$$

becomes

$$g' \frac{d}{l} \cdot dl^2 \tau^2 = l^2 dl;$$

$$\tau^2 = \frac{l^2}{g'd},$$

$$\tau = \frac{l}{\sqrt{g'd}}. \tag{84}$$

∴ The periodic times of the motions are directly as the ratio of the horizontal dimensions of the bodies and inversely as the square root of the ratio of the depths. g', the ratio of the forces of gravity, may be taken as unity.

Supposing that for small motions, equation 94, Part IV A,

$$\frac{\partial^2 \zeta}{\partial t^2} = gh\left(\frac{\partial^2 \zeta}{\partial x^2} + \frac{\partial^2 \zeta}{\partial y^2}\right),$$

represent the motion in one body of water; similar motion in the second body will take place provided

$$\frac{d'}{\tau^2} \frac{\partial^2 \zeta}{dt^2} = g' d \cdot gh\left(\frac{d'}{l^2} \frac{\partial^2 \zeta}{\partial x^2} + \frac{d'}{l^2} \frac{\partial^2 \zeta}{\partial y^2}\right), \tag{85}$$

where d' denotes the amplitude ratio, reduces to the above equation. This it will do, provided

$$\tau = \frac{l}{\sqrt{g'd}}. \tag{86}$$

If the depths of the two bodies be not uniform, but are characterized by a fixed ratio d, the equations

$$\frac{\partial^2\zeta}{\partial t^2}=g\left\{\frac{\partial}{\partial x}\left(h\frac{\partial\zeta}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\frac{\partial\zeta}{\partial y}\right)\right\}, \qquad *(87)$$

$$\frac{d'}{\tau^2}\frac{\partial^2\zeta}{\partial t^2}=gg'\left\{\frac{dd'}{l^2}\frac{\partial}{\partial x}\left(h\frac{\partial\zeta}{\partial x}\right)+\frac{dd'}{l^2}\frac{\partial}{\partial y}\left(h\frac{\partial\zeta}{dy}\right)\right\}, \qquad (88)$$

become identical if

$$\tau=\frac{l}{\sqrt{g'd}}.$$

In long-wave motion the vertical and horizontal scales may be anything whatever and the character motion will not be altered. The periods will be inversely as the square roots of the depths.

The only requirement is that the motion at all points be sensibly horizontal; that is, if considerable slopes anywhere exist, the motion must there be small.

19. *To change a formula expressed in certain units into one expressed in other units.* Ascertain the dimensions of every numerical term or coefficient or factor by aid of the formula itself. Multiply these numerical quantities by the unit ratios raised to powers indicated by the dimensions of the factors of the several terms. By unit ratios are meant quotients obtained by dividing the magnitudes of the units used in the original formula by the magnitudes of the units to be used in the transformed formula.

For example, Torricelli's theorem* might be written

$$v^2=19.62h,$$

where the meter is the unit of length and g is assumed to be 9.81. Now the numerical coefficient is of dimension+1 in length. ∴ assuming a meter =3.28 feet, 19.62 must be multiplied by this quantity, thus giving

$$v^2=64.3h.$$

But if we write

$$v^2=2gh,$$

then the numerical coefficient 2 is of dimension zero, and so to pass from meters to feet, 2 must be multiplied by $(3.28)^0=1$, and the formula remains

$$v^2=2gh$$

for all units. Here the dimensions in time do not have to be considered because the second is the unit in both cases.

If c of Chézy's formula,

$$v=c\sqrt{mi}, \qquad (89)$$

be taken as 90 when the foot is the unit of length, it becomes $\left(\frac{1}{3.28}\right)^{\frac{1}{2}}\times 90=50$ when the meter is the unit.

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*Lamb: Hydrodynamics, sec. 189.

CHAPTER II.

CONSIDERATIONS OF DIMENSION AND RESISTANCE IN TIDAL WAVES.

20. *Tides in a canal encircling the earth along a parallel of latitude, friction being taken into account.*

Since the tide in a uniform canal coinciding with a parallel of latitude must be periodic in time and distance, we may write

$$\xi = A\cos\,(a't - l'\,x + \alpha), \tag{90}$$

where x and ξ are reckoned westward.

By equation (10), Part IV A, the westward tidal force may be written

$$H\sin\,(a't - l'x), \tag{91}$$

where the origin of x is the initial meridian for time as well as distance.

The dynamical equation to be satisfied is

$$\frac{\partial^2 \xi}{\partial t^2} + \mu\frac{\partial \xi}{\partial t} - gh\frac{\partial^2 \xi}{\partial x^2} = H\sin\,(a't - l'x) \tag{92}$$

while $\zeta = -h\,\dfrac{\partial \xi}{\partial x}$.

Upon substituting for ξ in (92) its value (90) and equating the entire coefficient of $\sin\,(a't - l'x)$ and of $\cos\,(a't - l'x)$ to zero, we have

$$\tan\alpha = \frac{a'\mu}{a'^2 - ghl'^2}, \tag{93}$$

$$A = \mp\frac{H}{[(a'^2 - ghl'^2)^2 + a'^2\mu^2]^{1/2}}, \tag{94}$$

where the upper or lower sign is to be used according as $a'^2 - ghl'^2$ is positive or negative.

$$\therefore \xi = \mp\frac{H}{[(a'^2 - ghl'^2)^2 + a'^2\mu^2]^{1/2}}\sin\left(a't - l'x + \tan^{-1}\frac{a'\mu}{a'^2 - ghl'^2}\right), \tag{95}$$

$$\zeta = \mp\frac{Hhl'}{[(a'^2 - ghl'^2)^2 + a'^2\mu^2]^{1/2}}\cos\left(a't - lx + \tan^{-1}\frac{a'\mu}{a'^2 - ghl'^2}\right). \tag{96}$$

By section 9, Part I, these may be written in the form

$$\xi = -\frac{H}{(a'^2 - ghl'^2)^2 + \mu^2 a'^2}[(a'^2 - ghl'^2)\sin\,(a't - l'x) + \mu a'\cos\,(a't - l'x)], \tag{97}$$

$$\zeta = -\frac{Hhl'}{(a'^2 - ghl'^2)^2 + \mu^2 a'^2}[(a'^2 - ghl'^2)\cos(a't - l'x) - \mu a'\sin\,(a't - l'x)]. \tag{98}$$

When $a't - l'x = 0$, the tidal body is on the meridian of the place. For moderately deep water $a'^2 - ghl'^2$ is positive, and for very deep water, negative. Upon referring to (96) and (98) it will be seen that in the case of moderately deep water the argument or angle of ζ at the time of transit of the tidal body is greater than zero. Hence, low water occurs a little before the time of transit. In case of very deep water the angle of ζ is less than zero, and so high water will occur a little after the time of transit.

For an equatorial canal, $l' = a'\sqrt{gh}$, and for one following a parallel of latitude, $l' = \dfrac{a'}{\cos\lambda}\sqrt{gh}.$

The more general case, where the canal follows any circle great or small drawn upon the earth, has been discussed by Levy in sections 96-101 of his treatise on tides.

21. *Tides in a canal closed at both ends whose waters are acted upon by a periodic force.*

From equation (320), Part IV A,

$$\zeta = \frac{hf}{a'\sqrt{gh}\cos\frac{a'L}{\sqrt{gh}}}\sin\frac{a'(x-L)}{\sqrt{gh}}\cos(a't+\alpha) \tag{99}$$

where the impressed periodic force is $f\cos(a't+\alpha)$.

Let l' be written for $a'/\sqrt{gh}$. This equation becomes

$$\zeta = \frac{f}{gl'\cos l'L}\sin(l'x-l'L)\cos(a't+\alpha) \tag{100}$$

Consider the tide at the far end of the canal (where $x=2L$) at the time when the force has its maximum value in the direction $+x$; then $\sin(l'x-l'L)$ becomes $\sin l'L$ and $\cos(a't+\alpha)$, unity.

$$\therefore \zeta = \frac{f}{gl'}\tan l'L = \frac{f}{g}\frac{\sqrt{gh}}{a'}\tan l'L. \tag{101}$$

In case of M_2, $f=0.000\ 000\ 076\ 5\ g$, $a'=0.000\ 140\ 519$ radian per second.

$$\therefore \zeta = 0.003\ 088\ \sqrt{h}\ \tan l'L \tag{102}$$

The equilibrium tide is

$$0.000\ 000\ 076\ 5\ L \tag{103}$$

Suppose λ denote the length of wave due to depth h and whose period is τ, i. e., $\lambda=\tau\sqrt{gh}$. Suppose the length of the canal to vary from nothing to λ, the intermediate length being fractions of λ. The following table shows the value of ζ from (102). For a depth of 10 000 feet, $\sqrt{h}=100$ feet:

Height of tide.

Length = 2 L											
$\frac{0}{360}\lambda$	$\frac{20}{360}\lambda$	$\frac{40}{360}\lambda$	$\frac{60}{360}\lambda$	$\frac{80}{360}\lambda$	$\frac{100}{360}\lambda$	$\frac{120}{360}\lambda$	$\frac{140}{360}\lambda$	$\frac{160}{360}\lambda$	$\frac{170}{360}\lambda$	$\frac{175}{360}\lambda$	$\frac{179}{360}\lambda$
$\sqrt{h}$ 0.000 0000	$\sqrt{h}$ 0.000 5 445	$\sqrt{h}$ 0.00 1 124	$\sqrt{h}$ 0.00 1 783	$\sqrt{h}$ 0.00 2 591	$\sqrt{h}$ 0.00 3 680	$\sqrt{h}$ 0.00 5 349	$\sqrt{h}$ 0.00 8 484	$\sqrt{h}$ 0.0 1 751	$\sqrt{h}$ 0.0 3 530	$\sqrt{h}$ 0.0 7 073	$\sqrt{h}$ 0. 3 539
$\frac{180}{360}\lambda$	$\frac{181}{360}\lambda$	$\frac{185}{360}\lambda$	$\frac{190}{360}\lambda$	$\frac{200}{360}\lambda$	$\frac{220}{360}\lambda$	$\frac{240}{360}\lambda$	$\frac{260}{360}\lambda$	$\frac{280}{360}\lambda$	$\frac{300}{360}\lambda$	$\frac{320}{360}\lambda$	$\frac{340}{360}\lambda$
$\pm\sqrt{h}$ ∞	$-\sqrt{h}$ 0. 3 539	$-\sqrt{h}$ 0.0 7 073	$-\sqrt{h}$ 0.0 3 530	$-\sqrt{h}$ 0.0 1 751	$-\sqrt{h}$ 0.00 8 484	$-\sqrt{h}$ 0.00 5 349	$-\sqrt{h}$ 0.00 3 680	$-\sqrt{h}$ 0.00 2 591	$-\sqrt{h}$ 0.00 1 783	$-\sqrt{h}$ 0.00 1 124	$-\sqrt{h}$ 0.000 5 445

These results should apply fairly well to hypothetical terrestrial canals whose lengths are not greater than, say, 45° of a great circle, if all resistance could be left out of consideration. The value of the sustaining forces taken in the direction of the canal, can be ascertained from sections 1, 2, and Fig. 1, Part IV A, and as a rule only the value at the middle of the canal need be computed.

When the force is variable over the length of the canal, a progressive wave will generally accompany the stationary wave unless the canal lies along a meridian.

22. *Tides in a canal which extends along a meridian from the Equator to either pole.*

By equation (12), Part IV A, the tidal forces for a semidaily tide and acting in a northerly direction may be written

$$-f\cos\lambda\sin\lambda\cos(a't+\alpha) \qquad (104)$$

where λ denotes north latitude. The dynamical equation becomes

$$\frac{\partial^2\xi}{\partial t^2}=gh\frac{\partial^2\xi}{\partial x^2}+f\cos\frac{x}{r}\sin\frac{x}{r}\cos(a't+\alpha) \qquad (105)$$

r denoting the radius of the earth, and x the distance north of the Equator. The equation of continuity is, of course,

$$\zeta=-h\frac{\partial\xi}{\partial x}.$$

The values of ξ and ζ satisfying these equations are

$$\xi=-\frac{1}{2}\frac{r^2f}{4gh-a'^2r^2}\sin 2\frac{x}{r}\cos(a't+\alpha), \qquad (106)$$

$$\zeta=\frac{fhr}{4gh-a'^2r^2}\cos 2\frac{x}{r}\cos(a't+\alpha), \qquad (107)$$

as is easily seen upon substituting the value of ξ in (105).

Hence, the wave is stationary. If the canal have great depth, equation (107) shows that when the tidal body is on meridian, it is high water in latitudes below 45° and low water in higher latitudes. If the canal have ordinary oceanic depth, this rule is reversed.

The general problem of finding the tides in canals, whether circular, closed at one end, or at both ends, friction being taken into account, has been treated by Airy in subsection 6 of his Tides and Waves. Similar matters are treated by Ferrel in Chapter IV of his Tidal Researches, and by Lévy in Chapter VIII of his treatise on tides.

The problem of finding the tide in a canal of any length bounded at both ends and whose waters are acted upon by a force periodic in time and varying or not varying over the canal, although a special case of the more general problem, is nevertheless one of considerable difficulty. For a solution, see Airy's Tides and Waves, article 337, and for numerical examples of east-and-west canals, see Ferrel's Tidal Researches, sections 144–149.

On account of the difficulties connected with problems of the class just mentioned and the questionability of the results obtained being applicable to the existing ocean tides, it seems best to here rest content with giving the above references.

23. *Concerning the "ages" and coefficients of tidal inequalities.*

In case of a compound pendulum oscillating in a resisting medium, it is easy to see that if the sustaining force is not exactly isochronous with its natural period, the departures in phase from the phase obtained upon the assumption of exact isochronism are proportional to the departure of speed from the critical speed.

For, in equation (297), Part IV A,

$$\tan \alpha_1 = \frac{C''a'\lambda^2}{M(a^2-a'^2)\,\bar{\lambda}^2}. \tag{108}$$

Here α_1 denotes the phase of the sustaining force (intensity) when the phase of the oscillation (displacement) is 180°, a' is the speed of the sustaining force, a that of the free pendulum. Suppose $a'=a+\varepsilon$; then

$$\tan \alpha_1 = \frac{C''\ \lambda^2\ \ (a+\varepsilon)}{M(-2a\varepsilon)\ \ \bar{\lambda}^2} \doteq -\frac{C''\ \ \lambda^2}{2M\varepsilon\ \ \bar{\lambda}^2}. \tag{109}$$

Now since the difference between the phase of the force and phase of the oscillation is about 90°, we may write

$$\tan \alpha_1 = \tan (90°+E)$$

when E is a small angle. But

$$\tan (90°+E) \doteq -\frac{1}{E}; \tag{110}$$

or

$$\varepsilon/E = \text{constant};$$

and so the departure of the phase of a pendulum from 90°, or its critical value, is proportional to the departure of the natural "speed" of the pendulum from the "speed" of the sustaining force.

Equation (296), Part IV A,

$$A' = -\frac{F_1\bar{\lambda}\lambda_1 \sin \alpha_1}{C'a'\lambda^2} \tag{111}$$

shows that the amplitude of the oscillation varies but slowly on account of the variation in phase, provided α_1 lies near to $\pm 90°$. Other things being equal, the amplitude of the oscillation is then very nearly proportional to the amplitude of the impressed force. The above expression may be written

$$\frac{A'}{F_1} = K \sin \alpha_1 = K \cos E \doteq K\left(1-\frac{E^2}{2}\right), \tag{112}$$

showing that the defect in this proportionality is proportional to the square of small angle E or to the square $\varepsilon = a'-a$.

Suppose the amplitude of the vibration with resistance to be reduced thereby to μ' times the amplitude of the vibration without resistance.

From equation (298), Part IV A, the amplitude of a vibration without resistance is

$$\pm\frac{F_1\lambda_1}{M(a'^2-a^2)\lambda'}. \tag{113}$$

Now, by hypothesis the amplitude with friction is to be μ' times this expression. For a pendulum resembling a simple pendulum as most pendulums do $\breve{\lambda}=\breve{\lambda}'=\lambda_1=\bar{\lambda}$. The amplitude with resistance then becomes

$$A'=-\frac{F_1\sin\alpha_1}{C''a'}=\pm\mu'\frac{F_1}{M(a'^2-a^2)}; \tag{114}$$

also, from equation (294),

$$\cos\alpha_1=\frac{A'M(a'^2-a^2)}{F_1}; \tag{115}$$

$$\therefore\ \cos\alpha_1=\pm\mu', \tag{116}$$

a result independent of a/a'; i. e., α_1 depends only upon the ratio of the amplitude of the actual vibration to the amplitude of the theoretical one without resistance.

Suppose $\mu'=\frac{1}{2}$. Then, $\alpha_1=60°$, or $120°$; that is, the force phase relatively to that of the displacement of the pendulum is within 30° of the value which it would assume were the length exactly critical and so resistance in absolute control.

24. Considering, first, only areas in which fairly large tides are produced; it will be seen that the values of S_2/M_2, N_2/M_2, $S_2^\circ-M_2^\circ$, $M_2^\circ-N_2^\circ$ (sec. 97, Part IV A; sec. 19, Part IV B) do not differ very greatly in going from place to place. Now, if the departure from the critical dimensions suited to the several semidiurnal components were a matter of prime importance, we would find places where one or more of the ratios of the amplitudes would be widely different from the ratios of the amplitudes of the forces, and where it would be reasonable to suppose one or more of the epoch differences would be approximately 180° instead of zero degrees. For, if the free period of an "area" were greater than the period of one of the components and less than the period of another component, the epochs of the tides with reference to the forces should differ by 180°. At any rate, this condition could be realized in comparing different areas.

From the table in section 21 it can be seen that in the case of no resistance, great variations in amplitude ratios should, in an area of nearly critical dimensions, result from slight variations in the speeds of the components. But, as already stated, such great variations do not occur in areas having fairly large tides. It follows that the resistance, including dissipation, must be paramount.

As already noted, the amplitude of the forced oscillations of a pendulum in a period closely approximating its natural period is nearly proportional to the sustaining force.

On the other hand, the existence of positive ages for most areas having good tides indicates that the difference in speed of the semidiurnal components is felt to a limited extent. That is, the epochs of two components are not equal to each other, nor do they differ by 180°; but the epoch belonging to the faster component is generally a few degrees greater than the epoch belonging to the other, the amount in degrees, when two differences are compared, being roughly proportional to the speed differences.

This statement accords with what has already been shown with reference to a pendulum sustained by forces whose periods are nearly equal to the free period of the pendulum.

Now if the length (i. e., variation from the critical length) had no sensible effect upon the phase or epoch, it is doubtful if the phase would be altered in this manner by resistance.

To convince one that ages, if due to only resistance and variation in force intensity, must be smaller than those commonly found in nature, suppose, if possible, that the tide owes its existence to $2n$ successive impulses (n in either direction), each contributing equally to its formation. The amplitude of the tide at any given time will then be proportional, not to the forces acting at that time, but to the average value of the forces during the n preceding periods, and so approximately proportional to the force $\frac{n}{2}$ periods before the time of tide. But it is reasonable to suppose that the effect of the impulse nearest the time of tide is much greater than the effect of any one of the earlier impulses. Consequently the greatest tides must follow the greatest forces by a time or age not exceeding a small fraction of $\frac{n}{2}$ periods in length. For the semidaily tide it is probable that n periods do not exceed three or four days.

We are thus led to believe that the small departures of the periods of the components from the free period of a body are necessary in order that the resistances may cause the "ages" of the inequalities; but that such departures, unless considerable, generally have but a moderate influence upon the amplitude ratios.

If a component nearly fits an area, the phase of the tide will not be sufficiently altered to depart far from the phase determined upon the assumption of exact agreement between period of the component and free period of the body and where resistance controls.

In some cases, even where the range of the ocean tide is not remarkably small, the ratios S_2/M_2, N_2/M_2 may differ greatly from the theoretical values. Similarly the values of $S_2^0-M_2^0$, $M_2^0-N_2^0$ may in some instances be almost anything.

These conditions may be brought about through the close correspondence in period between two or more modes of free oscillation and the components involved. This may occur because the outlines of the body are generally irregular and the dimensions not very definite. In fact, it is easy to imagine a rectangular area where the lines of motion in an oscillation suited to S_2 shall lie at right angles to the lines of motion suited to M_2.

Along the southern coasts of Australia and around Lower California the ratio S_2/M_2 is unusually large. In such localities "dodging tides" may occur in extreme cases.

The ratio S_2/M_2 may be considerably too small in a well-defined area and where but one mode of oscillation could be expected, because the free period of the area differs considerably from the period of S_2. An example of this occurs along the Atlantic coast of the United States. The coast of New Zealand and the Pacific coast of southern Chile are probably examples of this, but on account of the expanse of the Pacific Ocean there is a possibility of the S_2-oscillation differing in mode from the M_2-oscillation.

Where the ocean tide is small the ratios S_2/M_2, N_2/M_2 may depart from their theoretical values or values where the tide is large; and the values of $S_2^0-M_2^0$, $M_2^0-N_2^0$ may be almost anything, because the nodal line of a stationary oscillation for M_2 may not be the nodal line of a stationary oscillation for S_2 or N_2. Near the nodal lines the above ratios would naturally vary, especially in a dependent fractional area. Examples of this are the tides at the mouth of the Bay of Bengal and near Portland, England.

If the cause of the small ocean tides can not be seen, it is reasonable to suppose that different modes of oscillation for different components account for many of these apparent irregularities. It may be that in many places of small tides the forced oscillations of bodies whose periods do not closely approach the semidaily period are of sufficient size to be comparable with the other tides there existing. But it is probable that the ratios in such oscillations if considered alone would approach the theoretical values and that the ages would be very short, thus approaching the conditions of equilibrium tides. In fact, there are doubtless basins in all oceans in which approximate equilibrium tides arise (particularly diurnal tides), but these are generally obscured by the derived waves from other sources.

Generally speaking, the bodies of water in which fairly large tides are generated approach more nearly to M_2 in the matter of free periods than to S_2. Hence the theoretical hours laid down in Fig. 23, Part IV A, belong, as a rule, to the lunar rather than the solar tide. The dimensions of the "areas" generally indicate this, and the smallness of S_2/M_2 gives further confirmation. The values of N_2/M_2 being generally greater than the force ratio or 0.1936 for the Atlantic and Pacific coasts of the United States indicates, perhaps, that N_2 is fitted by the "areas" better than is M_2. The large value of N_2/M_2 for Suez is probably due to the fact that the Gulf of Suez approaches nearer to a critical length $(\frac{1}{4}\lambda)$ for the N_2-wave than for the M_2-or S_2-wave. Owing to the rapidity with which the tidal impulses are destroyed through dissipation and friction, and also to the possibility of somewhat different modes of oscillation for the various semidaily tidal constituents, it is not reasonable to suppose that their amplitudes will be very nearly proportional to the forces, nor that their epochs will follow any simple law.

25. *On the dissipation or want of motion.*

Observation shows that ocean tides generally are too great to be produced by a single impulse of the tidal forces (as in the case of equilibrium tides); it shows the existence of fairly well-defined nodal lines and loops, thus establishing beyond all doubt the existence of stationary waves in certain oceanic areas. Moreover, the computed free periods for such areas generally approximate to the periods of the tidal forces; i. e., the areas have approximately critical dimensions.

Regarding this hypothesis as sufficiently well established, the questions now to be considered relate to the resistances which check or reduce the motion and affect the phase of the oscillation relatively to that of the forces.

In determining the time of elongation of the water particles, according to sections 62–67, Part IV A, it is assumed that the dimensions of the oscillating body are so nearly critical that the resistance is the important factor. It should have been noted earlier that equation (305), Part IV A, can be written in a more general form, thus adapting it to less restricted hypotheses. For example, the assumed mode of division of the body of water into elements might be quite different in the resistance term from the mode of division used in the other terms. That is, it is of no consequence how the body is divided for resistance provided the resistance from all parts be finally added together. The resistance coefficient may be great in one locality and small in another; that is, C' should take a subscript (ν or κ), and so, from what has been said, the last term of (305), Part IV A, may be written in the more general form

$$-Aa\sum_{\kappa} C'_{\kappa} m_{\kappa} \sin^2 lx_{\kappa} \sin at. \qquad (117).$$

Evidently the rules laid down in the sections referred to for connecting the forces with the time of tide will not be altered by this generalization, but it becomes important when one attempts to look more closely into the nature of the resistance; in fact, it is obvious that the distribution of the resisting causes may vary greatly in different cases.

The term resistance will be used to denote the cause of all absence, diminution, or loss of motion, judged from what would have resulted under given sustaining forces had all boundaries been regular and complete and had the liquid been a perfect fluid.

The part of the resistance due to imperfect and incomplete boundaries may be called either "dissipation" or "virtual resistance;" while the part due to motion in the area only, such as friction and viscosity, is real or actual resistance.

For a body of water a little less than $\frac{1}{2}\lambda$ long having a complete regular boundary and being devoid of all resistance, the high water in either half of the body occurs when the horizontal force is greatest in the direction of the half considered. The wave, however, is the result of several or many impulses of these forces, and so the one most nearly coinciding with the time of a particular high water is responsible for only a small part of the motion. Each impulse acting in this way has very little power to sustain the oscillation. Now, if resistance occurs the observed oscillation is the result of forces acting in a manner best suited to sustain it; for if not, some other arrangement would arise which would cause a greater amplitude to the motion.

It is obvious that in order to overcome friction the sustaining forces must act more with the moving particles than against them.

If the area is very nearly $\frac{1}{2}\lambda$ in length and the amplitude is kept down by friction proportional to the velocity, it is easily seen that the forces must be of the same phase as the velocities, in order to sustain the greatest actual oscillation; in other words, the phase of the displacements must be $\frac{1}{4}\tau$ or 90° behind the phase of the forces.

Dissipation because of incomplete boundaries generally takes place through either stationary or progressive wave motion.

Imagine a rectangular body or area of approximately critical dimensions to have solid barriers at the ends only. Experiment shows that the oscillation in such a body has a much smaller amplitude than would have been the case had all boundaries been solid; also that across the imaginary sides, particularly near the loops, a transverse stationary motion simultaneous with the longitudinal motion is going on. The reason for this transverse motion is obvious. For, an elevation at one loop causes an outward slope and so an outward acceleration. This gives a maximum outward velocity when the water at the loop has fallen to mean-water level. Similarly the greatest velocity toward this loop will occur at the time of mean level when the water is there rising.

The outgoing water crowds up the water situated well outside of the area and so tends to cause it there to rise. If a rigid barrier were placed at a suitable distance beyond this free or imaginary side of the area, a considerable rise would actually take place. As no such barrier exists, the outward-going motion, well outside of the area, is not converted into height; it is communicated to waters not susceptible of taking up good oscillations. Consequently the succeeding inward motion does not have the benefit of any considerable height energy in the outer part of the transversely moving water. The same result as to the loss of transverse motion will be obtained by considering in the first place a low water at the loop.

The lateral boundaries of the main area being only imaginary, it is clear that every increment of energy given to the area by the forces is offset by a loss of motion going on across the missing or imaginary boundaries. The shorter the solid ends in comparison with the missing sides, the smaller will be the oscillation set up and maintained. In fact the length of the end walls must be at least about $\frac{1}{4}\lambda$ in length if any considerable oscillation is to occur (see sec. 53, Part IV A).

It will be noticed that energy is leaving the system most rapidly at the time of mean level rising or falling, and that none escapes at the times of high and low water; at intermediate times the escape is proportional to the velocity which could have, under other conditions, been converted into height. Therefore, whether much motion exists or not, it follows that the amplitude of the oscillation is kept down by destructive agencies most active at the times of mean level and which can be approximately represented by the term (117) which includes frictional resistance and is based upon the assumption that all resistance varies with the first power of the velocity. The dissipation term implied in the equation of virtual work [(302), Part IV A] may be written $-\sum_{\nu} K_{\nu} m_{\nu} \xi_{\nu} \frac{\partial \xi_{\nu}}{\partial t}$. The corresponding term implied in (305), Part IV A, is $-A_a \sum_{\nu} K_{\nu} m_{\nu} \sin^2 l\, x_{\nu} \sin at$, and so may be considered as being covered by the given resistance term, (117).

If an area were entirely surrounded by solid walls, excepting one narrow opening into a tideless sea, the above law of dissipation, so far as dissipation occurs, holds here because according to sections 35, 103, Part IV A, the motion in the strait is a stationary oscillation simultaneous with the motion in the oscillating area sustaining it.

If one of the four walls surrounding an area consists of a shore line made somewhat irregular by headlands and bays, then, provided the bays are nonpropagative arms of water, it is obvious that the motion in these is greatest at the time of mean level outside. Hence whatever resistance occurs in these arms, whether from friction proper or from the fact that the motion in them sustained by the rise and fall of the area is in part dissipated in the area, must follow the above law, at least very approximately.

In the next place, imagine one of the four rigid walls surrounding an area to contain an opening through which a wave is propagated; for example, the mouth of a tidal river or other propagative arm of the ocean.

The mass of water occupying the immediate approaches to the mouth of the river or bay rises and falls with the area upon which it depends. From the rise and fall of this mass, the energy expended in the river or bay is immediately derived. The size of this intermediary mass as compared with that of the oscillating system indicates, in a measure, how much the motion in the latter will be reduced. At the time of mean level, energy is being transferred from the system proper to the intermediary mass at a maximum rate; at the time of high or low water none is being thus transferred. The question here simply relates to the transference of energy from the main body to the intermediary mass and has little to do with what goes on between this mass and the river proper.

The resistance in the river tends to diminish the rise and fall at its mouth, hence the necessity of supplying energy to the mass in maintaining the rise and fall at the river's mouth.

If one of the end boundaries of an oscillating area contain an opening of considerable size and through which a progression occurs, a progressive character is given to the tides of the area a considerable distance from the opening (antecedent wave). This progressive wave may result from two causes: (1) that just given, viz., the necessity of agreement in height between the water's surface off the mouth of the river or strait and that of the principal oscillation; (2) the fact that particles in and near the opening are not turned back at the time of elongation of principal oscillation, but somewhat later. In either case it is necessary to go into the area some distance from the opening in order to observe the true time of rise and fall for the principal oscillation. In either case, also, there must be an intermediary mass of water whereby energy is transferred from the principal oscillation to the progressive wave. In deep water this wave may be felt nearly across the area, and is often sustained in part by the horizontal motion across the nodal line.

In the case of a stationary-dissipation movement, the greatest crowding of the waters into which the motion is dissipated takes place on the falling tide of the neighboring loop.

In case of a progressive-dissipation movement, the greatest crowding of the waters immediately adjacent to the area takes place on the rising tide of the neighboring loop.

More generally, the oscillation in an area having incomplete boundaries is kept down because the impulses of the tidal forces in their efforts to sustain or augment the oscillation tend to cause a crowding together or drawing asunder of the water particles near by. If the boundary were complete, an increased oscillation would result. Being incomplete, only a moderate rise and fall results. The failure to make the crowding effective in increasing the height at a loop of the area is most rapid at the time of half-tide level. This is also the time when the height of the surface is changing most rapidly.

Incomplete boundaries are in fact the chief reason why the tide in a given area always falls much short of its theoretical dynamical value. Whether the reduction of motion be due to irregularities in the shore line or to incompleteness of boundary, the forces will select a critical strip of water, if such exist; but on account of these defects of boundary the forces will act to comparatively poor advantage, especially in the case of the terrestrial oceans.

It must not be inferred that energy is always expended most rapidly on account of a break in a boundary of the oscillating area or system at the time of half-tide level. Where hydraulic effects occur it may be otherwise. If the principal resistance of the area were of this character, the forces would not precede the displacements by $\frac{1}{4}T$, or 90°, as usual; for example, a lake or bay communicating with the sea through a narrow and short strait. In this case the energy of the oscillation is being most rapidly reduced at about the time of high or low water outside, for then the surfaces of near-by waters have their greatest difference in height. It does not seem probable that dissipations of this kind are great enough to have a sensible influence upon ocean tides. And even in the case just supposed, as the opening becomes larger there will be less tendency to depart from the general rule.

In section 23 it is shown that if the amplitude of vibration of a pendulum in a resisting medium be μ' times the value when free from resistance, the impressed forces remaining the same in both cases, then the phase of the forces relatively to that of the displacement of the pendulum is given by the equation

$$\cos \alpha_1 = \pm \mu'.$$

Now, assuming that a tidal oscillation follows this law for all forms of resistance, as is probably very nearly the case, it follows that if the observed amplitude has $\frac{1}{4}$ of its theoretical value with no resistance, then the phase of maximum velocity of the particles differs from the phase of maximum forces by 14° 29′, or about half an hour for a semidaily tide.

The nearer to critical dimensions are the dimensions of the oscillating areas, the greater will be their tides and the more will these tides overshadow all other tides which may arise from less suitable areas, and the more will the resultant tides be controlled by them; hence their great liability to chiefly constitute the observed tide. This state of affairs is, in fact, necessary wherever much incompleteness and irregularity of boundary exist; that is, μ' must be small on account of these defects in boundary and the dimensions of an area must be nearly critical in order that a sensible tide may arise in an area thus imperfectly surrounded.

26. *To find the frictional resistance upon a canal-like sheet of water, the length approximating to* $\frac{1}{2}\lambda$.

Let the body be divided longitudinally into strips one unit in width. Taking the left end of the canal as space origin and the time origin at the time when the particles are at elongation to the left, the equations of the motion are

$$\xi = -A \sin lx \cos at,$$

$$\zeta = Alh \cos lx \cos at, = A' \cos lx \cos at; \tag{118}$$

$$\therefore \text{velocity} = \frac{\partial \xi}{\partial t} = Aa \sin lx \sin at = A'\sqrt{\frac{g}{h}} \sin lx \sin at. \tag{119}$$

If the amplitude of the tide is one foot, the values of the maximum velocity at the nodal line are as follows for various depths, h:

$h=$	600,	1200,	3000,	6000,	9000,	12000,	15000,	18000,	feet.
$\sqrt{\frac{g}{h}}=$	0.23156,	0.16374,	0.10356,	0.07323,	0.05979,	0.05178,	0.04631,	0.04228	feet per second.

It thus appears that for anything like oceanic depths, the maximum velocity of the water particles is less than 1/10 foot per second for each foot of semi-range of tide. The resistance per square foot of bottom area is F (secs. 7, 8). The total maximum resistance of a strip of water $\frac{1}{2}\lambda$ long and one foot wide is

$$\frac{1}{2}\lambda\frac{2}{\pi}F$$

pounds where the maximum velocity at the nodal line is used in F. The weight of water composing this strip is $\frac{1}{2}\lambda h\gamma$. The amplitude of the M_2 tidal force acting upon this strip is, for a canal so short that we may disregard the variations of forces over it,

$$\frac{1}{2}\lambda h\gamma \times 0.000\,000\,076\,5 \tag{120}$$

pounds (sec. 2, Part IV A). The tidal force divided by the resisting force is

$$\frac{0.000\,000\,076\,5h\gamma}{\frac{2}{\pi}F} = 0.003\,20\,\frac{h}{v} \tag{121}$$

where $\gamma = 64$ pounds and $F = 0.002\,4v$. This shows that for ocean depths frictional resistance is only a small fraction of the tidal force.

27. *Tidal retardation of the earth's axial rotation*:

If the earth were a homogeneous ellipsoid of revolution, its moment of inertia about its axis of revolution would be

$$\frac{2}{5}\text{ Mass (equatorial radius)}^2. \tag{122}$$

where

$$\text{Mass} = \frac{4}{3}\pi r'^3\mu$$

where equatorial radius $= 20\,925\,000$; r' = the average radius $= 20\,902\,000$ feet; μ = mass per unit volume $= 62.4 \times 5.5 = 343.2$ pounds. These values give for the moment of inertia I, $2\,299 \times 10^{36}$ foot poundals or $7\,396 \times 10^{34}$ foot pounds.

The energy of rotation is $\frac{1}{2}I\omega^2$ where ω denotes the angular velocity of rotation = 0.000 072 72 radian per sidereal second.

$$\therefore \frac{1}{2}I\,\omega^2 = 608 \times 10^{28}\text{ foot poundals.} \tag{123}$$

But the density of the earth increases from the surface toward the center according to some law not fully known. Among the hypotheses which have been used in questions connected with the earth's figure are Legendre's (or Laplace's), Roche's, Lipschitz's, Maurice Levy's, and Wiechert's.

Without going into the computation in accordance with any of these hypotheses, we may use the value

$$504 \times 10^{28}\text{ foot poundals}$$

given in the Smithsonian Tables, and which depends directly upon Harkness' values of the principal moments of inertia.

Let ε denote the constant lengthening of the sidereal day per sidereal day; then after t days the original length of the day will be increased by $t\,\varepsilon$. The total time lost during a period of t days will be

$$\varepsilon\int_{t=0}^{t=t} t\,d\,t=\frac{t^2}{2}\varepsilon=s, \qquad (124)$$

$$\therefore \varepsilon=2\frac{s}{t^2}.$$

The energies at $t=0$ and $t=t$ are connected by the equation

$$(\text{Energy})_0 : (\text{energy})_t = 1^2 : \left(\frac{1}{1+\varepsilon t}\right)^2;$$

$$\therefore \frac{\text{energy}_t}{\text{energy}_0}=1-2\varepsilon t. \qquad (125)$$

The energy lost in t days is therefore very nearly equal to the original (or final) energy multiplied by $2\,\varepsilon\,t$, where ε is expressed as a small fraction of a day.

If in 100 years, the earth's meridian is 22 (sidereal) seconds behind the position it would have assumed had the rotation not been retarded, we have $s=22$ seconds$=0.000255$ day.

$$\therefore \varepsilon=2\frac{0.000\,255}{366^2\ 100^2}=3.81\times10^{-13} \qquad (126)$$

and

$$504\times10^{28}\times2\varepsilon=384\times10^{16}$$

for the number of poundals of work lost in a sidereal day.

According to Krümmel the area of the oceans and inland seas is

374 058 000 sq. k. = 144 424 168 sq. st. miles = 4 026 314 780 000 000 sq. feet.

The average depth exceeds 9 000 feet, and the average range of tide is about 2 feet. These values give for the average maximum velocity in feet per second of the water particles

$$A'\sqrt{\frac{g}{9\,000}}=0.059\,8\doteq0.06$$

where $A'=1$ and $g=32.172\,2$; the average mean velocity will be $0.06\times\frac{2}{\pi}=0.038$.

$$\text{Total resistance}=F\times\text{area}\doteq0.002\,4\times\ \text{velocity}\times\text{area}=3.65\times10^{11}\text{ lbs.} \qquad (127)$$

Average distance traveled by a particle in a sidereal day = 3 274 feet. The energy expended in a sidereal day is

$$3.65\times10^{11}\times3\,274=1\ 195\times10^{12}\text{ foot pounds},=384\times10^{14}\text{ foot poundals.} \qquad (128)$$

According to this estimate, the tidal resistance of the ocean and inland seas causes the earth's meridian to fall behind 0.22 second per century instead of 22 seconds.

This value should be considerably increased on account of the fact that in shallow water the frictional resistance is many times greater per square mile or foot of area than in deep water.

The following are a few references to the question of retardation of the earth's axial rotation due to tidal friction:

Thomson and Tait: Natural Philosophy, 2d ed., secs. 276, 830, Ap. G (a) and (b) (by Darwin).

Lord Kelvin: Popular Lectures and Addresses, Vol. II (1894), pp. 20–24, 65–72, 90–96, 270–272.

Sir Robt. S. Ball: Time and Tide.

This manual, Part I, secs. 140, 142, and references there given.

CHAPTER III.

SHALLOW-WATER AND RIVER TIDES.

28. To Airy belongs the credit of having first obtained the exact equation of long-wave motion (No. 129 below). His approximate solution of this equation enabled him to partially explain the change in form of a wave where the depth is but a moderate multiple of the amplitude of the tide.*

In 1871 M. de Saint-Venant gave as the rate of advance of a free wave $3\sqrt{gz}-2\sqrt{gh}$ where z denotes the depth and h the undisturbed depth.†

In 1892 J. McCowan published an important paper entitled "On the theory of long waves and its application to the tidal phenomena of rivers and estuaries."‡

Prof. Maurice Lévy gives a very complete discussion of river tides in Chapter IX of his Théorie des Marées.§

The aim of the present chapter is to give some of the more essential parts of Airy's, McCowan's, and Lévy's developments, together with some modifications and additional matters.

As noted in section 17, Part I, the equation of motion for a canal in which the rise and fall amounts to a considerable fraction of its depths is

$$\frac{\partial^2 \xi}{\partial t^2}=gh\frac{\dfrac{\partial^2 \xi}{\partial x^2}}{\left(1+\dfrac{\partial \xi}{\partial x}\right)^3}=gh\frac{\partial^2 \xi}{\partial x^2}\left[1-3\frac{\partial \xi}{\partial x}+6\left(\frac{\partial \xi}{\partial x}\right)^2-\ .\ .\ .\ \right] \tag{129}$$

while the equation of continuity is

$$\left(1+\frac{\partial \xi}{\partial x}\right)\left(1+\frac{\zeta}{h}\right)=1;\ \text{or,}\ \frac{\zeta}{h}=-\frac{\partial \xi}{\partial x}+\left(\frac{\partial \xi}{\partial x}\right)^2-\ .\ .\ .\ \tag{130}$$

The approximate solution of (129) where $\frac{\partial \xi}{\partial x}$ is small in comparison with unity is

$$\psi\,(\kappa t+x)\ \pm\ \psi\,(\kappa t-x) \tag{131}$$

where $\kappa^2=gh$. Therefore assume as an approximate solution of (129)

$$\xi=A\ \sin\ (at-lx+\alpha) \tag{132}$$

* Tides and Waves, secs. 195 et seq. See also Stokes, "Report on recent researches in hydrodynamics," and "Notes on hydrodynamics," Mathematical and Physical Papers, Vol. I, pp. 157–176, and Vol. II, pp. 222–229; also this manual, Part I, secs. 113, 117.

† Comptes rendus de l'Académie des Sciences, Vol. 73 (1871), pp. 147–154. See also Vol. 71 (1870), pp. 186–195.

‡ Philosophical Magazine, Vol. III, pp. 250–265.

§ Première Partie, Paris, 1898.

where $a/l=\sqrt{gh}$. Equation (129) may now be written

$$\frac{\partial^2 \xi}{\partial t^2}-\kappa^2\frac{\partial^2 \xi}{\partial x^2}=-\frac{3}{2}(A\,l)^2\,l\kappa^2\sin 2\,(at-lx+\alpha)+\text{higher powers in } Al \tag{133}$$

where Alh=the original amplitude of the semidaily tide=A'.

If ξ were of the form (132), the left member of (133) would be zero; consequently besides containing terms of the form (132), ξ must contain a part such that when

$\frac{\partial^2}{\partial t^2}-\kappa^2\frac{\partial^2}{\partial x^2}$ is applied to it the result shall be $-\frac{3}{2}A^2l^3\kappa^2\sin 2\,(at-lx+\alpha)$.

The part answering to this description is

$$\frac{3}{8}A^2l^2x\cos 2\,(at-lx+\alpha)\ +\ \text{any function satisfying}\ \frac{\partial^2}{\partial t^2}-\kappa^2\frac{\partial^2}{\partial x^2}=0.$$

Assume this function to be

$$A_2\sin 2\ (at-lx+\alpha_2)+Pt+Qx+R$$

and suppose A_2 to be small in comparison with A. Upon substituting the entire value of ξ in the equation of continuity (130), and carrying the result to the second power of quantities of the magnitude Al, there results

$$\frac{\zeta}{h}=Al\ \cos\ (at-lx+\alpha)-\frac{3}{4}A^2l^3\ x\ \sin\ 2(at-lx+\alpha)-\frac{3}{8}A^2l^2\ \cos\ 2(at-lx+\alpha)$$

$$+2A_2l\cos 2(at-lx+\alpha_2)+A^2l^2\,\frac{1+\cos 2(at-lx+\alpha)}{2}-Q. \tag{134}$$

If the term Qx were not included in the expression for ξ, it might be inferred from (134) that the mean value of ζ must be

$$\frac{1}{2}A^2l^2h,\ \text{or}\ \frac{1}{2}A'^2/h\ \text{where}\ A'=Alh$$

is the amplitude of the principal term in the expression for ζ. This would seem to indicate that the mean of all ordinates of the tide curve at any given point of a river or canal lies a little above the level of the ocean or of a tideless canal.* This conclusion is wrong, because, from the nature of the case, the mean level of the river near the mouth can not be sensibly raised above mean sea level just outside.

At the mouth of the river where $x=0$ the tide is assumed to be simply harmonic and so the terms in $2at-2lx$ and whose coefficients do not contain x must vanish for all values of x; also the mean half-tide level must be that of the sea. Equation (134) then gives, since an amplitude is essentially positive,

$$A_2=\frac{1}{16}A^2l,\ \alpha_2=\alpha+\frac{\pi}{2},\ Q=\frac{A^2l^2}{2}. \tag{135}$$

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*Cf. Ferrel, Tidal Researches, Equation 273 and secs. 248–253; and Airy, Tides and Waves, arts. 515, 531.

If $x'=x+\xi$, it will be the coördinate of the particle in its disturbed position. Equation (134) then becomes approximately

$$\frac{\zeta}{h}=Al\cos(at-lx'+\alpha)-\frac{3}{4}A^2l^3x'\sin 2(at-lx'+\alpha)$$

$$-A^2l^2\frac{1-\cos 2(at-lx'+\alpha)}{2}-\frac{3}{8}A^2l^2\cos 2(at-lx'+\alpha)$$

$$+2A_2l\cos 2(at-lx'+\alpha_2)+A^2l^2\,\frac{1+\cos 2(at-lx'+\alpha)}{2}-Q$$

$$=Al\cos(at-lx'+\alpha)-\frac{3}{4}A^2l^3x'\sin 2(at-lx'+\alpha)$$

$$+\frac{5}{8}A^2l^2\cos 2(at-lx'+\alpha)+2\,A_2l\cos 2(at-lx'+\alpha_2)-Q. \qquad (136)$$

The conditions that the height of water in the mouth of the canal must agree with the height outside gives

$$A_2=\frac{5}{16}A^2l,\ \alpha_2=\alpha+\frac{\pi}{2},\ \ Q=0. \qquad (137)$$

The value of ξ may now be written

$$\xi=A\sin(at-lx+\alpha)+\frac{3}{8}A^2l^2\,x\cos 2\,(at-lx+\alpha)-\frac{1}{16}A^2l\sin 2\,(at-lx+\alpha)+Pt$$
$$+\frac{A^2\,l^2}{2}x+R. \qquad (138)$$

The velocity of a particle whose undisturbed or mean abscissa is x is

$$u=\frac{d\xi}{dt}=Aa\cos(at-lx+\alpha)-\frac{3}{4}A^2al^2\,x\sin 2\,(at-lx+\alpha)$$
$$-\frac{1}{8}A^2al\cos 2\,(at-lx+\alpha)+P. \qquad (139)$$

The fact that ζ contains only simple cosine or sine terms shows that its mean value must be zero. The velocity can not follow exactly a similar simple law. For, at the time of flood the depth is greater than it is at the time of ebb, and so, in order that the same amount of water shall cross a given cross section on the ebb as on the flood, the ebb current must average the stronger. In order to represent the decrease in the velocity on the flood, and the increase on the ebb, with neither increase nor decrease at the time of mean river level, it is natural to add a term proportional to the square of the velocity and finally determine P. Take a section so near to the mouth of the river that the term having x in its coefficient may be neglected. Then

$$u=Aa\cos(at-lx+\alpha)+Ku^2,$$

or

$$-\frac{1}{8}A^2al\cos 2\,(at-lx+\alpha)+P=Ku^2;$$

whence

$$K=-\frac{1}{4}\frac{l}{a},\ P=-\frac{1}{8}A^2\,al.$$

The value of u thus becomes

$$u=Aa\cos\,(at-lx+\alpha)-\frac{3}{4}A^2al^2x\sin 2\,(at-lx+\alpha)$$
$$-\frac{1}{8}A^2al\cos 2\,(at-lx+\alpha)-\frac{1}{8}A^2al. \qquad (140)$$

This value of u is allowable because velocities are not, like heights, restricted to a simple periodic term where $x=0$. The velocity becomes zero wherever $at-lx+\alpha$ is an odd multiple of 90°, i. e., at the time of mean river level.

Because of relations (135), equation (134) may be written

$$\frac{\zeta}{h}=Al\cos\,(at-lx+\alpha)-\frac{3}{4}A^2l^3x\sin 2\,(at-lx+\alpha), \qquad (141)$$

where ζ is the height of the surface for a point whose undisturbed abscissa is x.

From (139) and (141) it is evident that the first approximate value of the velocity of the current at a point whose undisturbed abscissa is x, is

$$u=\frac{a}{l}\frac{\zeta}{h}=\zeta\sqrt{\frac{g}{h}},\ \text{since}\ \frac{a}{l}=\frac{\lambda}{\tau}=\sqrt{gh}. \qquad (142)$$

The second approximate value of the velocity is

$$u=\frac{a}{l}\left(\frac{\zeta}{h}-\frac{\zeta^2}{4h^2}\right), \qquad (143)$$

as can be seen upon substituting the value of $\frac{\zeta}{h}$ from (141) in (139).

If $x'-\xi$ be written for x in the expression for the velocity, it becomes

$$u=Aa\cos\,(at-lx'+\alpha)-\frac{3}{4}A^2al^2x'\sin 2(at-lx'+\alpha)$$
$$+\frac{3}{8}A^2al\cos 2\,(at-lx'+\alpha)+P, \qquad (144)$$

which gives $P=\frac{3}{8}A^2al$.

The magnitude of the coefficient of $\sin 2\,(at-lx+\alpha)$ or $\sin 2\,(at-lx'+\alpha)$ is readily computed by aid of the relation $l=a/\sqrt{gh}$ where $a=0.000\,140\,5$ radian per second for the M_2-wave. Let $A'=Alh=$ original amplitude of the tide. Then

$$\frac{3}{4}A^2l^3x'=\frac{3}{4}A'^2.\ \frac{lx'}{h}; \qquad (145)$$

and so for the mean lunar tide,

$$M_4=\frac{3}{4}M_2^2\,\frac{lx'}{h}. \qquad (146)$$

The value of $l, = 2\pi / \lambda$, is given in the last column of Table 50 for various depths. To find the l for any other component whose speed is b, multiply the tabular values by b/a.

The amplitude of the tide whose speed is $2a$, is $\frac{3}{4} A^2 l^3 h x'$, and the angle or phase is double the angle or phase of the fundamental—this double angle being increased by 90° if the second term of (134) is to be written as a positive cosine term: ∴ by equations (45) and (46), Part III, high water is accelerated $\frac{3}{2} A l^2 x'$ radians or degrees, according to the manner in which x' is expressed, or $\frac{3}{2}\frac{A l^2 x'}{a}$ hours; low water is retarded by the same amount. Hence the duration of rise is $3\frac{A l^2 x'}{a}$ hours less than $180°/a$, or a quarter lunar day for the lunar wave, while the duration of fall is $3\frac{A l^2 x'}{a}$ greater than $180°/a$. If the time origin be such that $\alpha = 0$, the time of high water at x' is

$$T = \frac{x'}{\sqrt{gh}} - \frac{3}{2}\frac{A l x'}{\sqrt{gh}}. \tag{147}$$

The reciprocal of $\frac{dT}{dx'}$, i. e., the rate of advance of the high-water phase, is

$$\sqrt{gh}\left(1+\frac{3}{2}Al\right) \doteq \sqrt{gh\,(1+3\,A\,l)} = \sqrt{gh(1+3\frac{A'}{h}}. \tag{148}$$

For the low-water phase the approximate rate of advance is

$$\sqrt{gh\,(1-3\frac{A'}{h}}. \tag{149}$$

For the mean lunar tide

$$M_4^\circ = 2\,M_2^\circ - 90°. \tag{150}$$

To approximately take into account the proper outward velocity of the stream (U), these rates of propagation should be diminished by U. Similarly, the value of the velocity of the current will be approximately $u - U$.

29. *Tides in a canal stopped by a barrier.**

Taking the mouth of the canal as the origin, and denoting its length by L, the approximate displacements are, by section 30, Part I,

$$\xi = \frac{A}{\cos lL}\sin\,[l(L-x)]\,\cos\,(at+\alpha), \tag{151}$$

$$\zeta = \frac{A\,lh}{\cos lL}\cos\,[l(L-x)]\,\cos\,(at+\alpha). \tag{152}$$

The dynamical equation taken in connection with the equation of continuity is

$$\frac{\partial^2\xi}{\partial t^2} = gh\frac{\partial^2\xi}{\partial x^2}\left[1-3\frac{\partial\xi}{\partial x}+6\left(\frac{\partial\xi}{\partial x}\right)^2 - \ldots\right].$$

* Cf. Airy, Tides and Waves, art. 309.

Substituting the value of $\frac{\partial\xi}{\partial x}$ as obtained from (151) in the second term in the brackets and disregarding the third and later terms, this equation becomes

$$\frac{\partial\xi^2}{\partial t^2}-gh\frac{\partial^2\xi}{\partial x^2}=-3gh\frac{A^2l^3}{2\cos^2 lL}\sin 2[l(L-x)]\frac{1+\cos 2(at+\alpha)}{2}. \tag{153}$$

As a second approximation, assume

$$\begin{aligned}\xi=&\frac{A}{\cos lL}\sin\,[l\,(L-x)]\cos\,(at+\alpha)\\ &-\frac{3}{16}\left(\frac{A}{\cos lL}\right)^2 l^2(L-x)\cos 2\,[l\,(L-x)]\cos 2\,(at+\alpha)\\ &-\frac{3}{16}\left(\frac{A}{\cos lL}\right)^2 l\sin 2\,[l\,(L-x)].\end{aligned} \tag{154}$$

This displacement becomes zero at $x=L$ for all values of t.

The result of applying $\frac{\partial^2}{\partial t^2}-gh\frac{\partial^2}{\partial x^2}$ to this value of ξ is

$$\begin{aligned}&-gh\frac{3}{4}\left(\frac{A}{\cos lL}\right)^2 l^3\sin 2[l(L-x)]\cos 2(at+\alpha)\\ &-\frac{3}{4}gh\left(\frac{A}{\cos lL}\right)^2 l^3\sin 2[l(L-x)].\end{aligned}$$

This shows that (154) satisfies (153);

$$\begin{aligned}\therefore\frac{\partial\xi}{\partial t}=&-\frac{Aa}{\cos lL}\sin\,[l(L-x)]\sin\,(at+\alpha)\\ &+\frac{3a}{8}\left(\frac{A}{\cos lL}\right)^2 l^2(L-x)\cos 2[l(L-x)]\sin 2\,(at+\alpha).\end{aligned} \tag{155}$$

This indicates that the velocity curve is composed of two simple harmonic waves. Hence, because of the difference in depth at different stages of the tide, the rise and fall can not be exactly of this character.

The corresponding value of ζ/h is, by (130),

$$\begin{aligned}&\frac{Al}{\cos lL}\cos\,[l(L-x)]\cos\,(at+\alpha)\\ &+\frac{3}{8}\left(\frac{A}{\cos lL}\right)^2 l^3(L-x)\sin 2[l(L-x)]\cos 2\,(at+\alpha)\\ &-\frac{3}{16}\left(\frac{A}{\cos lL}\right)^2 l^2\cos 2\,[l(L-x)]\cos 2\,(at+\alpha)\\ &+\left(\frac{A}{\cos lL}\right)^2 l^2\cos^2 2\,[l(L-x)]\cos^2 2\,(at+\alpha)\\ &-\frac{3}{8}\left(\frac{A}{\cos lL}\right)^2 l^2\cos 2\,[l(L-x)].\end{aligned} \tag{156}$$

At the mouth of the canal, where $x=0$, the rise and fall is not exactly in agreement with the tide outside, owing to the fact that at the head of the canal the horizontal motion is assumed to be zero, thus implying a reflection to each pulse travelling inward.

If $x'-\xi$ be substituted for x in the expression for ζ/h, the term in $\cos^2$ goes out.

For a short canal, the harmonic term of greatest importance is

$$-\frac{3}{16}\left(\frac{A}{\cos lL}\right)^2 l^2 \cos 2\ [l(L-x')] \cos 2\ (at+\alpha). \tag{157}$$

For such cases

$$M_4^0=2M_2^0\pm 180^0. \tag{158}$$

30. *Approximate results, there being a permanent current in deep water.**

To a first approximation the equation of continuity and of motion may be written

$$\frac{\partial\xi}{\partial x}=-\frac{\zeta}{h}, \tag{159}$$

and

$$\frac{\partial^2\zeta}{\partial t^2}=gh\frac{\partial^2\zeta}{\partial x^2}. \tag{160}$$

Equation (160) is satisfied by any function of $\sqrt{gh}t-x$. Consequently one may write

$$\zeta=\phi\left(\frac{\sqrt{gh}t-x}{\sqrt{gh}-U}\right). \tag{161}$$

If U denotes the constant outward velocity of the permanent current, the true abscissa of the section is

$$x'=x-Ut+\xi,$$

or

$$x'=x-Ut$$

if the displacement due to wave motion be neglected, as may be done in the argument of the function upon which the height depends.

$$\therefore \zeta=\phi\left(t-\frac{x'}{\sqrt{gh}-U}\right). \tag{162}$$

If $x'=0$, $\zeta=\phi\ (t)$ expresses the law of rise and fall at the river's mouth. The coefficient of t divided by the coefficient of $-x'$ gives the rate of wave propagation, which therefore is $\sqrt{gh}-U$ up the stream.

The velocity of the current at x' in the flood direction is $\frac{\partial x'}{\partial t}$.

From equation (159)

$$\xi=\frac{\sqrt{gh}-U}{h}\int\phi(w)dw+F(x) \tag{163}$$

*Cf. Maurice Lévy, Leçons sur la théorie des marées, Chap. IX.

where w is written temporarily for $\frac{\sqrt{gh}t-x}{\sqrt{gh}-U}$ or $t-\frac{x'}{\sqrt{gh}-U}$;

$$\therefore \frac{\partial x'}{\partial t}=-U+\frac{\sqrt{gh}-U}{h}\phi\left(t-\frac{x'}{\sqrt{gh}-U}\right) \tag{164}$$

since

$$\frac{\partial \xi}{\partial t}=\frac{\partial \xi}{\partial w}\frac{\partial w}{\partial t}.$$

$$\therefore \frac{\partial x'}{\partial t}=-U+\frac{\sqrt{gh}-U}{h}\zeta=\zeta\sqrt{\frac{g}{h}}-\left(1+\frac{\zeta}{h}\right)U. \tag{165}$$

This expresses the velocity of the current at any stage of the tide, x' is positive for the upstream direction and ζ for heights above mean water level.

Where there is no permanent current

$$\dot{\xi}=\frac{\partial \xi}{\partial t}=\zeta\sqrt{\frac{g}{h}}. \tag{166}$$

31. *Exact results, the cross section being rectangular.*

As before, let x' denote the actual abscissa of a moving slice of the liquid and x the abscissa of the slice before disturbance, both reckoned from any assumed origin; and so the displacement $\xi=x'-x$. Then the equations of continuity, velocity, and acceleration are

$$\frac{\partial x'}{\partial x}=\frac{h}{z}=\frac{1}{1+\frac{\zeta}{h}} \tag{167}$$

or

$$\frac{\partial \xi}{\partial x}=-1+\frac{1}{1+\frac{\zeta}{h}}, \tag{168}$$

and

$$\frac{\partial x'}{\partial t}=u,$$

$$\frac{\partial^2 x'}{\partial t^2}=-\frac{g}{\gamma}\frac{z\partial p}{h\partial x}=-g\frac{z\partial z}{h\partial x}=-g\left(1+\frac{\zeta}{h}\right)\frac{\partial \zeta}{\partial x}=gh\frac{\partial^2 \xi}{\partial x^2}\left(1+\frac{\partial \xi}{\partial x}\right)^3. \tag{169}$$

Differentiating (169) with respect to x, we have

$$h\frac{\partial^3 x'}{\partial x\partial t^2}=-\frac{\partial}{\partial x}gz\frac{\partial z}{\partial x}=-g\left(\frac{\partial z}{\partial x}\right)^2-gz\frac{\partial^2 z}{\partial x^2}$$

$$=-gh\left[\frac{\partial^2 \zeta}{\partial x^2}+\frac{\zeta\partial^2 \zeta}{h\partial x^2}+\frac{1}{h}\left(\frac{\partial \zeta}{\partial x}\right)^2\right] \tag{170}$$

and differentiating (167) with respect to t,

$$h\frac{\partial^3 x'}{\partial x\partial t^2}=-\frac{\partial}{\partial t}\frac{h^2}{z^2}\frac{\partial z}{\partial t}=-\frac{h^2\partial^2 z}{z^2\partial t^2}+2\frac{h^2}{z^3}\left(\frac{\partial z}{\partial t}\right)^2$$

$$=h\left[-\frac{1}{h}\frac{\partial^2 \zeta}{\partial t^2}+\frac{2\zeta}{h^2}\frac{\partial^2 \zeta}{\partial t^2}+\frac{2}{h^2}\left(\frac{\partial \zeta}{\partial t}\right)^2\right] \tag{171}$$

whence

$$\frac{\partial}{\partial t}\frac{h^2}{z^2}\frac{\partial z}{\partial t}=\frac{\partial}{\partial x}gz\frac{\partial z}{\partial x} \tag{172}$$

The complete solution of (172) for an advancing series of waves of any form is

$$z=F'_{\circ}\,(x-tg^{\frac{1}{2}}h^{-1}z^{\frac{3}{2}}). \tag{173}$$

To prove this, assume a slightly more general form for z, viz,

$$z=F'_{\circ}(x-\alpha t) \tag{174}$$

where α is a function of z. Then regarding x as constant and t and z as variables,

$$\frac{\partial z}{\partial t}=-\frac{\alpha F'_{\circ}(x-\alpha t)}{1+tF'(x-\alpha t)\dfrac{d\alpha}{dz}}; \tag{175}$$

similarly regarding t as constant and x and z as variables

$$\frac{\partial z}{\partial x}=\frac{F'_{\circ}(x-\alpha t)}{1+tF'(x-\alpha t)\dfrac{d\alpha}{dz}}. \tag{176}$$

In either case the accent denotes, as usual, differentiation with reference to the quantity within the parenthesis. Hence

$$\frac{\partial z}{\partial t}=-\alpha\frac{\partial z}{\partial x}. \tag{177}$$

If β is also a function of z, then

$$\frac{\partial}{\partial t}\beta\frac{\partial z}{\partial t}=\frac{\partial}{\partial x}\,\alpha^2\beta\,\frac{\partial z}{\partial x}. \tag{178}$$

For, from (177),

$$\beta\,\frac{\partial z}{\partial t}=-\,\alpha\beta\,\frac{\partial z}{\partial x}, \tag{179}$$

and so

$$\frac{\partial}{\partial t}\beta\frac{\partial z}{\partial t}=-\frac{\partial}{\partial t}\alpha\beta\frac{\partial z}{\partial x}.$$

Again,

$$\frac{\partial}{\partial t}\alpha\beta\frac{\partial z}{\partial x}=\alpha\beta\frac{\partial^2 z}{\partial t\partial x}+\frac{\partial(\alpha\beta)}{\partial z}\frac{\partial z}{\partial t}\frac{\partial z}{\partial x}, \tag{180}$$

$$\frac{\partial}{\partial x}\alpha^2\beta\frac{\partial z}{\partial x}=\alpha^2\beta\frac{\partial^2 z}{\partial x^2}+\beta\frac{\partial(\alpha^2\beta)}{\partial z}\left(\frac{dz}{dx}\right)^2. \tag{181}$$

But

$$\frac{\partial(\alpha\beta)}{\partial z}=\beta\frac{\partial\alpha}{\partial z}+\alpha\frac{d\beta}{dz},\quad \frac{\partial(\alpha^2\beta)}{dz}=2\alpha\beta\frac{d\alpha}{dz}+\alpha^2\frac{d\beta}{dz}. \tag{181}$$

Because of (177), and these relations, the sum of the last terms of (180) and (181) becomes

$$\alpha\beta\frac{d\alpha}{dz}\left(\frac{\partial z}{\partial x}\right)^2.$$

From (177)

$$-\frac{\partial^2 z}{\partial t\partial x}=\frac{\partial}{\partial x}\,\alpha\,\frac{\partial z}{\partial x}=\frac{\partial\alpha\partial z}{\partial x\partial x}+\alpha\,\frac{\partial^2 z}{\partial x^2}. \qquad (182)$$

This equation taken in connection with

$$\frac{\partial\alpha}{\partial x}=\frac{\partial\alpha}{\partial z}\frac{\partial z}{\partial x}$$

shows that the sum of the second members of (180) and (181) is zero, therefore the sum of the first members is zero, and so the given equation (172) is satisfied by the assumed form of z.

In particular, if one puts $\alpha^2\beta=gz$, and $\beta=\frac{h^2}{z^2}$, equation (178) becomes identical with (172).

If $F_1\equiv F_0^{-1}$, i. e., if F_1 is such a function that

$$F_1\,[F_0\,(\qquad)]=(\qquad), \qquad (183)$$

then

$$x=F_1\,(z)+tg^{\frac{1}{2}}\,h^{-1}\,z^{\frac{3}{2}}. \qquad (184)$$

From (167)

$$\partial x'=\frac{h}{z}\,\partial x$$

and so

$$x'=\int\frac{h}{z}\,\frac{\partial F_1(z)}{\partial z}\,dz+tg^{\frac{1}{2}}h^{-1}\int\frac{h\partial z^{\frac{3}{2}}\,dz}{z\partial z}+\text{funct. } i,$$

$$=F_2\,(z)+3\,tg^{\frac{1}{2}}z^{\frac{1}{2}}+kt \qquad (185)$$

if the flow independent of the tide is assumed to be constant.

If $F\equiv F_2^{-1}$,

$$z=F\,[\,x'-(3g^{\frac{1}{2}}\,z^{\frac{1}{2}}-k)\;t]$$

$$=f\left(\,at-\frac{ax'}{3\sqrt{gz}-k}\right). \qquad (186)$$

$$z=F\,(x')=f\left(\frac{-ax'}{3\sqrt{gz}-k}\right) \qquad (187)$$

is the equation of the wave surface when $t=0$

$$u=\frac{dx'}{dt}=\frac{\partial x'}{\partial z}\;\frac{\partial z}{\partial t}+\frac{\partial x'}{\partial t}\;\frac{\partial t}{\partial t}. \qquad (188)$$

From (167)

$$\frac{h}{z}=\frac{\partial x'}{\partial x}=\frac{\partial x'}{\partial z}\ \frac{\partial z}{\partial x}; \tag{189}$$

and so by (175), (176)

$$\frac{\partial x'}{\partial z}\ \frac{\partial z}{\partial t}=\frac{h}{z}\frac{\partial z}{\partial t}\Big/\frac{\partial z}{\partial x}=-\sqrt{gz}; \tag{190}$$

and by (185)

$$\frac{\partial x'}{\partial t}=3\sqrt{gz}+k.$$

$$\therefore\ u=2\sqrt{gz}-k. \tag{191}$$

From this it is evident that in a river without a permanent current the greatest velocity of the tidal current occurs at the time of high or low water.

In case of a tidal river, let the space origin be taken at its mouth and the time origin at the time of high water there; then

$$z-h=\zeta=A'\cos at$$

represents the tide at the river's mouth and

$$\zeta=A'\cos\left[at-\frac{ax'}{3\sqrt{g(h+\zeta)}-k}\right] \tag{192}$$

the elevation at any section distant x' from the mouth.

From this it is seen that the rate of advance is

$$\frac{\lambda}{\tau}=\frac{a}{l}=3\sqrt{g\ (h+\zeta)}-k. \tag{193}$$

To determine k, make $\zeta=0$; then the rule found in the preceding section becomes accurate, i. e., the rate of advance up the river is $\sqrt{gh}$ less U the velocity of the permanent current;

$$\therefore\ 3\sqrt{gh}-k=\sqrt{gh}-U \tag{194}$$

or

$$k=2\sqrt{gh}+U$$

$\therefore$ rate of advance

$$=\sqrt{gh}(1+\frac{3}{2}\ \frac{\zeta}{h}-\frac{3}{4}\ \frac{\zeta^2}{h^2}+\ .\ .\ .\ )-U\doteq\sqrt{gh}(1+3\frac{\zeta}{h})^{\frac{1}{2}}-U \tag{195}$$

velocity of current

$$=2\sqrt{g(h+\zeta)}-2\sqrt{gh}-U=\sqrt{gh}(\frac{\zeta}{h}-\frac{\zeta^2}{4h^2}+\ .\ .\ .\ )-U. \tag{196}$$

Hence the velocity of the current at a given point depends only upon the height of the tide at that point.

If there be no permanent current, $k=2\sqrt{gh}$ and (192) becomes approximately

$$\zeta=A' \cos \left(at-\frac{ax'}{\sqrt{gh}}+\frac{3}{2}\frac{ax'}{\sqrt{gh}}\frac{\zeta}{h}\right). \tag{197}$$

Expanding by Taylor's theorem and using for ζ its first approximate value we have

$$\zeta=A' \cos \left(at-\frac{ax'}{\sqrt{gh}}\right)-\frac{3}{4}\frac{A'^2ax'}{\sqrt{gh}h} \sin 2\left(at-\frac{ax'}{\sqrt{gh}}\right), \tag{198}$$

which agrees with equation (136).

Differentiating (192) with respect to t, the duration of fall becomes

$$\tfrac{1}{2}\tau+x'\left(\frac{1}{3\sqrt{g(h-A')}-k}-\frac{1}{3\sqrt{g(h+A')}-k}\right) \tag{199}$$

or, approximately, taking $k=U+2\sqrt{gh}$ and neglecting higher power of A'/h,

$$\tfrac{1}{2}\tau+x'\frac{3\sqrt{gh}\;A'/h}{(\sqrt{gh}-U)^2}. \tag{200}$$

The duration of rise is

$$\tfrac{1}{2}\tau-x'\frac{3\sqrt{gh}\;A'/h}{(\sqrt{gh}-U)^2}. \tag{201}$$

Hence, the difference between these two intervals increases directly with x' or A'; it is also greater, the greater the velocity (U) of the permanent current.

Since $u=2\sqrt{g(h+\zeta)}-k$, it follows that the times of slack after flood and after ebb are given by the equation

$$2\sqrt{g(h+\zeta)}\doteq 2\sqrt{gh}+\zeta\sqrt{\frac{g}{h}}=k=2\sqrt{gh}+U \tag{202}$$

$$\therefore \pm\frac{1}{2}\zeta\sqrt{\frac{g}{h}}\doteq U$$

The flood slack occurs at a time when the height of the river is $\sqrt{\frac{h}{g}}U$ above the undisturbed level. Therefore by (192)

$$t=\frac{1}{a}\cos^{-1}\frac{\zeta}{A'}\doteq\frac{1}{a}\left(\frac{\pi}{2}-\frac{\zeta}{A'}\right)=\frac{1}{a}\left(\frac{\pi}{2}-\frac{1}{A'}\sqrt{\frac{h}{g}}U\right), \tag{203}$$

where ζ has the above value, gives the time of slack water after the time of high water. Similarly, the time of the ebb slack reckoned from high water is

$$t=\frac{1}{a}\cos^{-1}\left(\pi-\frac{\zeta}{A'}\right)\doteq\frac{1}{a}\left(\frac{3\pi}{2}-\frac{\zeta}{A'}\right)=\frac{1}{a}\left(\frac{3\pi}{2}+\frac{1}{A'}\sqrt{\frac{h}{g}}U\right). \tag{204}$$

The duration of flood is

$$\frac{1}{2}\tau-\frac{2}{A'a}\sqrt{\frac{h}{g}}\,U \tag{205}$$

and of ebb

$$\frac{1}{2}\tau+\frac{2}{A'a}\sqrt{\frac{h}{g}}\,U \tag{206}$$

When the cross section of the channel is of any given form, its area, which is assumed to be constant, may be written $\psi\,(z)$. The equation of continuity then becomes

$$\frac{\partial x'}{\partial x}=\frac{\psi(h)}{\psi(z)}$$

One can proceed as before, considering α and β to denote suitable functions of z. For this and other more general developments, see McCowan's paper already referred to and from which the essentials of the work just given have been taken.

For the equations in ζ, we have from (170) and (171)

$$\frac{\partial^2\left(1+\frac{\zeta}{h}\right)^{-1}}{\partial t^2}+\frac{gh}{2}\,\frac{\partial^2\left(1+\frac{\zeta}{h}\right)^2}{\partial x^2}=0,\quad \frac{\partial^2\zeta}{\partial t^2}-gh\frac{\partial^2\zeta}{\partial x^2}=\frac{1}{h}\,\frac{\partial^2\zeta^2}{\partial t^2}+\frac{g}{2}\,\frac{\partial^2\zeta^2}{\partial x^2}. \tag{207}$$

This is satisfied by putting

$$\zeta=\phi\left(t-\frac{x'}{\omega}\right) \tag{208}$$

where

$$\omega=\sqrt{gh}\left(1+\frac{3}{2}\,\frac{\zeta}{h}\right)-U.*$$

For (207) is the equivalent of (172) and this latter is satisfied by

$$z=\phi\left(t-\frac{x'}{3\sqrt{gz}-k}\right) \tag{209}$$

where

$$k=2\,\sqrt{gh}+U,$$

as has just been shown, and

$$3(gh+g\,\zeta)^{\frac{1}{2}}-k=3\,\sqrt{gh}\,\left(1+\frac{1}{2}\frac{\zeta}{h}-\ .\ .\ .\right)-2gh-U. \tag{210}$$

32. *The equation of motion where there is a natural slope to the bed.*

Let the variable upward slope of the surface (in going up the river) be denoted by I_s, the resistance per unit area by F, and the heaviness of the liquid by γ. For a broad stream the hydraulic mean depth is approximately equal to z. The acceleration, or force per unit mass, is

$$\frac{\partial^2 x'}{\partial t^2}=-g\sin I_s-\frac{gF}{\gamma z}, \tag{211}$$

or

$$\frac{\partial^2 x'}{\partial t^2}=-g\sin I-g\frac{\partial z}{\partial x'}-\frac{g}{\gamma}\,\frac{F}{z}, \tag{212}$$

if I be the uniform upward slope of the bed.

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* Cf. Levy, l. c., § 128.

Since

$$x' = x - Ut + \xi,\ z = h + \zeta,$$

the above equation multiplied by $\frac{\partial x'}{\partial x}$ becomes

$$\left[\frac{\partial^2 \xi}{\partial t^2} + g \sin I + \frac{g}{\gamma}\,\frac{F}{h}\left(1+\frac{\zeta}{h}\right)^{-1}\right]\left(1+\frac{\partial \xi}{\partial x}\right) = -g\frac{\partial \zeta}{\partial x}. \tag{213}$$

The equation of continuity is

$$\Omega\frac{\partial x'}{\partial x} = \Omega_0, \text{ or } b'z\frac{\partial x'}{\partial x} = bh, \text{ or } \frac{b'}{b}\left(1+\frac{\partial \xi}{\partial x}\right) = \left(1+\frac{\zeta}{h}\right)^{-1} \tag{214}$$

where Ω_0 and Ω denote the areas of the cross sections and b and b' the breadths at x and x', respectively.

For a nontidal stream

$$g \sin I + \frac{gF_0}{\gamma h} = 0 \tag{215}$$

where F_0 denotes the resistance per unit area for the permanent stream.

Equation (213) may, for a canal of uniform breadth, be written

$$\frac{\partial^2 \xi}{\partial t^2} + g \sin I + \frac{gF}{\gamma h}\left(1+\frac{\zeta}{h}\right)^{-1} = -\frac{gh}{2}\,\frac{\partial\left(1+\frac{\zeta}{h}\right)^2}{\partial x} \tag{216}$$

since

$$\frac{\partial x'}{\partial x} = 1 + \frac{\partial \xi}{\partial x} = \left(1+\frac{\zeta}{h}\right)^{-1};$$

or, approximately,

$$\frac{\partial^2 \xi}{\partial t^2} + g \sin I + \frac{gF}{\gamma h}\left(1-\frac{\zeta}{h}\right) = -\frac{gh}{2}\,\frac{\partial\left(1+\frac{\zeta}{h}\right)^2}{\partial x}. \tag{217}$$

In this equation F is supposed to be a known function of u where

$$u = \frac{\partial x'}{\partial t} = -U + \frac{\partial \xi}{\partial t}.$$

Expressions for F are given in sections 7 and 8.

This equation is treated in some detail by Lévy.* His results have more especial reference to the assumption that the resistance is directly proportional to the velocity.

Supposing the slope of the bed to be negligible and the amplitude of the wave small in comparison with the depth, equation (213) becomes, approximately,

$$\frac{\partial^2 \xi}{\partial t^2} + \frac{gF}{\gamma h} = gh\,\frac{\partial^2 \xi}{\partial x^2}, \tag{218}$$

which equation is obvious upon recalling that γ/g = density or mass per unit volume, and h = depth or volume per unit area of bottom.

* L. c., secs. 138–141.

If

$$F=\pm\zeta' u^2 \frac{\gamma}{2g}+\bar{\zeta} u \frac{\gamma}{2g}, \tag{219}$$

then

$$\frac{\partial^2 \xi}{\partial t^2}\pm\frac{\zeta'}{2h}\left(\frac{d\xi}{dt}\right)^2+\frac{\bar{\zeta}}{2h}\left(\frac{d\xi}{dt}\right)=gh\frac{\partial^2 \xi}{\partial x^2} \tag{220}$$

where the upper sign goes with the flood stream and the lower with the ebb, ξ being positive in the direction of the flood.

If the bed has a slope, the corresponding equation is

$$\frac{\partial^2 \xi}{\partial t^2}+\frac{gF}{\gamma h}+g \sin I=gh\frac{d^2 \xi}{\partial x^2}. \tag{221}$$

If the cross section has a variable width, the equation is

$$\frac{\partial^2 \xi}{\partial^2 t}\pm\frac{\zeta'}{2h}\left(\frac{\partial \xi}{\partial t}\right)^2+\frac{\bar{\zeta}}{2h}\frac{\partial \xi}{\partial t}+g \sin I-\frac{gh}{b}\left(\frac{\partial^2 b\xi}{\partial x^2}-\frac{1}{b}\frac{\partial b}{\partial x}\frac{\partial b\xi}{\partial x}\right)=0 \tag{222}$$

since the equation of continuity for long-wave motion is then

$$\zeta=-\frac{h}{b}\frac{\partial b\xi}{\partial x} \tag{223}$$

and the force of restitution per unit mass is

$$gh\frac{\partial\left(\frac{1}{b}\frac{\partial b\xi}{\partial x}\right)}{\partial x} \tag{224}$$

It is evident that a solution of (222) involves the law or function connecting b and x, i. e., connecting the breadth and length of the river.

33. *To find the form of an estuary the undisturbed depth of water being constant, and the tide wave progressive.*

The energy contained in a wave length, the amplitude being A' at a given cross section distant x from the sea, is

$$\frac{1}{2}\gamma A'^2 b\lambda, \tag{225}$$

where b denotes the breadth at the same cross section.

For, the potential energy of a wave length is

$$\gamma\lambda\int_0^\zeta zb\,dz=\frac{1}{2}\gamma\lambda\zeta^2 b \tag{226}$$

where ζ denotes the elevation of the free surface; or $\frac{1}{4}\gamma\lambda A'^2 b$ if the oscillation is harmonic.

The kinetic energy is

$$\frac{1}{2}\frac{\gamma}{g}bh\int_{x=0}^{x=\lambda} u^2 \quad dx \tag{227}$$

or $\frac{1}{4}\frac{\gamma}{g}\lambda\ bh\dot{A}^2$ if the oscillation is harmonic. Since $u=\zeta\sqrt{\frac{g}{h}}$, and so $A=A'\sqrt{\frac{g}{h}}$, the kinetic energy is $\frac{1}{4}\ \gamma\lambda A'^2 b$.

The total energy of a wave length is $\frac{1}{2}\ \gamma\lambda\ A'^2\ b$.

This shows that if the energy of a long wave remains constant, the amplitude of the tide in a canal of slowly varying section will vary inversely as the square root of the breadth and inversely as the fourth root of the depth.

The energy contained in a wave length whose amplitude is $A'_{,,}$ at a cross section distant $x_{,,}$ from the sea is, of course, $\frac{1}{2}\ \gamma\lambda A'^2_{,,}b_{,,}$, where $b_{,,}$ denotes the breadth at the upper cross section.

The resistance for a slice $d\ x$ in length is

$$\zeta'\frac{\gamma}{2g}\ u^2bdx, \tag{228}$$

This quantity multiplied by the distance the water particles of the slice travel during the time $d\ t$, or $u\ d\ t$, gives the energy consumed upon this elementary slice during the time $d\ t$, viz.,

$$\zeta'\frac{\gamma}{2g}\ u^3bdxdt \tag{229}$$

or

$$\frac{4}{3\ \pi}\ \zeta'\ \frac{\gamma}{2g}\dot{A}^3bdxdt \tag{230}$$

if the oscillation is harmonic. Replacing $\dot{A}$ by $A'\sqrt{\frac{g}{h}}$ and integrating from $t=0$ to $t=\tau$, and from $x=x$ to $x=x,''$ the energy consumed during the time τ on the portion of the estuary above x and below $x_{,,}$ is

$$\frac{\tau}{3}\frac{4}{\pi}\zeta'\frac{\gamma}{2}\int_{x=x}^{x=x_{,,}} A'^3\, b\,\frac{g^{\frac{1}{2}}}{h^{\frac{3}{2}}}\,dx. \tag{231}$$

Since the energy of a wave where the breadth of the channel is b must equal the energy consumed between $x=x$ and $x=x''$ during the time τ, plus the energy of a wave where the breadth is $b_{,,}$, it follows that

$$A'^2\ b\lambda=\frac{\tau}{3}\frac{4}{\pi}\zeta'\int_{x=x}^{x=x_{,,}} A'^3\, b\,\frac{g^{\frac{1}{2}}}{h^{\frac{3}{2}}}\,dx+A'^2_{,,}\ b_{,,}\lambda. \tag{232}$$

$$A'^2\, b=\frac{4}{3\ \pi}\frac{\zeta'}{h^2}\int_{x=x}^{x=x_{,,}} A'^3\, b\ dx+A'^2_{,,}\ b_{,,} \tag{233}$$

since $\lambda/\tau=\sqrt{gh}$. $A'_{,,}$, $b_{,,}$ are the values of the amplitude and width at $x=x_{,,}$.

Assuming the depth to be constant, the above equation shows how A', $A'_{,,}$, b, and $b_{,,}$ are related. Hence, if the amplitudes of the tide at two cross sections and one of the widths of the channel be given or one amplitude and two of the widths, the remaining width or amplitude can be approximately inferred.

Special cases.—Suppose A'=constant; then, differentiating with respect to x, we have

$$\frac{1}{b}\frac{db}{dx}=-\frac{4}{3}\frac{\zeta'}{\pi h^2}A'. \tag{234}$$

The general solution of this is

$$\log b=-KA'x+\text{constant}$$

or

$$b=Ce^{-KA'x} \tag{235}$$

where C=constant and $K=\frac{4\zeta'}{3\pi h^2}$.

Where $x=0$,

$$b=b_0, \text{ and so } C=b_0;$$
$$\therefore \log b_0-\log b=KA'x. \tag{236}$$

Since $\dot{A}=A'\sqrt{\frac{g}{h}}$, it follows that the average velocity of the tidal stream is the same for all cross sections. This assumption seems to be reasonable or even fundamental in the formation of estuaries; for, if at any point the velocity were unusually great, the banks would there be more eroded than elsewhere by tidal action, and so the width would there increase and the velocity be reduced in the same ratio. At any rate, for purposes of commerce, the velocity and depth should be made as uniform as possible.

Wheeler, on page 183 of his treatise on tidal rivers, gives an empirical formula for the breadth of a tidal river at different parts of its course. He applies his formula to the Humber River, the width being known at each end, i. e., at Spurn Point and Goole. His results are quoted here, and to them are added the values obtained by equation (236) using the same assumed data.

River Humber.

Distance from Spurn Point	Mean low water width	Width by Wheeler's formula	Width calculated by average rate of increase	Width by formula (236)
Stat. miles	*Feet*	*Feet*	*Feet*	*Feet*
0	18 000	18 000	18 000	18 000
5	10 800	12 935	16 100	12 942
15	7 392	6 505	12 309	6 690
20	4 950	4 687	10 411	4 810
25	3 300	3 441	8 514	3 458
40	1 320	1 281	2 821	1 285
45	924	924	924	924

In this computation K was determined from the known or assumed end widths and the distance between these two sections.

Theoretically, only one width is necessary for the determination of all others.

In case of the Humber River, the low-water width at the mouth is 18 000 feet; required the width at a distance of 45 statute miles up the river. The average value of A' is 7 feet; the depth h, about 35 feet; and ζ' may be taken as 0.007. These make K 0.000 002 43. The required width is, according to computation, 316 feet, which is about one-third of the measured value. Of course only a very rough agreement between theory and fact could be expected in such cases—hardly more than an agreement in order of magnitude.

Suppose the width of the stream to be constant. The equation (233) becomes

$$A'^2 = K\int_{x=x}^{x=x_{\prime\prime}} A'^3\,dx + A'_{\prime\prime}{}^2. \tag{237}$$

$$\therefore\ \frac{1}{A'} = +\frac{K}{2}x + \text{constant}, \tag{238}$$

where constant $= 1/A_0$. This shows that the relation between the amplitude of the tide and the distance x can be represented by a hyperbola.

For a short distance, $x_{\prime\prime}-x$, the above integral becomes

$$A'^2 - A'_{\prime\prime}{}^2 = KA'^3\,(x_{\prime\prime}-x);$$

$$\therefore\ A'_{\prime\prime} \doteq A' - \frac{K}{2}A'^2\,(x_{\prime\prime}-x), \tag{239}$$

Starting with A' at the mouth of the river, the value of $A'_{\prime\prime}$ can be computed by this formula for a section a few miles higher up the river; starting with this value of the amplitude of the tide, and proceeding as before, the value for a section still higher up can be found; and so on.

34. *Harmonic constants for shallow water components, and related quantities.*

The following table contains the constants for the principal shallow-water tides. The second set of values of S_4, MS, S_4^0, and MS^0 are inferred in accordance with section 48, Part II, and are given for the purpose of testing this mode of inference. The high-water and low-water intervals have been computed from M_2 and its harmonics in accordance with Part III. The tidal or cotidal hour is not the time of the M_2 tide alone, but is the hour obtained by using the high-water interval. It should, for each place given, agree with the tidal hour taken from a chart of cotidal lines (Part IV B).

No.	Station	Geographic position			M_2	M_2^0		S_2	S_2^0	M_4	M_4^0	M_6
		Latitude	Longitude			Degrees	Lunar hours					
			Arc	Time								
	EAST COAST OF AMERICA	° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	
		North	*West*									
6	Beechey Island, Barrow Str........	74 43	92 00	6 08	2.00	347	11.57	0.69	34	0.024	268	......
7	Port Leopold, Barrow Str..........	73 50	90 25	6 02	2.00	338	11.27	0.64	29	0.015	202	......
15	Kingua Fiord.................. ...	66 36	67 20	4 29	7.43	159	5.30	2.67	202	......	......	......
20	Godthaab.....................	64 12	51 44	3 27	4.46	193	6.43	1.54	229	......	......	......
25	Fort Conger, Discovery Har.......	81 44	64 44	4 19	1.96	335	11.17	0.89	19	0.018	322	......
28	St. Johns, Newfoundland..........	47 34	52 41	3 31	1.17	209.6	6.99	0.48	254	0.020	48	0.020
32	Quebec..........	46 49	71 12	4 45	5.80	186.9	6.23	1.37	236	0.901	283	0.228
36	St. Paul I., Gulf of St. Lawrence...	47 14	60 08	4 01	0.98	245.4	8.18	0.33	287	0.017	176	0.003
40	Halifax	44 40	63 35	4 14	2.04	223.5	7.45	0.45	258	0.116	25	0.013
42	St. John, New Brunswick..........	45 14	66 04	4 24	10.04	324.7	10.82	1.62	4	0.119	146	0.092
44	Eastport	44 54	66 59	4 28	8.58	326.1	10.87	1.40	6	0.208	180	0.171
45	Pulpit Harbor......................	44 09	68 53	4 36	4.89	320.4	10.68	0.77	355	0.025	143	0.120
46	Portland	43 40	70 14	4 41	4.34	323.6	10.79	0.68	0	0.034	75	0.042
50	Boston	42 22	71 03	4 44	4.44	335.4	11.18	0.71	14	0.056	164	0.189
58	Newport	41 29	71 20	4 45	1.66	217.5	7.25	0.38	237	0.179	120	0.011
59	Bristol............................	41 40	71 16	4 45	1.90	222.4	7.41	0.43	233	0.292	134	......
60	Providence........................	41 49	71 24	4 46	2.02	228.1	7.60	0.44	252	0.344	150	0.087
63	New London.......................	41 21	72 05	4 48	1.14	274.1	9.14	0.21	288	0.064	62	0.039
66	Willets Point...........	40 48	73 46	4 55	3.65	328.6	10.95	0.64	352	0.096	211	0.210
67	New York, Governors Island......	40 42	74 01	4 56	2.12	231.0	7.70	0.41	257	0.087	332	0.076
70	Sandy Hook, The Horseshoe	40 27	74 00	4 56	2.22	217.6	7.25	0.43	246	0.026	336	0.054
77	Philadelphia, Washington Ave ...	39 56	75 09	5 01	2.46	43.5	1.45	0.34	82	0.368	7	0.112
85	Old Point Comfort	37 00	76 18	5 05	1.22	248.4	8.28	0.23	269	0.039	244	0.016
90	Washington Navy-Yard, D. C......	38 52	76 59	5 08	1.43	227.9	7.60	0.20	271	0.083	350	0.021
95	Baltimore, Fells Point	39 17	76 35	5 06	0.57	190.2	6.34	0.08	225	0.011	329	0.006
98	Wilmington, N. C.................	34 14	77 57	5 12	1.15	292.1	9.74	0.10	344	0.183	149	0.026
101	Charleston, Custom-house wharf..	32 46	79 56	5 20	2.48	213.6	7.12	0.43	240	0.090	242	0.025
103	Savannah Entr., Tybee I. Light...	32 02	80 51	5 23	3.22	209.5	6.98	0.59	235	0.058	287	0.021
105	Fernandina, Dade St..............	30 41	81 28	5 26	2.85	228.3	7.61	0.51	258	0.030	295	0.032
113	Key West, Fort Taylor............	24 33	81 48	5 27	0.56	260.3	8.68	0.17	280	0.036	235	0.011
114	Tortugas Harbor Light............	24 38	82 53	5 32	0.48	278.1	9.27	0.17	292	0.010	297	0.004
119	Cedar Keys........................	29 08	83 02	5 32	1.06	24.4	0.81	0.42	51	0.054	276	0.012
120	St. Marks Light, Apalachee Bay ..	30 04	84 11	5 37	1.12	43.5	1.45	0.44	73	......	......	......
125	Warrington Navy Yd., Pensacola B.	30 21	87 16	5 49	0.06	317.0	10.57	0.03	315	0.008	318	0.001
128	Biloxi Light.......................	30 24	88 54	5 56	0.11	11.3	0.37	0.09	32	0.019	138	0.003
129	Cat Island Light..................	30 14	89 09	5 57	0.12	11.0	0.37	0.07	24	......	......	......
131	Port Eads, South Pass, Miss. R....	29 01	89 10	5 57	0.06	316.5	10.53	0.04	298	0.006	91	0.001
140	Galveston, Doswell's wharf........	29 19	94 47	6 19	0.22	124.5	4.15	0.04	134	0.002	128	0.004
143	Tampico	22 16	97 49	6 31	0.08	62.6	2.09	0.03	73	0.004	63	......
145	Vera Cruz.........................	19 12	96 08	6 25	0.20	74.6	2.49	0.06	355	0.009	247	0.002
154	Nassau, Bahamas.................	25 05	77 21	5 09	1.24	213.4	7.11	0.21	237	0.017	65	0.006
155	Great Harbor, Culebra Island.....	18 18	65 17	4 21	0.29	241.2	8.04	0.04	266	0.017	40	0.009
156	San Juan..........................	18 29	66 07	4 24	0.49	246.3	8.21	0.07	267	0.007	84	0.007
157	Ponce, P. R.......................	17 59	66 40	4 27	0.03	280.0	9.33	0.02	264	0.007	57	0.001
		South										
175	Pernambuco (Recife Arsenal).....	8 04	34 54	2 20	2.49	133.6	4.45	0.87	151	0.050	243	0.011
184	Montevideo	34 53	36 12	3 45	0.19	34.2	1.14	0.04	318	0.034	146	0.012
186	Buenos Ayres, La Plata R..........	34 36	58 22	3 53	0.81	184.7	6.16	0.17	266	0.073	90	0.018
190	South Georgia (Royal Bay)........	54 31	36 01	2 24	0.74	213	7.10	0.38	236	0.01	308	.....
195	Port Louis, Berkeley Sound	51 29	58 00	3 52	1.54	157	5.23	0.49	195	0.068	357	0.012

M_6^0	S_4	S_4^0	MS	MS^0	$\frac{S_2}{M_2}$	$\frac{M_4}{M_2}$	$\frac{M_6}{M_2}$	$2M_2^0-M_4^0$	$3M_2^0-M_6^0$	$M_4\left(\frac{S_2}{M_2}\right)^2$ $(=S_4)$	$M_4\frac{2S_2}{M_2}$ $(=MS)$	$M_4^0+2S_2^0-2M_2^0$ $(=S_4^0)$	$M_4^0+S_2^0-M_2^0$ $(=MS^0)$	HWI	LWI	Co-tidal hour	No.
......	......	......	......	......	0.35	0.012	......	66	......	0.003	0.017	......	......	......	......	......	6
......	0.007	257	......	......	0.32	0.008	......	114	......	0.002	0.010	304	......	......	......	......	7
......	......	......	......	......	0.36	......	......	......	......	......	......	......	......	......	......	......	15
......	......	......	......	......	0.35	......	......	......	......	......	......	......	......	......	......	......	20
......	......	......	......	......	0.45	0.009	......	348	......	0.004	0.016	......	......	......	......	......	25
344	......	......	......	......	0.41	0.018	0.017	12	285	0.003	0.016	......	......	7 18	1 08	10.57	28
258	0.053	35	0.478	337	0.24	0.155	0.039	91	303	0.052	0.432	21	332	6 04	0 52	10.61	32
308	......	......	0.004	21	0.34	0.017	0.003	314	68	0.002	0.012	260	218	8 30	2 12	12.23	36
72	0.021	313	0.060	154	0.22	0.057	0.006	62	238	0.006	0.051	94	60	7 33	1 46	11.53	40
173	0.010	208	0.047	179	0.16	0.012	0.009	143	81	0.003	0.038	225	185	11 08	4 59	3.16	42
242	......	......	......	......	0.16	0.024	0.020	113	16	0.005	......	......	......	11 09	5 05	3.24	44
62	0.005	9	0.021	325	0.16	0.005	0.025	138	179	0.001	0.008	212	177	......	......	......	45
71	......	......	......	......	0.16	0.008	0.010	212	180	0.001	......	......	......	11 11	4 56	3.49	46
262	......	......	......	......	0.16	0.013	0.043	146	25	0.001	......	......	......	11 28	5 18	3.81	50
127	......	......	......	......	0.23	0.108	0.007	315	166	0.009	......	......	......	7 44	0 49	12.22	58
......	......	......	......	......	0.23	0.154	......	310	......	0.015	......	......	......	......	......	......	59
264	......	......	......	......	0.22	0.170	0.043	307	60	0.017	......	......	......	......	......	......	60
134	......	......	......	......	0.18	0.056	0.034	126	328	0.002	......	......	......	9 27	3 30	1.93	63
84	......	......	......	......	0.18	0.026	0.058	87	182	0.003	......	......	......	11 09	5 22	3.69	66
89	......	......	......	......	0.19	0.041	0.036	130	244	0.003	......	......	......	8 04	2 05	12.73	67
353	......	......	......	......	0.19	0.012	0.024	99	300	0.001	......	......	......	7 35	1 27	12.26	70
206	......	......	......	......	0.14	0.149	0.045	80	284	0.007	......	......	......	1 22	8 34	6.34	77
191	......	......	......	......	0.19	0.032	0.013	253	194	0.001	......	......	......	8 44	2 15	1.52	85
82	......	......	0.024	207	0.14	0.058	0.015	106	242	0.0016	0.0232	76	33	7 52	2 04	12.73	90
185	......	......	......	......	0.14	0.019	0.011	51	26	0.0002	0.0031	39	4	6 29	0 23	11.36	95
278	......	......	0.033	201	0.09	0.159	0.023	76	239	0.0014	0.0318	252	201	9 37	4 47	2.49	98
311	......	......	......	......	0.17	0.036	0.010	185	329	0.0027	0.0311	295	268	7 25	1 10	12.50	101
286	......	......	......	......	0.18	0.018	0.007	132	343	0.0019	0.0212	338	312	7 11	1 05	12.32	103
8	0.028	12	......	......	0.18	0.011	0.011	161	317	0.0010	0.0107	355	325	7 54	1 43	1.07	105
180	......	......	......	......	0.30	0.064	0.020	285	240	0.0033	0.0219	275	255	9 20	2 36	2.47	113
183	......	......	......	......	0.35	0.021	0.008	259	291	0.0013	0.0071	325	311	9 44	3 21	2.94	114
90	......	......	......	......	0.40	0.051	0.011	133	343	0.0085	0.0428	329	302	......	......	......	119
......	......	......	......	......	0.39	......	......	......	......	......	......	......	......	......	......	......	120
359	......	......	......	......	0.50	0.133	0.017	316	232	0.0020	0.0080	314	316	11 19	4 08	4.75	125
205	......	......	......	......	0.82	0.173	0.027	244	189	0.0127	0.0312	180	159	......	......	......	128
......	......	......	......	......	0.58	......	......	......	......	......	......	......	......	......	......	......	129
46	......	......	......	......	0.67	0.100	0.017	182	184	0.0027	0.0080	54	72	......	......	......	131
29	......	......	......	......	0.18	0.009	0.018	121	345	0.0001	0.0007	147	138	4 18	10 33	10.47	140
......	......	......	......	......	0.38	0.052	......	62	......	0.0006	0.0032	84	74	2 00	8 34	8.45	143
337	......	......	......	......	0.30	0.045	0.010	262	246	0.0008	0.0005	88	168	......	......	......	145
279	0.004	319	......	......	0.17	0.014	0.005	1	1	0.0005	0.0058	112	89	7 22	1 09	12.27	154
331	......	......	......	......	0.14	0.059	0.032	83	32	0.0003	0.0048	89	64	8 04	2 14	12.14	155
308	......	......	......	......	0.14	0.013	0.013	49	71	0.0001	0.0019	125	105	8 23	2 15	12.50	156
58	......	......	......	......	0.67	0.233	0.033	143	63	0.0031	0.0093	25	41	8 28	3 37	12.63	157
301	......	......	......	......	0.35	0.020	0.004	24	99	0.0061	0.0349	278	260	4 33	10 50	6.73	175
333	......	......	......	......	0.21	0.018	0.063	283	129	0.0015	0.0145	353	69	1 41	5 46	5.38	184
292	......	......	......	......	0.21	0.090	0.022	280	262	0.0032	0.0307	252	171	6 50	12 21	10.49	186
......	0.004	39	......	......	0.51	0.001	......	118	......	0.0026	0.0103	354	331	......	......	......	190
76	0.007	64	......	......	0.32	0.044	0.008	317	35	0.0069	0.0432	73	35	......	......	......	195

No.	Station.	Geographic position			M_2	M_2^0		S_2	S_2^0	M_4	M_4^0	M_6
		Latitude	Longitude			Degrees	Lunar hours					
			Arc	Time								
		° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	
	WEST COAST OF AMERICA	South	West									
201	Cape Horn, Orange Bay, Chile	55 31	68 05	4 32	1.93	104	3.47	0.30	134	0.016	197	0.017
205	Valparaiso, Chile	33 02	71 39	4 47	1.65	279.2	9.31	0.47	300	0.007	147	0.004
		North										
210	Panama (Naos I.)	8 55	79 32	5 18	5.93	86.7	2.89	1.66	144	0.218	358	0.041
215	Mazatlan	23 11	106 27	7 06	1.08	265.2	8.83	0.74	254	0.014	294	0.012
217	Magdalena Bay	24 38	112 09	7 29	1.59	244	8.13	1.01	253	......	......	......
218	San Juanico Bay	26 15	112 28	7 30	1.72	246	8.20	1.02	252	......	......	......
219	Ambreojos Pt., Ballenas Bay	26 43	113 34	7 34	2.14	261	8.70	1.07	275	......	......	......
221	San Diego, La Playa, Cal	32 42	117 14	7 49	1.70	276.6	9.22	0.70	275	0.026	186	0.010
224	San Francisco Entr., Fort Point	37 50	122 28	8 10	1.70	330.7	11.02	0.38	335	0.086	32	0.012
225	Sausalito	37 51	122 29	8 10	1.57	336.7	11.22	0.35	348	0.033	55	0.021
227	Astoria, Oregon	46 11	123 50	8 15	2.97	8.6	0.29	0.77	39	0.100	317	0.034
230	Port Townsend	48 07	122 45	8 11	2.22	105.6	3.52	0.55	130	0.131	290	0.033
235	Victoria Harbor	48 25	123 23	8 14	1.22	68.8	2.29	0.33	86	0.057	317	0.042
241	Sand Heads, Fraser River	49 05	123 16	8 13	2.81	142.0	4.73	0.69	171	0.008	297	0.025
246	Seymour Narrows, Discovery Pt	50 08	125 23	8 22	2.93	70.9	2.36	0.62	100	0.363	253	0.140
248	Port Alice	55 48	133 36	8 54	4.04	1.3	0.04	1.30	34	0.048	41	0.018
250	Sitka, Baranof Island	57 03	135 20	9 01	3.58	2.8	0.09	1.14	34	0.013	140	0.002
251	Sergius Narrows	57 25	135 38	9 03	4.93	11.7	0.39	1.66	45	0.100	230	0.046
251.5	Hooniah	58 07	135 47	9 03	5.97	14.2	0.47	2.03	48	0.069	218	0.016
252	Port Althorp	58 07	136 17	9 05	3.61	353.5	11.78	1.13	35	0.018	329	0.058
252.5	Granite Cove	58 12	136 24	9 06	4.01	5.9	0.20	1.29	38	0.036	204	0.029
255	Kokinhenic I	60 18	145 03	9 40	1.12	11.9	0.40	0.28	51	0.319	13	0.052
256	Pete Dahl Slough	60 23	145 24	9 42	3.52	12.7	0.42	1.05	46	0.188	296	0.084
259	Orca, Prince William Sound	60 34	145 41	9 43	4.52	357.7	11.92	1.61	40	0.167	138	0.087
260	Orca, Cape Whitshed	60 28	145 55	9 44	4.42	8.4	0.28	1.56	44	0.363	231	0.143
261	Camp April	60 32	146 00	9 44	4.54	356.0	11.87	1.53	32	0.061	138	0.023
262	Valdez Arm	61 07	146 27	9 46	4.51	353.7	11.79	1.52	25	0.090	141	0.029
265	Kodiak (St. Paul), Kodiak Id	57 48	152 21	10 09	3.23	7.7	0.26	1.08	40	0.038	97	0.032
267	Peterson Bay	54 23	162 38	10 51	1.92	354.8	11.83	0.73	18	0.053	290	0.063
268	Tigalda Bay	54 05	165 10	11 01	0.38	60.1	2.00	0.28	5	0.026	265	0.007
269	Unalga Bay	54 00	166 10	11 05	0.61	105.2	3.51	0.13	304	0.042	280	0.043
270	Dutch Harbor	53 54	166 32	11 06	0.86	111.5	3.72	0.07	350	0.009	280	0.005
271	Kaskega Bay	53 28	167 05	11 08	0.71	95.5	3.18	0.11	92	0.024	15	0.013
280	St. Michael	63 29	162 02	10 48	0.55	235.4	7.85	0.12	338	0.042	150	0.018
285	Port Clarence	65 14	166 24	11 06	0.47	213.4	7.11	0.03	346	0.097	301	0.028
295	Point Barrow	71 18	156 40	10 27	0.17	336.2	11.21	0.07	16	0.003	319	0.003
	EAST COAST OF ASIA		East									
342	Yokohama (Nishihatoba)	35 27	139 39	9 19	1.57	154.3	5.14	0.73	185	0.048	98	0.012
392	Nagasaki	32 44	129 51	8 39	2.84	228.9	7.63	1.17	259	......	......	......
420	Chemulpho, inner harbor	37 29	126 37	8 26	9.43	107.8	3.59	3.84	187	0.278	67	0.079
425	Tientsin Entr., Taku Lightship	38 55	117 52	7 51	3.47	94.4	3.15	0.53	157	0.281	99	......
430	Shanghai, Wusung Bar	31 21	121 30	8 06	3.11	30.3	1.01	1.03	77	0.700	331	......
435	Amoy, inner bar	24 23	118 10	7 53	6.12	1.2	0.04	1.34	57	0.042	92	......
436	Swatow, China	23 23	116 39	7 47	1.35	23	0.77	0.32	86	0.228	154	0.053
438	Whampoa	23 05	113 26	7 34	2.18	32	1.07	0.67	64	0.160	313	......
440	Hongkong	22 18	114 10	7 37	1.43	266	8.87	0.56	292	0.076	322	0.014
490	Singapore	1 17	103 51	6 55	2.60	300	10.00	1.07	348	0.053	264	0.035

M_6^0	S_4	S_4^0	MS	MS^0	$\frac{S_2}{M_2}$	$\frac{M_4}{M_2}$	$\frac{M_6}{M_2}$	$2M_2^0-M_4^0$	$3M_2^0-M_6^0$	$M_4\left(\frac{S_2}{M_2}\right)^2$ (=S_4)	$M_4\frac{2S_2}{M_2}$ (=MS)	$M_4^0+2S_2^0-2M_2^0$ (=S_4^0)	$M_4^0+S_2^0-M_2^0$ (=MS^0)	HWI	LWI	Co-tidal hour	No.
313	......	......	......	......	0.16	0.008	0.009	11	359	0.0004	0.0048	257	227	3 35	9 49	8.00	201
107	......	......	......	......	0.28	0.004	0.002	51	10	0.0006	0.0039	189	168	9 37	3 26	2.07	205
276	......	......	......	......	0.28	0.037	0.007	176	343	0.0171	0.1221	112	55	2 59	9 13	8.18	210
30	......	......	......	......	0.69	0.013	0.011	236	46	0.0066	0.0192	272	283	......	......	......	215
......	......	......	......	......	0.64	......	......	......	......	......	......	......	......	......	......	......	217
......	......	......	......	......	0.59	......	......	......	......	......	......	......	......	......	......	......	218
......	......	......	......	......	0.50	......	......	......	......	......	......	......	......	......	......	......	219
112	......	......	......	......	0.41	0.015	0.006	7	358	0.0044	0.0214	183	185	9 32	3 20	5.03	221
342	......	......	......	......	0.22	0.051	0.007	269	290	0.0043	0.0385	41	36	11 39	5 03	7.42	224
338	......	......	......	......	0.22	0.021	0.013	258	312	0.0016	0.0145	78	66	......	......	......	225
106	......	......	0.054	340	0.26	0.033	0.011	60	280	0.0068	0.0517	18	347	0 15	6 42	8.50	227
233	......	......	0.067	313	0.25	0.059	0.015	281	84	0.0081	0.0635	339	314	3 47	9 32	11.84	230
176	......	......	......	......	0.27	0.046	0.035	181	30	0.0041	0.0306	351	334	2 17	8 31	10.44	235
11	......	......	0.002	268	0.25	0.003	0.009	347	55	0.0005	0.0039	356	326	......	......	......	241
132	......	......	......	......	0.21	0.124	0.048	248	81	0.0163	0.1537	312	282	......	......	......	246
257	......	......	......	......	0.32	0.012	0.044	322	107	0.0050	0.0307	105	73	0 03	6 12	8.95	248
94	......	......	......	......	0.32	0.004	0.001	225	275	0.0013	0.0083	203	172	0 07	6 18	9.13	250
89	......	......	......	......	0.34	0.020	0.009	153	306	0.0011	0.0671	297	264	0 25	6 41	9.45	251
20	......	......	......	......	0.34	0.012	0.003	171	23	0.0080	0.0469	285	252	0 29	6 42	9.52	251.5
326	......	......	......	......	0.31	0.005	0.016	18	16	0.0018	0.0113	51	10	12 10	5 58	8.84	252
48	......	......	......	......	0.32	0.009	0.007	168	330	0.0038	0.0232	268	236	0 13	6 26	9.31	252.5
346	......	......	......	......	0.25	0.284	0.047	11	50	0.0199	0.1600	91	52	0 14	6 42	9.89	255
355	......	......	......	......	0.30	0.053	0.024	89	43	0.0168	0.1126	3	329	0 11	6 45	9.88	256
30	......	......	......	......	0.36	0.037	0.019	218	323	0.0212	0.1190	222	180	0 05	6 07	9.80	259
11	......	......	......	......	0.35	0.082	0.032	145	14	0.0454	0.2564	303	267	0 04	6 36	9.80	260
129	......	......	......	......	0.34	0.013	0.005	214	219	0.0070	0.0411	210	174	12 20	6 04	9.65	261
190	......	......	......	......	0.34	0.020	0.006	206	151	0.0102	0.0604	204	173	12 13	5 56	9.57	262
239	......	......	......	......	0.33	0.012	0.010	279	144	0.0042	0.0254	161	129	0 17	6 23	10.42	265
4	......	......	......	......	0.38	0.028	0.033	59	340	0.0077	0.0404	337	313	12 13	6 10	10.65	267
83	......	......	......	......	0.74	0.068	0.019	215	97	0.0141	0.0381	155	210	0 08	8 55	11.15	268
203	......	......	......	......	0.21	0.069	0.070	291	112	0.0020	0.0184	317	118	3 28	8 56	2.43	269
238	......	......	......	......	0.08	0.010	0.006	303	96	0.0001	0.0014	37	159	3 51	9 59	2.82	270
235	......	......	......	......	0.15	0.034	0.018	176	51	0.0006	0.0074	7	11	3 12	9 27	2.22	271
266	......	......	......	......	0.22	0.076	0.032	321	80	0.0020	0.0182	356	253	8 07	1 27	6.64	280
212	......	......	......	......	0.06	0.206	0.060	125	68	0.0004	0.0124	207	74	6 10	1 10	5.06	285
106	......	......	......	......	0.41	0.018	0.018	354	183	0.0005	0.0025	37	358	11 37	5 22	9.67	295
109	......	......	......	......	0.46	0.031	0.008	211	354	0.0105	0.0449	159	129	5 24	11 29	7.90	342
......	......	......	......	......	0.41	......	......	......	......	......	......	......	......	7 49	1 41	10.90	392
7	......	......	0.226	146	0.41	0.030	0.008	148	317	0.0461	0.2268	226	147	......	......	......	420
......	......	......	0.086	161	0.15	0.081	......	90	......	0.0066	0.0860	224	162	......	......	......	425
......	......	......	0.465	18	0.33	0.225	......	90	......	0.0772	0.4648	64	18	0 13	8 06	4.11	430
......	......	......	......	......	0.22	0.007	......	270	......	0.0020	0.0184	204	148	0 04	6 13	4.18	435
172	0.025	216	0.103	200	0.24	0.169	0.039	252	257	0.0128	0.1081	280	217	1 53	6 39	6.04	436
......	0.003	16	0.144	359	0.31	0.073	......	111	......	0.0152	0.0986	17	345	0 48	7 34	5.21	438
140	0.007	37	0.067	301	0.39	0.053	0.010	210	298	0.0117	0.0596	14	348	9 23	2 56	1.45	440
43	......	......	......	......	0.41	0.020	0.014	336	137	0.0090	0.0437	0	312	10 20	4 02	3.07	490

No.	Station	Geographic position			M_2	M_2^0		S_2	S_2^0	M_4	M_4^0	M_6
		Latitude	Longitude: Arc	Longitude: Time		Degrees	Lunar hours					
	OCEANICA	° ′	° ′	h. m.	*Ft.*	°	*h.*	*Ft.*	°	*Ft.*	°	
		North	*East*									
590	Boeloengan, Borneo	2 50	117 22	7 49	0.93	336	11.20	0.49	291	......	......	......
		South										
591	Samarinda, Borneo	0 30	117 08	7 49	1.39	209	6.97	0.86	261	0.076	113	......
593	Moera Djawa, Borneo	0 37	117 18	7 49	1.61	198	6.60	1.05	256	0.052	292	......
594	Bay of Balik Papan, Borneo	1 16	116 48	7 47	1.89	153	5.10	1.64	204	......	......	......
598	Macassar	5 08	119 24	7 58	0.27	70	2.33	0.36	194	......	......	......
600	Donggala	0 40	119 44	7 59	1.55	159	5.30	1.30	208	......	......	......
		North										
602	Tontoli	1 00	120 53	8 04	1.38	161	5.37	1.16	199	......	......	......
633	Maimbun	5 55	121 01	8 04	1.32	178	5.94	0.76	221	0.038	325	0.029
634	Iloilo, Point Gimalik	10 42	122 35	8 10	1.35	332.6	11.09	0.64	18	0.109	248	0.042
634.5	Cebu	10 18	123 54	8 16	1.37	334.3	11.14	0.75	22	0.014	73	0.005
635	Tacloban	11 15	125 00	8 20	0.53	220.6	7.35	0.13	269	0.066	355	0.045
635.5	Santa Elena	11 26	124 59	8 20	0.49	312.3	10.41	0.34	30	0.017	317	0.026
636	Santa Rita Island	11 26	124 57	8 20	1.18	347.8	11.59	0.76	50	0.042	39	0.025
636.5	Catbalogan	11 47	124 52	8 19	1.50	341.1	11.37	0.90	36	0.044	78	0.040
637	Calbayog	12 07	124 38	8 19	1.11	342.7	11.42	0.74	42	0.052	335	0.025
637.5	Halsey Harbor	11 48	119 57	8 00	0.78	311.1	10.37	0.33	4	0.028	239	0.013
640	Manila	14 36	120 57	8 04	0.72	310.2	10.34	0.30	29	0.016	347	0.010
641	Olongapo	14 49	120 17	8 01	0.56	292.9	9.76	0.20	325	0.002	114	0.009
642	Santa Cruz	15 46	119 54	8 00	0.38	271.0	9.03	0.06	324	0.032	341	0.013
643	Bolinao	16 24	119 56	8 00	0.32	278.3	9.28	0.12	306	0.020	357	0.028
644	Sual	16 04	120 06	8 00	0.29	275.9	9.20	0.09	311	0.018	348	0.018
645	Tabaco	13 22	123 44	8 15	1.75	174.7	5.82	0.77	199	0.035	222	0.004
			West									
660	Honolulu, Oahu Island	21 18	157 52	10 31	0.52	109.4	3.65	0.16	109	0.001	28	0.002
		South										
670	Apia, Upolu Island	13 46	171 44	11 27	1.26	186.0	6.20	0.29	184	......	......	......
			East									
675	Finschhafen	6 35	147 50	9 51	0.22	75.2	2.51	0.31	124	0.03	211	0.02
680	Port Russell, Bay of Islands	35 16	174 08	11 37	2.54	215.9	7.20	0.39	276	0.197	37	0.102
680.2	Auckland	36 51	174 48	11 39	3.78	204.8	6.83	0.63	265	0.20	74	0.10
680.5	Wellington	41 17	174 46	11 39	1.60	137.1	4.57	0.09	325	0.045	332	0.015
681	Port Chalmers	45 50	172 30	11 30	2.39	99.0	3.30	0.27	96	0.044	239	0.052
681.5	Port Darwin	12 23	130 37	8 42	6.56	144	4.80	3.44	193	0.013	279	0.006
682	Cooktown	15 27	145 15	9 41	1.87	282	9.40	0.79	258	......	......	......
682.5	Cairns Harbor	16 55	145 47	9 43	1.96	282	9.40	1.12	245	......	......	......
683	Brisbane Bar	27 31	153 00	10 12	2.20	290	9.67	0.58	315	......	......	......
683.5	Ballina	28 52	153 33	10 14	1.08	262	8.73	0.28	275	0.058	121	0.025
684	Newcastle	32 57	151 44	10 07	1.60	249	8.30	0.39	265	0.027	233	0.018
687	Melbourne (Williamstown)	37 53	144 55	9 40	0.81	69.4	2.31	0.10	164	0.021	49	......
689	Port Adelaide (Semaphore)	34 51	138 30	9 14	1.70	120.0	4.00	1.68	181	0.02	174	0.01
689.5	Princess Royal Harbor	35 08	118 00	7 52	0.16	339	11.30	0.26	342	0.005	16	0.002
690	Freemantle, Swan River Entrance	32 03	115 45	7 43	0.16	286.0	9.53	0.14	292	0.010	260	0.007
	INDIAN OCEAN.	*North*										
710	Mergui (Bay of Bengal)	12 26	98 36	6 34	5.50	310.0	10.33	2.92	349	0.120	133	0.072
720	Amherst, Moulmein River	16 05	97 34	6 30	6.32	67.3	2.24	2.71	102	0.324	43	0.131
722	Moulmein, Moulmein River	16 29	97 37	6 30	3.79	113.5	3.78	1.36	149	0.896	172	0.094
725	Elephant Point, Rangoon River	16 30	96 18	6 25	5.90	103.0	3.43	2 38	140	0.281	88	0.244
726	Rangoon, Rangoon River	16 46	96 10	6 25	5.78	131.4	4.38	2.09	170	0.432	170	0.220

M_6^0	S_4	S_4^0	MS	MS^0	$\frac{S_2}{M_2}$	$\frac{M_4}{M_2}$	$\frac{M_6}{M_2}$	$2M_2^0-M_4^0$	$3M_2^0-M_6^0$	$M_4\left(\frac{S_2}{M_2}\right)^2$ $(=S_4)$	$M_4\frac{2S_2}{M_2}$ $(=MS)$	$M_4^0+2S_2^0-2M_2^0$ $(=S_4^0)$	$M_4^0+S_2^0-M_2^0$ $(=MS^0)$	HWI	LWI	Co-tidal hour	No.
......	......	......	......	......	0.53	......	......	......	......	......	......	......	......	......	......	......	590
......	......	......	......	......	0.62	0.054	......	305	......	0.0289	0.0936	217	165	......	......	......	591
......	......	......	......	......	0.65	0.033	......	104	......	0.0223	0.0685	48	350	......	......	......	593
......	......	......	......	......	0.87	......	......	......	......	......	......	......	......	......	......	......	594
......	......	......	......	......	1.33	......	......	......	......	......	......	......	......	......	......	......	598
......	......	......	......	......	0.84	......	......	......	......	......	......	......	......	......	......	......	600
......	......	......	......	......	0.84	......	......	......	......	......	......	......	......	......	......	......	602
81	......	......	......	......	0.58	0.028	0.022	31	93	0.0124	0.0431	52	8	5 58	12 17	9.70	633
186	......	......	......	......	0.47	0.081	0.031	58	92	0.0245	0.1032	338	293	11 06	5 22	2.56	634
315	......	......	......	......	0.55	0.010	0.003	236	328	0.0404	0.0148	168	121	11 35	5 18	2.92	634.5
230	......	......	......	......	0.25	0.125	0.084	86	72	0.0040	0.0325	93	44	6 53	1 25	10.32	635
122	......	......	......	......	0.70	0.034	0.054	308	95	0.0081	0.0235	113	35	10 35	4 05	1.89	635.5
234	......	......	......	......	0.64	0.035	0.021	297	89	0.0173	0.0536	163	100	12 00	5 31	3.26	636
295	......	......	......	......	0.60	0.029	0.026	244	9	0.0159	0.0529	188	133	11 50	5 28	3.12	636.5
240	......	......	......	......	0.67	0.047	0.022	351	68	0.0230	0.0589	93	34	11 45	5 26	3.04	637
152	......	......	......	......	0.42	0.036	0.016	23	61	0.0050	0.0255	345	292	10 37	4 30	2.26	637.5
274	......	......	......	......	0.42	0.022	0.014	274	297	0.0028	0.0135	144	66	10 51	4 29	2.42	640
127	......	......	......	......	0.36	0.003	0.015	112	32	0.0002	0.0011	178	146	10 03	3 52	1.69	641
250	......	......	......	......	0.16	0.085	0.035	201	203	0.0008	0.0102	87	34	9 49	3 05	1.48	642
203	......	......	......	......	0.38	0.063	0.086	200	272	0.0028	0.0151	53	25	10 21	3 44	2.00	643
230	......	......	......	......	0.31	0.063	0.064	203	238	0.0018	0.0114	59	24	10 20	3 33	1.98	644
265	......	......	......	......	0.44	0.020	0.002	128	259	0.0069	0.0312	270	246	5 59	12 19	9.53	645
69	......	......	......	......	0.31	0.002	0.004	191	259	0.0001	0.0006	27	28	3 48	10 00	2.19	660*
......	......	......	......	......	0.23	......	......	......	......	......	......	......	......	6 25	0 12	5.65	670
222	0.01	272	......	......	1.41	0.136	0.091	299	4	0.0597	0.0085	309	260	2 47	8 32	4.84	675
62	......	......	......	......	0.15	0.078	0.040	35	226	0.0047	0.0607	157	97	7 26	1 55	7.56	680
67	......	......	......	......	0.17	0.053	0.026	336	187	0.0056	0.0668	195	134	7 11	0 44	7.29	680.2
135	......	......	......	......	0.06	0.028	0.009	302	277	0.0001	0.0051	348	160	4 52	10 54	5.05	680.5
334	......	......	......	......	0.11	0.018	0.022	319	323	0.0006	0.0100	233	236	3 31	9 39	3.90	681
167	......	......	......	......	0.52	0.002	0.010	9	265	0.0036	0.0136	377	328	......	......	......	681.5
......	......	......	......	......	0.42	......	......	......	......	......	......	......	......	9 44	3 31	11.72	682
......	......	......	......	......	0.57	......	......	......	......	......	......	......	......	9 44	3 31	11.69	682.5
......	......	......	......	......	0.26	......	......	......	......	......	......	......	......	10 00	3 48	11.46	683
133	0.003	246	0.043	199	0.26	0.054	0.023	43	293	0.0039	0.0302	147	134	9 02	3 07	10.49	683.5
74	0.006	289	0.062	252	0.24	0.017	0.011	265	313	0.0016	0.0132	265	249	8 42	2 22	10.29	684
......	......	......	......	......	0.12	......	......	90	......	0.0003	0.0052	238	144	......	......	......	687
259	0.03	186	0.09	99	0.99	0.012	0.006	66	101	0.0195	0.0396	296	234	4 04	10 22	6.70	689
227	0.012	204	0.015	268	1.62	0.031	0.012	302	70	0.0131	0.0162	22	19	11 43	5 18	3.45	689.5
277	0.004	72	......	......	0.88	0.062	0.044	312	221	0.0077	0.0175	272	266	......	......	......	690
237	0.044	233	0.157	176	0.53	0.022	0.013	127	333	0.0338	0.1274	211	172	......	......	......	710
252	0.095	114	0.318	75	0.43	0.051	0.021	92	310	0.0596	0.2780	112	78	......	......	......	720
204	0.068	228	0.708	213	0.36	0.236	0.025	55	137	0.1156	0.6433	243	208	......	......	......	722
336	0.084	176	0.291	127	0.40	0.048	0.041	118	333	0.0455	0.2265	162	125	......	......	......	725
86	0.084	259	0.404	212	0.36	0.075	0.038	93	309	0.0566	0.3128	247	208	4 26	11 07	9.87	726

12770—07——20

No.	Station	Geographic position: Latitude	Geographic position: Longitude, Arc	Geographic position: Longitude, Time	M_2	M_2^0 Degrees	M_2^0 Lunar hours	S_2	S_2^0	M_4	M_4^0	M_6
		° ′	° ′	h. m.	Ft.	°	h.	Ft.	°	Ft.	°	
	INDIAN OCEAN—continued	*North*	*East*									
735	Akyab	20 08	92 54	6 12	2.56	278.1	9.27	1.13	308	0.007	274	0.023
740	Chittagong	22 20	91 50	6 07	4.44	35.2	1.17	1.57	69	0.406	343	0.140
745	Dublat, Hoogly River	21 38	88 06	5 52	4.61	290.8	9.70	2.11	328	0.088	149	0.011
746	Diamond Harbor, Hoogly River	22 11	88 12	5 53	5.16	344.5	11.48	2.23	26	0.752	247	0.150
747	Calcutta (Kidderpore)	22 32	88 20	5 53	3.63	57.7	1.92	1.50	100	0.740	37	0.154
748	False Point	20 25	86 47	5 47	2.25	269	8.97	1.01	302	0.035	229	0.010
755	Vizagapatam	17 41	83 17	5 33	1.47	253.7	8.46	0.65	286	0.013	320	0.005
756	Cocanada	16 56	82 15	5 29	1.51	252.6	8.42	0.64	286	0.030	106	0.016
763	Madras	13 06	80 18	5 21	1.03	250.8	8.36	0.44	280	0.007	193	0.008
765	Negapatam	10 46	79 51	5 19	0.71	251.2	8.37	0.27	283	0.022	79	0.011
770	Pamban Pass, Rāmesvaram Island	9 16	79 12	5 17	0.58	47.2	1.57	0.37	92	0.016	194	0.010
772	Tuticorin	8 48	78 09	5 13	0.66	43.4	1.45	0.47	84	0.025	156	0.015
773	Trincomalee Ceylon	8 33	81 13	5 25	0.58	241.0	8.03	0.20	265	0.012	224	0.005
775	Point de Galle, Ceylon	6 02	80 13	5 21	0.53	56.9	1.90	0.36	94	0.012	164	0.003
776	Colombo, Ceylon	6 57	79 51	5 19	0.58	49.9	1.66	0.39	95	0.016	170	0.004
780	Port Blair, Andaman Islands	11 41	92 45	6 11	2.00	280.0	9.33	0.96	316	0.011	132	0.004
785	Cochin	9 58	76 15	5 05	0.73	332.1	11.07	0.26	29	0.026	75	0.009
787	Beypore	11 10	75 48	5 03	0.94	328.3	10.94	0.33	17	0.021	38	0.008
793	Kárwár	14 48	74 06	4 56	1.74	301.8	10.06	0.62	335	0.055	17	0.011
795	Goa or Mormugõa	15 25	73 48	4 55	1.81	300.2	10.01	0.64	332	0.047	6	0.011
800	Bombay	18 55	72 50	4 51	4.04	330.3	11.01	1.61	4	0.130	329	0.010
802	Bhávnagar	21 48	72 09	4 49	10.9	134.2	4.47	3.47	176	0.894	152	0.239
805	Port Albert Victor	20 58	71 33	4 46	2.88	58.3	1.94	1.13	82.8	0.212	176	0.126
807	Porbándar	21 37	69 37	4 38	2.13	292.8	9.76	0.78	323.6	0.033	124	0.029
809	Okha Point and Bet Harbor	22 28	69 05	4 36	3.82	347	11.57	1.22	14	0.136	107	0.007
810	Navanar	22 44	69 43	4 39	6.04	24.4	0.81	1.89	55	0.109	273	0.065
811	Hanstal	22 56	70 21	4 41	6.85	45.6	1.52	1.93	85	0.727	330	0.305
815	Karachi	24 48	66 58	4 28	2.54	293.7	9.79	0.95	323	0.028	7	0.048
820	Minikoi Light	8 17	73 03	4 52	0.86	329.4	10.98	0.35	20	0.009	67	0.002
825	Bushire	29 00	50 52	3 23	1.06	211.1	7.04	0.39	261.9	0.025	337	0.008
830	Maskat	23 37	58 35	3 54	2.07	276.2	9.21	0.78	306	0.006	65	0.006
840	Aden	12 47	44 59	3 00	1.57	226.5	7.55	0.69	246	0.006	313	0.005
845	Suez	29 56	32 33	2 10	1.84	342.5	11.42	0.46	8	0.029	127	0.010
850	Perim	12 38	43 24	2 54	1.20	226.4	7.55	0.56	243	0.024	13	0.006
		South										
870	Port Louis, Mauritius Island	20 08	57 29	3 50	0.43	23	0.77	0.33	26	0.004	296	0.005
880	Betsy Cove, Kerguelen Island	49 09	70 12	4 41	1.42	9	0.30	0.80	52	0.03	289	......
890	Durban, Port Natal	29 53	31 04	2 04	1.72	115	3.83	0.95	150	......	......	......
	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	0.039	96	0.013
		North										
908	Duala (Kamerun) Africa	4 03	9 40	0 39	2.45	156.3	5.21	0.81	195	0.236	139	0.062
923	Valetta Harbor, Malta	35 55	14 30	0 58	0.20	93	3.10	0.12	100	0.003	350	0.001
925	Toulon	43 07	5 56	0 24	0.20	246	8.20	0.09	250	0.014	352	0.001
926	Marseilles	43 18	5 23	0 22	0.22	228	7.60	0.08	247	0.019	0	......
			West									
932	Lisbon	38 41	9 06	0 36	3.83	59.1	1.97	1.50	83	0.233	196	0.032
938	Socoa	43 24	1 40	0 07	4.37	89.1	2.97	1.56	121	0.097	323	0.017

M_6^0	S_4	S_4^0	MS	MS^0	$\frac{S_2}{M_2}$	$\frac{M_4}{M_2}$	$\frac{M_6}{M_2}$	$2M_2^0-M_4^0$	$3M_2^0-M_6^0$	$M_4\left(\frac{S_2}{M_2}\right)^2$ $(=S_4)$	$M_4\frac{2S_2}{M_2}$ $(=MS)$	$M_4^0+2S_2^0-2M_2^0$ $(=S_4^0)$	$M_4^0+S_2^0-M_2^0$ $(=MS^0)$	HWI	LWI	Co-tidal hour	No.
123	0.007	196	0.014	274	0.44	0.003	0.009	282	352	0.0014	0.0062	334	304	......	......	......	735
190	0.055	61	0.346	23	0.35	0.091	0.032	87	275	0.0508	0.2874	51	17	......	......	......	740
221	0.016	223	0.074	170	0.46	0.019	0.002	73	291	0.0185	0.0806	223	186	......	......	......	745
108	0.123	327	0.706	287	0.43	0.146	0.029	82	206	0.1414	0.6512	330	289	......	......	......	746
322	0.092	113	0.673	80	0.41	0.204	0.042	78	211	0.1265	0.6127	122	79	1 14	9 40	7.31	747
78	0.008	320	0.040	268	0.45	0.016	0.004	309	9	0.0071	0.0314	295	262	......	......	......	748
69	0.004	50	0.011	356	0.44	0.009	0.003	187	332	0.0025	0.0115	25	352	......	......	......	755
97	0.006	134	0.022	136	0.42	0.020	0.011	39	301	0.0054	0.0254	173	139	......	......	......	756
157	0.002	233	0.006	254	0.43	0.007	0.008	309	236	0.0013	0.0060	252	222	8 35	2 26	2.94	763
130	0.005	135	0.019	99	0.38	0.031	0.016	63	264	0.0032	0.0167	143	111	......	......	......	765
42	0.003	261	0.018	292	0.64	0.028	0.017	260	100	0.0065	0.0205	284	239	......	......	......	770
19	0.006	234	0.012	258	0.71	0.038	0.023	290	111	0.0127	0.0355	238	197	......	......	......	772
112	0.006	217	0.011	242	0.35	0.021	0.009	258	251	0.0014	0.0083	272	248	......	......	......	773
341	0.003	235	0.007	255	0.68	0.023	0.006	310	190	0.0055	0.0163	238	201	......	......	......	775
27	0.005	236	0.009	253	0.67	0.028	0.007	289	123	0.0072	0.0214	261	215	1 47	7 47	8.41	776
116	0.004	358	0.012	229	0.48	0.006	0.002	68	4	0.0025	0.0106	204	168	......	......	......	780
87	0.006	175	0.020	140	0.36	0.036	0.012	229	190	0.0033	0.0185	189	132	......	......	......	785
133	0.005	135	0.010	74	0.35	0.022	0.008	258	132	0.0026	0.0147	136	87	......	......	......	787
224	0.010	98	0.026	67	0.36	0.032	0.006	227	322	0.0070	0.0393	83	50	......	......	......	793
249	0.009	92	0.024	48	0.35	0.026	0.006	234	291	0.0059	0.0333	70	38	......	......	......	795
86	0.012	256	0.138	30	0.40	0.032	0.002	332	185	0.0207	0.1040	36	3	11 27	5 07	6.21	800
125	0.121	235	0.661	196	0.32	0.082	0.022	117	278	0.0902	0.5686	235	194	......	......	......	802
129	0.025	266	0.158	213	0.39	0.074	0.044	301	46	0.0326	0.1666	225	200	......	......	......	805
307	0.004	277	0.028	204	0.37	0.016	0.014	102	211	0.0044	0.0242	186	155	......	......	......	807
270	0.013	117	0.064	111	0.32	0.036	0.002	227	51	0.0137	0.0868	161	134	......	......	......	809
41	0.013	360	......	......	0.31	0.018	0.011	136	32	0.0107	0.0682	334	304	0 46	7 04	8.09	810
246	0.021	62	0.351	12	0.28	0.106	0.044	122	251	0.0578	0.4100	48	9	1 24	8 20	8.67	811
206	0.010	20	0.031	320	0.37	0.011	0.019	221	315	0.0039	0.0209	65	36	10 14	3 58	5.42	815
64	0.003	87	0.007	49	0.41	0.010	0.002	232	204	0.0015	0.0073	168	117	......	......	......	820
330	0.007	104	0.027	34	0.37	0.024	0.008	85	304	0.0034	0.0184	78	28	......	......	......	825
24	0.004	333	0.014	305	0.38	0.003	0.003	127	85	0.0009	0.0045	125	95	......	......	......	830
342	0.005	283	0.017	157	0.44	0.004	0.003	140	338	0.0010	0.0048	352	333	7 48	1 37	4.54	840
66	0.004	171	0.016	158	0.25	0.016	0.005	198	241	0.0018	0.0146	178	152	......	......	......	845
2	0.005	328	0.016	83	0.47	0.020	0.005	79	318	0.0052	0.0224	47	30	......	......	......	850
94	0.003	116	......	......	0.77	0.009	0.012	110	335	0.0024	0.0061	302	299	......	......	......	870
......	......	......	......	......	0.56	0.021	......	89	......	0.0095	0.0339	15	332	......	......	......	880
......	0.02	70	......	......	0.55	0.0	......	......	......	......	......	......	......	......	......	......	890
296	......	......	......	......	0.42	0.024	0.008	353	198	0.0069	0.0327	183	140	1 34	7 45	0.28	900
127	......	......	......	......	0.33	0.096	0.025	173	342	0.0260	0.1562	217	178	5 24	11 40	4.57	908
26	0.001	37	......	......	0.60	0.015	0.005	196	253	0.0011	0.0036	364	357	......	......	......	923
145	0.002	288	......	......	0.45	0.070	0.005	140	233	0.0028	0.0126	0	356	......	......	......	925
......	0.003	277	......	......	0.36	0.086	......	96	......	0.0025	0.0138	38	19	......	......	......	926
284	......	......	0.195	228	0.39	0.061	0.008	282	254	0.0359	0.1827	244	220	2 04	7 46	2.60	932
112	0.004	92	0.174	67	0.36	0.022	0.004	215	155	0.0124	0.0695	27	355	3 07	9 14	3.13	938

No.	Station	Geographic position: Latitude	Geographic position: Longitude, Arc	Geographic position: Longitude, Time	M_2	M_2^0: Degrees	M_2^0: Lunar hours	S_2	S_2^0	M_4	M_4^0	M_6
	WEST COAST OF AFRICA AND EUROPE—continued	° ′	° ′	*h. m.*	*Ft.*	°	*h.*	*Ft.*	°	*Ft.*	°	
		North	*West*									
942	Boyard	46 00	1 13	0 05	5.82	92.3	3.08	2.11	126	0.915	356	0.080
943	Rochelle	46 09	1 09	0 05	5.72	92.3	3.08	2.03	126	0.804	2	0.088
944	Saint Nazaire	47 16	2 12	0 09	5.67	101	3.37	1.98	136	0.518	43	0.079
946	Brest	48 23	4 29	0 18	6.76	99.2	3.31	2.47	139	0.182	85	0.116
948	St. Malo	48 39	2 02	0 08	12.45	173.7	5.79	4.80	225	0.855	271	0.069
950	Cherbourg	49 39	1 37	0 06	6.16	225.3	7.51	2.26	269	0.450	345	0.081
			East									
952	Havre	49 29	0 06	0 00	8.74	285.5	9.52	2.89	333	0.786	85	0.574
			West									
954	Edinburgh	55 59	3 10	0 13	5.94	48.5	1.62	2.00	88	0.231	178	0.243
956	West Hartlepool	54 41	1 12	0 05	5.16	95.9	3.26	1.74	137	0.095	104	0.074
957	Hull	53 44	0 20	0 01	7.56	175.8	5.86	2.34	228	0.345	253	0.164
			East									
958	Sheerness	51 27	0 45	0 03	6.30	0.5	0.02	1.75	56	0.296	44	0.199
			West									
960	London Bridge	51 30	0 07	0 00	8.31	55.0	1.83	1.64	110	0.821	20	......
			East									
962	Ramsgate	51 20	1 25	0 06	6.14	343.7	11.46	1.88	36	0.548	248	0.164
964	Dover	51 07	1 19	0 05	7.20	336.1	11.20	2.07	28	0.743	229	0.173
			West									
966	Portland Breakwater	50 34	2 25	0 10	2.05	189.4	6.31	1.07	239	0.468	23	0.206
968	Pembroke	51 41	4 56	0 20	8.18	166.0	5.53	2.66	205	0.123	242	......
970	Helbre Island, Mersey River	53 22	3 18	0 13	9.76	312.9	10.43	3.13	356	0.479	200	0.070
971	Liverpool, Mersey River	53 24	3 00	0 12	9.98	320.7	10.69	3.16	6	0.691	211	0.196
978	Greenock	55 57	4 45	0 19	4.36	337	11.23	1.04	42	0.346	44	......
			East									
982	Ostende	51 14	2 55	0 12	5.92	12.3	0.41	1.80	64	0.364	345	0.232
982.2	Noord-Hinder, Light Ship	51 35	2 37	0 10	3.94	12.6	0.42	1.19	51	0.308	122	......
982.5	Schonwenbank, Light Ship	51 47	3 27	0 14	2.93	36.6	1.22	0.87	82	0.462	148	......
983	Hook of Holland	51 59	4 09	0 7	2.54	72	2.40	0.65	131	0.558	134	0.115
983.2	Maas, Light Ship	52 01	3 54	0 16	2.37	76.3	2.54	0.51	122	0.394	165	......
984	Ymuiden	52 28	4 34	0 18	2.20	113	3.77	0.58	180	0.620	154	0.177
984.8	Haaks, Light Ship	52 58	4 18	0 17	2.19	179.8	3.99	0.46	228	0.118	253	......
985	Helder	52 58	4 46	0 19	1.74	171	5.70	0.50	238	0.367	191	0.190
985.5	Terschellingerbank, Light Ship	53 27	4 52	0 19	2.81	213.0	7.10	0.68	257	0.295	308	.....
986	Wilhelmshaven, Jade River	53 31	8 09	0 33	5.34	358.4	11.95	1.35	71	0.299	178	0.184
987	Rothen Sande	53 51	8 05	0 32	4.00	338.5	11.28	1.09	53	0.199	191	0.120
990	Helgoland Island	54 11	7 53	0 32	3.18	334.8	11.16	0.83	40	0.218	189	0.063
995	Copenhagen, Baltic Sea	55 42	12 36	0 50	0.20	277	9.23	0.09	249	......	......	......
1000	Christiania	59 55	10 44	0 43	0.37	128	4.27	0.12	88	0.062	6	0.023
1001	Oscarsborg	59 41	10 37	0 42	0.47	129	4.30	0.16	90	0.072	3	0.026
1002	Arendal	58 27	8 46	0 35	0.28	100	3.33	0.09	68	......	......	......
1003	Stavanger	58 59	5 44	0 23	0.48	282.5	9.42	0.22	332	0.033	252	0.049
1004	Bergen	60 24	5 08	0 21	1.44	297.5	9.92	0.52	334	......	......	......
1006	Bodoe	67 17	14 23	0 58	2.84	356.5	11.88	0.98	35	0.162	292	......
1007	Fineide	67 17	15 30	1 02	1.74	57.0	1.90	0.50	106	0.039	61	0.039
1008	Kabelvaag	68 13	14 30	0 58	2.98	3.5	0.12	1.08	44	0.141	323	......
1011	Vardoe	70 20	31 06	2 04	3.29	163.5	5.45	0.92	208	0.039	202	......

M_6^0	S_4	S_4^0	MS	MS^0	$\frac{S_2}{M_2}$	$\frac{M_4}{M_2}$	$\frac{M_6}{M_2}$	$2M_2^0-M_4^0$	$3M_2^0-M_6^0$	$M_4\left(\frac{S_2}{M_2}\right)^2$ $(=S_4)$	$M_4\frac{2S_2}{M_2}$ $(=MS)$	$M_4^0+2S_2^0-2M_2^0$ $(=S_4^0)$	$M_4^0+S_2^0-M_2^0$ $(=MS^0)$	HWI	LWI	Co-tidal hour	No.
309	0.029	247	0.555	82	0.37	0.157	0.014	189	328	0.1198	0.6625	63	30	3 27	9 22	3.42	942
316	0.043	259	0.513	88	0.35	0.141	0.015	183	321	0.1005	0.5692	69	36	3 23	9 26	3.35	943
50	0.027	268	0.384	122	0.35	0.091	0.014	159	253	0.0632	0.3616	113	78	.....	.....	.....	944
325	0.005	301	0.264	107	0.37	0.027	0.017	114	333	0.0242	0.1327	164	124	3 23	9 45	3.57	946
3	0.006	90	0.257	321	0.39	0.069	0.006	76	158	0.1274	0.6601	14	323	5 43	0 04	5.66	948
91	1.838	74	0.078	60	0.37	0.073	0.013	106	224	0.0606	0.3303	72	29	7 30	1 54	7.35	950
301	0.006	227	0.407	170	0.33	0.090	0.066	126	195	0.0865	0.5202	180	132	9 03	4 14	8.74	952
284	.....	.....	.....	.....	0.34	0.039	0.041	279	221	0.0263	0.1555	257	218	2 05	7 54	2.23	954
43	0.022	174	0.044	122	0.34	0.018	0.014	88	245	0.0108	0.0642	186	145	3 19	9 41	3.29	956
211	.....	.....	.....	.....	0.31	0.046	0.022	99	316	0.0329	0.2132	357	305	5 59	0 05	5.80	957
60	.....	.....	.....	.....	0.28	0.047	0.032	317	301	0.0230	0.1652	155	99	0 14	6 16	0.18	958
.....	.....	.....	.....	.....	0.20	0.099	.....	90	.....	0.0277	0.3235	130	75	1 31	8 30	1.46	960
135	0.032	9	0.324	132	0.31	0.089	0.027	79	176	0.0513	0.3354	353	301	11 26	6 07	10.95	962
102	.....	.....	0.450	290	0.29	0.103	0.024	83	187	0.0616	0.4280	333	281	11 08	5 56	10.67	964
55	0.012	176	0.267	81	0.52	0.228	0.100	356	153	0.1278	0.4886	122	73	6 21	13 13	6.30	966
.....	.....	.....	.....	.....	0.33	0.015	.....	90	.....	0.0130	0.0800	320	281	.....	.....	.....	968
15	0.030	298	0.280	254	0.32	0.049	0.007	66	204	0.0493	0.3075	286	243	10 37	4 47	10.47	970
331	0.057	302	0.406	258	0.32	0.069	0.020	71	271	0.0690	0.4367	301	256	10 56	5 16	10.76	971
.....	.....	.....	.....	.....	0.24	0.079	.....	270	.....	0.0198	0.1654	174	109	11 44	5 18	11.65	978
315	.....	.....	0.234	53	0.30	0.062	0.039	39	82	0.0339	0.2220	89	37	0 07	6 33	11.91	982
.....	.....	.....	.....	.....	0.30	0.078	.....	264	.....	0.0281	0.1860	198	160	.....	.....	.....	982.2
.....	.....	.....	.....	.....	0.30	0.158	.....	285	.....	0.0407	0.2744	238	193	.....	.....	.....	982.5
74	0.039	265	0.312	176	0.26	0.220	0.045	10	142	0.0365	0.2857	252	193	2 17	8 46	1.92	983
.....	.....	.....	.....	.....	0.22	0.166	.....	347	.....	0.0182	0.1694	256	211	.....	.....	.....	983.2
241	0.023	293	0.338	204	0.26	0.282	0.080	72	98	0.0432	0.3274	288	221	2 48	11 04	2.40	984
.....	.....	.....	.....	.....	0.21	0.054	.....	107	.....	0.0052	0.0498	348	300	.....	.....	.....	984.8
293	0.013	353	0.203	236	0.29	0.211	0.109	151	220	0.0302	0.2107	325	258	5 52	0 29	5.35	985
.....	.....	.....	.....	.....	0.24	0.105	.....	118	.....	0.0173	0.1428	36	352	.....	.....	.....	985.5
30	0.026	51	0.242	274	0.25	0.056	0.034	179	325	0.0191	0.1513	323	251	0 03	6 14	11.50	986
15	0.017	97	0.115	244	0.27	0.050	0.030	126	280	0.0147	0.1083	340	266	.....	.....	.....	987
334	.....	.....	0.124	239	0.26	0.069	0.020	121	310	0.0148	0.1138	319	254	11 24	5 36	10.48	990
.....	.....	.....	.....	.....	0.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	995
75	.....	.....	0.039	101	0.32	0.168	0.062	250*	309	0.0066	0.0403	286	326	.....	.....	.....	1000
75	.....	.....	0.033	109	0.34	0.153	0.055	255	312	0.0083	0.0490	285	324	.....	.....	.....	1001
.....	.....	.....	.....	.....	0.32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1002
93	.....	.....	0.030	317	0.46	0.069	0.102	313	34	0.0069	0.0302	351	302	.....	.....	.....	1003
.....	.....	.....	0.377	318	0.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1004
.....	.....	.....	0.139	346	0.35	0.057	.....	60	.....	0.0193	0.1118	10	331	.....	.....	.....	1006
179	.....	.....	0.061	62	0.29	0.022	0.022	53	352	0.0032	0.0224	159	110	.....	.....	.....	1007
.....	.....	.....	0.154	28	0.36	0.047	.....	44	.....	0.0185	0.1021	44	4	.....	.....	.....	1008
.....	.....	.....	0.094	173	0.28	0.012	.....	125	.....	0.0031	0.0218	291	246	.....	.....	.....	1011

35. *Stations whose* M_4 *is due chiefly to propagation in shallow waters.*

The shallow waters are usually tidal rivers. The surmise that M_4 is due to propagation is confirmed by the fact that at places along their shores $2\ M_2^\circ - M_4^\circ \doteq 90^\circ$. At the following places this difference from 90° does not exceed 30° and is generally much less:

(32) Quebec, (40) Halifax, (44) Eastport, (66) Willets Point, (77) Philadelphia, (90) Washington, (98) Wilmington, (256) Pete Dahl Slough, (280) St. Michael, (425) Tientsin Entrance, (430) Shanghai, Wusung Bar, (438) Whampoa, (593) Moera-Djawa, Borneo, (635) Tacloban, (687) Melbourne (Williamstown), (689) Port Adelaide, (720) Amherst, Moulmien River, (725) Elephant Point, Rangoon River, (726) Rangoon, (740) Chittagong, (745) Dublat, Hoogly River, (746) Diamond Harbor, Hoogly River, (747) Calcutta (Kidderpore), (765) Negapatam, (802) Bhávnagar, (807) Porbandar, (825) Bushire, (850) Perim, (880) Betsy Cove, Kerguelen Island, (926) Marseilles, (946) Brest, (948) St. Malo, (950) Cherbourg, (956) West Hartlepool, (953) Hull, (960) London Bridge, (962) Ramsgate, (964) Dover, (968) Pembroke, (970) Helbre Island, Mersey River, (971) Liverpool, (984) Ymuiden, (984.8) Haaks Light Ship, (985.5) Terschellingerbank Light Ship.

In a few of these cases, the M_4 may be of a less obvious origin, and where it is very small the value of M_4° given in the table may be unreliable.

36. *Stations whose* M_4 *is due chiefly to a stationary wave.*

By section 29 the values of M_2° and M_4° should in a short canal closed at one end approximately satisfy the relation $2\ M_2^\circ - M_4^\circ = 180^\circ$. At the following places this relation is always satisfied to within 30° and generally much less. In many cases the stationary wave is the shallow marginal strip of the sea.

(101) Charleston, (105) Fernandina, (210) Panama, (251.5) Hooniah, (252.5) Granite Cove, (262) Valdez Arm, (271) Kaskega Bay, (440) Hongkong, (642) Santa Cruz, (643) Bolinao, (644) Sual, (660) Honolulu, (755) Vizagapatam, (845) Suez, (908) Duala (Kamerun), (942) Boyard, (943) Rochelle, (944) St. Nazaire, (986) Wilhelmshaven.

It will be seen from the table that, as might be expected, many stations are intermediate between these two cases: e. g., New York and Savannah; Hanstal Point, at the head of the Gulf of Kutch.

37. *Stations whose* M_4 *is due to a truncated low water.*

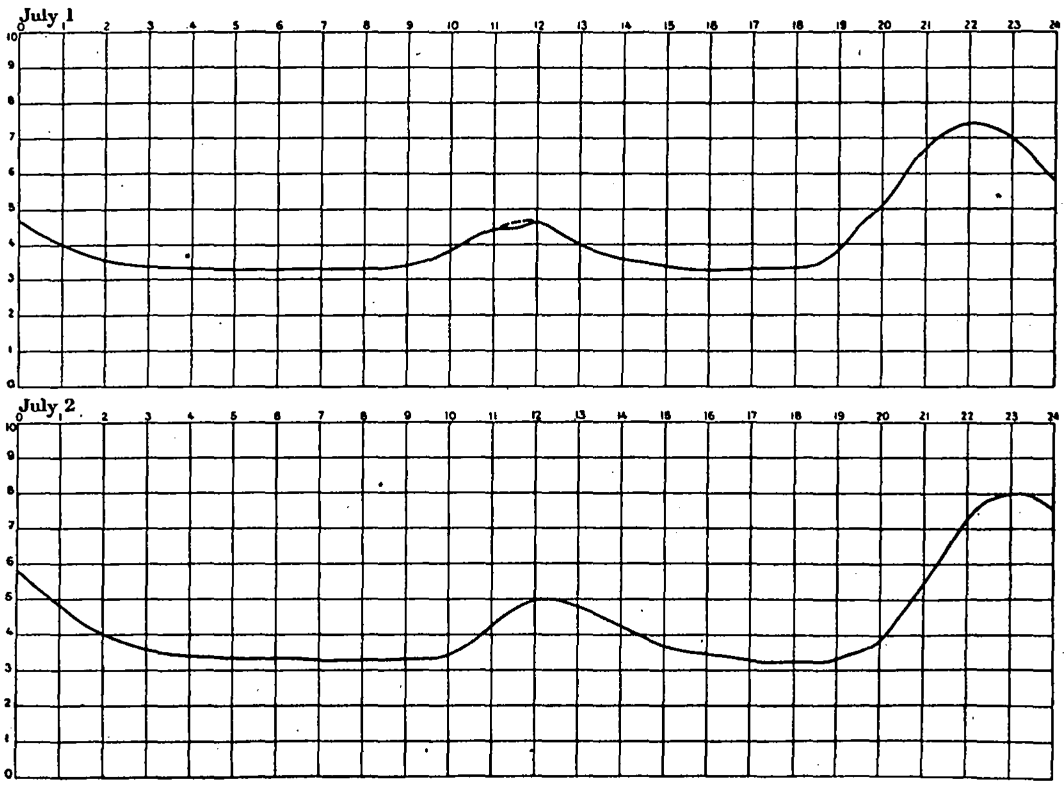
If the low waters are to be flattened while the high waters are undisturbed, it is evident that M_2° and M_4° should approximately satisfy the relation $2\ M_2^\circ - M_4^\circ = 0$.

The occurrence of truncated low waters must be rare. Kokinhenic Island, Copper River Delta, (latitude 60° 18'.1 N., longitude 145° 03' W.), is situated among extensive flats. At low water there is apparently little or no connection with the outside waters, for tides were there observed night and day during a period of two weeks (June 27 to July 11, 1898), by H. P. Ritter's hydrographic party, and the greatest variation in the height of low water during this time was less than 0.8 foot, notwithstanding the large low-water inequality along the outer coast (Fig. 2). See tables of harmonic constants given under section 19, Part IV B, and section 34, Part V. The truncated low waters should cause a large M_4, whose epoch expressed in time should approximately agree with that of M_2. Under No. 255, section 34, it is seen that $2\ M_2^\circ - M_4^\circ = 11^\circ$, and that $M_4/M_2 = 0.284$.

38. *Stations where* M_4 *is due to displacement of level due to currents rounding a point.*

From section 12, Part IV A, it appears that if a current rounds a cape and so causes the particles to describe arcs of concentric circles with equal angular velocities as seen from the common center, the amount of transverse tilting resulting therefrom will vary as the square of the velocity of the stream. Hence the outer threads of a stream harmonic in time will produce a sharpened elevatiou at the time of the maximum velocity; and at the same time the inner threads will produce a similar depression. $\therefore$ M_4 has its maximum or minimum at the time when the stream is swiftest. If the time of

No. 2.



Tide curve, Kokinhenic Island.

high water agree with the time of greatest flood velocity, then at the outer side of the curved stream $2\,M_2^\circ - M_4^\circ = 0$ and at the inner side $2\,M_2^\circ - M_4^\circ = 180^\circ$.

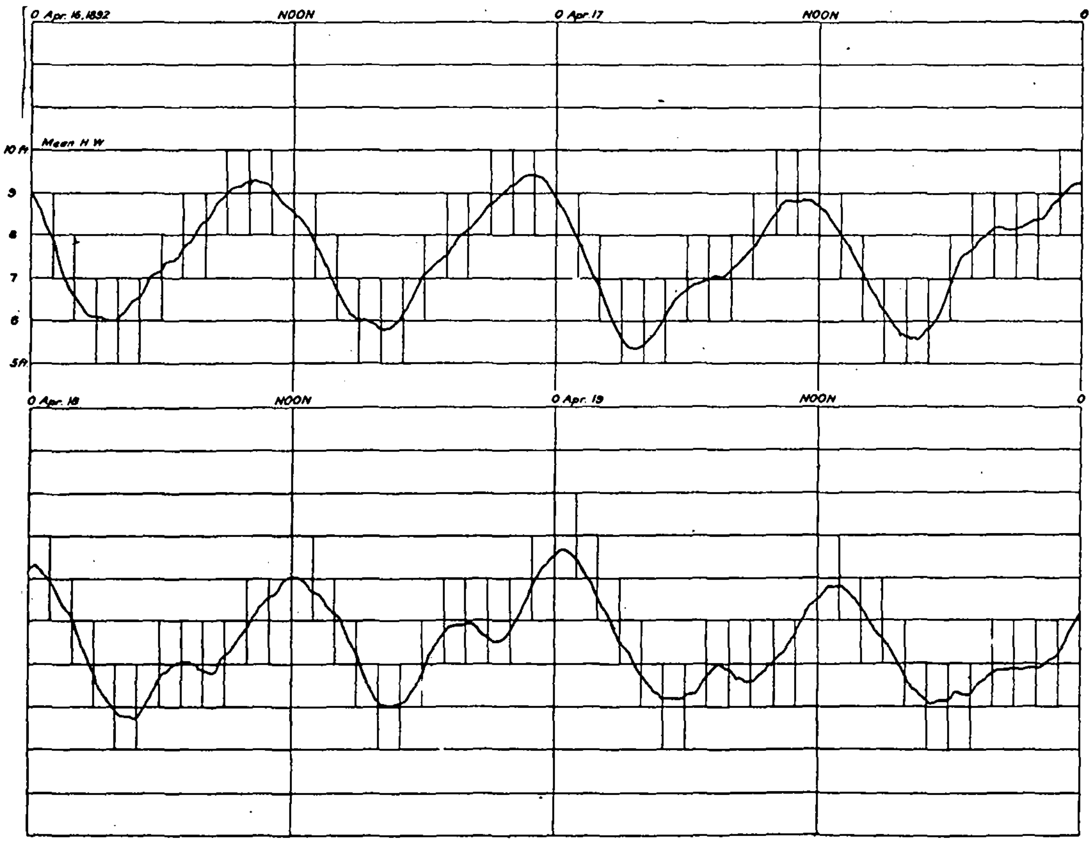
Off Victoria, Vancouver Island, the greatest maximum flood velocity occurs near the time of high water; being on the inner edge of the stream, $2\,M_2^\circ - M_4^\circ$ should lie near 180°. Observation makes this out to be 181°.

39. *Stations where the duration of rise exceeds the duration of fall.*

For tides of this character the relation $2\,M_2^\circ - M_4^\circ = 270^\circ$ should be approximately satisfied. The M_4 in such cases seems generally to be due, in some way not easily explained, to the fact that the station is situated either upon a strait or at or near the head of a bay or estuary. At the following stations this condition is satisfied to within 30 degrees or less:

(85) Old Point Comfort, (113) Key West, (114) Tortugas Harbor, (129) Biloxi, (145) Vera Cruz, (184) Montevideo, (186) Buenos Ayres, (224) Fort Point, (225) Sausalito, (230) Port Townsend, (246) Seymour Narrows, (265) Kodiak, (267) Unalga Bay, (435) Amoy, (436) Swatow, (636) Santa Rita I., (636.5) Catbalogan, (640) Manila, (675) Fenschhafen, (684) Newcastle, (735) Akyab, (770) Pamban Pass,

No. 3.



Tide curve, Providence.

(772) Tuticorin, (773) Trincomalee, (776) Colombo, (787) Beypore, (932) Lisbon, (954) Edinburgh, (978) Greenock, (982.2) Noord-Hinder Light Ship, (982.5) Schouwenbank Light Ship, (1000) Christiania, (1001) Oscarsborg.

40. *Stations whose* M_4 *is chiefly due to a fractional oscillating area.*

If the length of the arm of water upon which a station is situated approach $\frac{1}{4}\lambda$, where λ denotes the length of the M_4-wave, and if the water lying outside of this arm be shallow for some distance, then the M_4 will be unusually large at the station. According to section 34, Part IV A, one would expect that the phase of the M_4 tide in the arm of water should, in the critical case, be one-fourth of a period behind that of the M_4 tide outside. This, however, necessitates that shoal water exist at the outer end of the arm of water, in order that an inward progression shall arise. If everything is practically stationary immediately outside, then the arm will be in the same or in the opposite phase to the outside water according as its length is less or greater than $\frac{1}{4}\lambda$.

Consider Newport, Bristol, and Providence, upon Narragansett Bay. By the table M_4=0.18, 0.29, 0.34 foot. M_4°=120°, 134°, 150°, and $2\ M_2^\circ - M_4^\circ$=315°, 310°, 307°, respectively.

If a body of water symmetrical to Narragansett Bay were located to the south and joined the latter along an east-and-west line across the mouth, the period of free oscillation of the body composed of these two would, on account of the narrowness of the connecting passes, be very nearly 6 hours. But, as there is little progression in the locality of the mouth of the bay, the stationary wave will extend some distance seaward, and so be somewhat more than $\frac{1}{4}\lambda$ long. The phase of the M_4 oscillation in the bay will therefore be 180° different from its phase outside. Also, $2M_2^\circ - M_4^\circ$ should, because of the stationary character of the M_2 wave, be approximately 180° different in the bay from the corresponding value outside. Observations at Newport give $2\ M_2^\circ - M_4^\circ$=315°, and so the inferred outside value is 315°−180°=135°. This value seems reasonable, as it lies between the value for a progressive and stationary wave; and such is the character of the tide between Narragansett Bay and deep ocean water. Because of the critical length of the bay, a small M_4 outside will cause a large M_4 at Providence.

The values of $2\ M_2^\circ - M_4^\circ$ in the bay indicates that the duration of rise must exceed that of fall; also, that there is a tendency to a double low water, which becomes conspicuous at Providence. (See Fig. 3.)

At Portland Breakwater, England, the value of $2M_2^\circ - M_4^\circ$ is 356°, a value very favorable for double low waters. The cause of this peculiarity is not easily ascertained.*

41. *Stations where an apparent* M_6 *arises from want of free communication betwee the float box and outside water; or a real* M_6 *in a nearly inclosed harbor.*

As noted in section 9, Part IV A, an imperfect flow into and out of the float box will give rise to an M_6 whose epoch is connected with that of M_2 by the relation $3\ M_2^\circ - M_6^\circ = 0$.

Upon looking over the table it will be seen that at few if any stations is there a large M_6 whose epoch is such that the above relation is satisfied. Consequently it seems fair to conclude that the observations upon which these values are based were so carried on as to be practically free from such errors as would result from too restricted openings through the walls of the float box.

No analyses giving M_6 are available for harbors having very narrow openings. Probably this sharpening of the high and low waters on the marigram at Melbourne, Port Phillip, could be shown to exist if the M-sums were analyzed for M_6.

It will be noticed that those places given in the table where this relation is approximately satisfied, are in many instances land-locked harbors. It seems probable that this topographic feature explains the M_6 at such places.

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* For a tide curve at this place, see Plate 26, Eruption of Krakatoa and subsequent Phenomena.

42. *Stations where* M_6 *is due to the hydraulic effect in a strait connecting two tidal bodies.*

According to Section 37, Part I, the current curve for the strait has its maxima and minima flattened and so the duration of slack lessened, i. e., $3\dot{M}_2^0 - \dot{M}_6^0 = 180°$.

While it is assumed that the tides some distance from either end of the strait are not affected by the current and tide in the strait, a like assumption does not apply to the waters just off its ends.

Suppose the case of a short strait having a large stationary tide wave off one end. At about the time of its low water the current of the strait will be at its strength in that direction. This velocity will be greatly diminished upon leaving the strait because of the sudden enlargement of cross section of the stream. Whatever tide is thus made will occur at about the time of the slackening of the stream in this direction. This corresponds to the case of a small opening into a float box, Fig. 7, Part IV A (see also case just described). Hence the considerable sharpening of the $\overline{M}_2$ tide curve where the strait joins the larger body.

$\therefore\ 3\overline{M}_2^0 - M_6^0 = 0$ where $\overline{M}_2$ denotes the tide due to the strait. Also, $\overline{M}_2^0 = \dot{M}_2^0 + 90°$ where $\dot{M}_2^0$ refers to the current going toward the stationary wave.

$\therefore\ M_6^0 = 3\ (\dot{M}_2^0 + 90°) = 3\dot{M}_2^0 - 90°$.

East River joins Long Island Sound at Willets Point. The western end of the sound is largely surrounded by land, and so is influenced by the Hell Gate tide. Moreover, it is approximately low water in the western end of the sound at the time of maximum eastward velocity in East River. From Fig. 11 it is readily seen that for the eastern portion of East River $\dot{M}_2^0 = 6 \times 30° = 180°$. The relation $M_6^0 = 3\ \dot{M}_2^0 - 90°$ gives $M_6^0 = 90°$. From observations made at Willets Point $M_6^0 = 84°$. Here $3\ M_2^0 - M_6^0 = 182°$; hence the tendency to double high water and to double low water. (See Fig. 9, Pt. I.)

43. *References to discussions of tides not simply harmonic:*

E. Barlow: An Exact Survey of the Tide, pp. 149-153.

M. de Lalande: Astronomie, Vol. IV, sections 123, 151-154.

G. B. Airy: Tides and Waves, articles 503-520.

Wm. Ferrel: Tidal Researches, section 254.

M. Comoy: Étude Pratique sur les Marées Fluviales, et notamment sur le Mascaret.

O. Krümmel: Handbuch der Ozeanographie, Vol. II, pp, 256-275.

The bore:

G. B. Airy: Tides and Waves, articles 513, 514.

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V. Cornish: London Geographic Journal, Vol. 19 (1892), pp. 52-54.

W. B. Dawson: Survey of Tides and Currents in Canadian Waters, Report of Progress, 1899, pp. 22-25 and Plate II.

W. H. Wheeler: A Practical Manual of Tides and Waves, Chap. XII.

This manual, Part I, Fig. 19, sections 15, 65, 67, 73, 83; Part V, sections 86, 94.

CHAPTER IV.

COMBINATIONS OF MOTIONS.

44. *The combination of two progressive waves.*

Suppose the space origin to be situated at any convenient point, and suppose one progressive wave to move towards $+x$ and the other at some angle to this direction. Suppose the time to be reckoned from Greenwich or any other given meridian. Let T' denote the time of maximum positive velocity of the particles in the first wave at the origin and T'' that of the second at the origin. Then the maximum positive velocity may be written

$$u=A' \cos (at-lx-aT')=A' \cos (\theta-lx-\varepsilon') \tag{240}$$

$$v=A'' \cos (at-ly-aT'')=A'' \cos (\theta-ly-\varepsilon''), \tag{241}$$

where the axis of y is generally oblique to the axis of x. For convenience the dots which have been in many places used to indicate velocity, amplitudes, and epochs will be omitted in this chapter.

From $\dfrac{\partial\,(u^2+v^2)}{\partial\,\theta}=0$, we have, for finding the times of the resultant maximum and minimum velocities, if x and y are at right angles to each other,

$$\tan 2\theta=\frac{A'^2 \sin 2\,(lx+\varepsilon')+A''^2 \sin 2\,(ly+\varepsilon'')}{A'^2 \cos 2\,(lx+\varepsilon')+A''^2 \cos 2\,(ly+\varepsilon'')}. \tag{242}$$

For a given value of θ, this equation represents a cocurrent line in the xy-plane. If y coincides with x, then from

$$\frac{\partial(u+v)}{\partial\,\theta}=0,$$

$$\tan\theta=\frac{A' \sin\,(lx+\varepsilon')+A'' \sin\,(lx+\varepsilon'')}{A' \cos\,(lx+\varepsilon')+A'' \cos\,(lx+\varepsilon'')}, \tag{243}$$

$$\tan lx=\frac{A' \sin\,(\theta-\varepsilon')+A'' \sin\,(\theta-\varepsilon'')}{A' \cos\,(\theta-\varepsilon')+A'' \cos\,(\theta-\varepsilon'')}. \tag{244}$$

The time is referred to the time of maximum velocity (and also of high water) of the first wave at $x=0$ if $\varepsilon'=0$, and to the time of maximum velocity (and also of high water) of the second wave at $y=0$ if $\varepsilon''=0$. The amplitude of the velocity of the current at any point x, y, is obtained by substituting for θ in (240), (241), its value from (242), and afterwards taking the square root of u^2+v^2.

45. *The combination of a stationary and a progressive wave, both lying in the same direction.*

Suppose the space origin to be situated at a loop of the stationary wave, and suppose the progressive wave to move towards $+x$. Suppose the time to be reckoned from Greenwich or any other given meridian. Let T' denote the time of the maximum positive velocity of the first wave at (near) $x = 0$ and T'' that of the progressive wave at $x = 0$. Then the resultant velocity may be written

$$A' \sin lx \cos (at - a\tau') + A'' \cos (at - lx - a\tau''),$$

or

$$A' \sin lx \cos (\theta - \varepsilon') + A'' \cos (\theta - l\,x - \varepsilon''). \tag{245}$$

From $\dfrac{\partial\ (\text{velocity})}{\partial\ \theta} = 0$, we have, for finding the times of the resultant maximum and minimum velocities,

$$\tan \theta = \frac{A' \sin lx \sin \varepsilon' + A'' \sin (lx + \varepsilon'')}{A' \sin lx \cos \varepsilon' + A'' \cos (lx + \varepsilon'')}; \tag{246}$$

and for the position of maximum or minimum velocity at any given time or hour,

$$\cot lx = \cot (\theta - \varepsilon'') - \frac{A'\ \sin (\theta - \varepsilon')}{A''\ \sin (\theta - \varepsilon'')}. \tag{247}$$

The time is referred to the time of maximum positive velocity of the stationary wave if $\varepsilon' = 0$, and of the progressive wave at $x = 0$, if $\varepsilon'' = 0$. The former assumed time refers to mean water of the first wave and the latter to high water of the second. If ε' be replaced by $\varepsilon' + 90°$ in the above equations, the time will be referred to the time of high water at $x = 0$ of the stationary wave. The amplitude of the velocity at any point x is obtained by substituting for θ in (245) its value from (246).

46. *The combination of one stationary wave with another lying transversely to it.*

Suppose the space origin to be situated at a loop of each wave. Suppose the time to be reckoned from Greenwich or any other given meridian. Let T' denote the time of the maximum positive velocity at (near) $x = 0$ of the stationary wave whose motion is parallel to x, and T'' the time of the maximum positive velocity at (near) $y = 0$ of the stationary wave whose motion is parallel to y. Then

$$u = A' \sin lx \cos (at - aT') = A' \sin lx \cos (\theta - \varepsilon'), \tag{248}$$

$$v = A'' \sin ly \cos (at - aT'') = A'' \sin ly \cos (\theta - \varepsilon''). \tag{249}$$

$$\therefore\ u^2 + v^2 = A'^2 \sin^2 lx \cos^2 (\theta - \varepsilon') + A''^2 \sin^2 ly \cos^2 (\theta - \varepsilon'').$$

From $\dfrac{\partial (u^2 + v^2)}{\partial \theta} = 0$ we have, for finding the time of the resultant maximum and minimum velocities,

$$\tan 2\theta = \frac{A'^2 \sin^2 lx \sin 2\varepsilon' + A''^2 \sin^2 ly \sin 2\varepsilon''}{A'^2 \sin^2 lx \cos 2\varepsilon' + A''^2 \sin^2 ly \cos 2\varepsilon''}. \tag{250}$$

By assuming a value θ (i. e., to at), this equation gives a relation between x and y which is the equation of the cocurrent line from the assumed time.

From (250) we have

$$\frac{dy}{dx} = -\frac{A'^2 \cos 2lx \sin 2(\theta - \varepsilon')}{A''^2 \cos 2ly \sin 2(\theta - \varepsilon'')}, \tag{251}$$

which gives the direction of the cocurrent line whose characteristic is θ at any permissible point x, y. The ratio appears to be indeterminate where lx and ly are both odd multiples of $45°$. The value is, however $= -\frac{A'^2 \sin 2(\theta-\varepsilon')}{A''^2 \sin 2(\theta-\varepsilon'')}$. For the lines $lx=$ an odd multiple of $45°$, $\frac{dy}{dx}$ becomes generally zero, and for $ly=$ an odd multiple of $45°$, it generally becomes infinite. Hence:

The cocurrent lines are normal to the lines in a square oscillating area drawn parallel to the sides and at a distance therefrom equal to one-fourth the length of one side.

At the center of the square where $lx=90°$, $ly=90°$,

$$\frac{dy}{dx} = -\frac{A'^2 \sin 2(\theta-\varepsilon')}{A''^2 \sin 2(\theta-\varepsilon'')}. \tag{252}$$

From the fact that two stationary waves of different phases are combined together, and that at the centers of the sides the times of maximum velocity form a cycle of values, it is readily seen that the time of maximum current will assume all hours as we proceed around the square.

The equation

$$A'^2 \sin^2 ly \cos^2(\theta-\varepsilon') + A''^2 \sin^2 ly \cos^2(\theta-\varepsilon'') = (\text{constant})^2, \tag{253}$$

represents a line along which the velocity at any given time is constant, while the equation

$$\frac{A'' \sin ly \cos(\theta-\varepsilon'')}{A' \sin lx \cos(\theta-\varepsilon')} = \text{constant}, \tag{254}$$

represents a line along which the direction of motion is constant. This last expression is equivalent to the tangent of the angle formed by the direction of the motion and the x-axis.

If we eliminate θ between (253) and its derivative with respect to θ, the result will be the equation of a line of equal maximum velocity, i. e., of equal velocity amplitude. The result being the envelope of (253), it follows that all lines having one and the same velocity are tangent to the line of equal velocity amplitude.

If θ be eliminated between (254) and the derivative of (250), the result will be the equation of a line along which the direction of maximum velocity is constant.

The numerator and denominator in the expression for $\tan 2\theta$ will vanish, and so the time of maximum or minimum current becomes indeterminate if

$$A' \sin lx = A'' \sin ly,$$

$$2\varepsilon' = 2\varepsilon'' + (2\nu+1)\pi. \tag{255}$$

These values substituted in the expression for u and v show that the component velocities are there equal in amplitude and differ in phase by $90°$. Such points may be called "circular points." From them the cocurrent lines radiate, their direction for a given value of θ being the angle whose tangent is dy/dx as obtained from (251).

47. *The combination of a progressive wave with a stationary wave lying transversely to it.*

Suppose the space origin is so taken that $x=0$ at a loop of the stationary wave, and suppose the progressive wave to move towards $+y$, a direction transverse to the motion of the stationary wave. Suppose the time to be reckoned from Greenwich or any other given meridian. Let τ' denote the time of maximum velocity of the stationary wave at (near) $x=0$, and τ'' that of the progressive wave at $y=0$. The velocities may be written

$$u=A'' \sin lx \cos (at-a\tau')=A' \sin lx \cos (\theta-\varepsilon'), \tag{256}$$

$$v=A'' \cos (at-ly-a\tau'')=A'' \cos (\theta-ly-\varepsilon''). \tag{257}$$

From $\dfrac{\partial(u^2+v^2)}{\partial\theta}=0$ we have for finding the times of maximum and minimum velocities

$$\tan 2\theta=\frac{A'^2 \sin^2 lx \sin 2\varepsilon'+A''^2 \sin 2(ly+\varepsilon'')}{A'^2 \sin^2 lx \cos 2\varepsilon'+A''^2 \cos 2(ly+\varepsilon'')}. \tag{258}$$

By assigning a value to θ, (i. e., to at), this equation gives a relation between x and y, which is the equation of the cocurrent line for the assumed time.

The equation

$$A'^2 \sin^2 lx \cos^2(\theta-\varepsilon')+A''^2 \cos^2 (\theta-ly-\varepsilon'')=(\text{constant})^2 \tag{259}$$

represents a line along which the velocity at any given time is constant, while the equation

$$\frac{A'' \cos (\theta-ly-\varepsilon'')}{A' \sin lx \cos (\theta-\varepsilon')}=\text{constant} \tag{260}$$

represents a line along which the direction of motion is constant. This last expression is equivalent to the tangent of the angle formed by the direction of the motion and the x-axis.

If we eliminate θ between (259) and its derivative with respect to θ, the result will be the equation of a line of equal velocity amplitude, as in the preceding case. Similarly for the line along which the direction of maximum velocity is constant.

The particles will describe rectilinear paths if v/u is a constant, i. e., free from θ.

At any point defined by the equations

$$\begin{aligned} &A' \sin lx=\pm A'', \\ &\varepsilon'=ly+\varepsilon''+\begin{pmatrix} 2\nu \text{ or} \\ 2\nu+1 \end{pmatrix}\pi, \end{aligned} \tag{261}$$

it is observed from (256) and (257) that $u=v$, or $v/u=1$.

The numerator and denominator in the expression for $\tan 2\theta$ will vanish, and so the time of maximum or minimum current become indeterminate, at the points

$$\begin{aligned} &A' \sin lx=A'', \\ &2\varepsilon'=2(ly+\varepsilon'')+(2\nu+1)\pi. \end{aligned} \tag{262}$$

These values substituted in the expressions for u and v show that the component velocities are there equal in amplitude and differ in phase by 90°. Such points are also called "circular points." From them the cocurrent lines radiate, the direction for a given value of θ being the angle whose tangent is $\frac{dy}{dx}$ as obtained from (258).

48. *Currents in a marginal strip of shallow water.*

Given the rise and fall of tide and the varying depth of the water from the shore outward, required the current velocities at various distances from the shore upon the assumption that the tide in the region considered is a dependent stationary wave of sensibly constant range.

Let x be reckoned outward from the shore line and t from the time of high water. Let A' denote the amplitude of the tide and a its speed. Let $h=f(x)$ be the depth at mean-tide stage. Then the tidal volume, one unit broad and extending outward from the shore line a distance x is

$$Ax \cos at.$$

The cross section at x of unit width has for its area

$$f(x)+A \cos at.$$

Assuming the flow to take place in vertical slices, the velocity at any given time of tide is

$$\begin{aligned} u &= -\frac{1}{f(x)+A\cos at}\,\frac{\partial(Ax\cos at)}{\partial t}, \\ &= \frac{Aax \sin at}{f(x)+A\cos at}. \end{aligned} \tag{263}$$

This is not strictly harmonic. The last half of the flood and first half of the ebb will appear, upon a plotting of the current, more nearly like a straight line than would have been the case for simple harmonic motion, while the last half of the ebb and first half of the flood will have more curvature because of this irregularity.

Ignoring the effect of the rise and fall upon the cross section,

$$u=\frac{Aax \sin at}{f(x)},$$

which is simply harmonic.

For M_2, $a=m_2=0.000\ 140\ 5$ radian per second.

If $f(x)=\mu x+H$, H being the depth at the shore and μ the downward slope of the bottom, then

$$u=\frac{Aax \sin at}{\mu x+H};$$

and if $H=0$,

$$u=\frac{Aa}{\mu}\sin at.$$

Hence, the off or on shore velocity for a uniformly sloping bottom, the depth of water being zero at the shore, is independent of the distance from the shore.

If $\mu=0$,

$$u=\frac{Aax \sin at}{H};$$

that is, the off or on shore velocity for a shallow strip of water of uniform depth is directly proportional to the distance from the shore.

The cases found in nature often lie between the two just considered.

It is important to observe that for a uniformly sloping bottom the refluent under currents due to winds diminish from the shore in going outward.

Let τ' denote the time of high water of the stationary wave at $x=0$ and τ'' that of the progressive wave at $x=0$. Then the velocity due to a stationary wave normal to the shore line may be written

$$\frac{A'a}{\mu} \sin (at-a\tau')$$

where A' is amplitude of the stationary portion of the tide. The velocity for the progressive wave near the origin and along its line of advance is, equation (38), Part I,

$$A''\sqrt{\frac{g}{h}} \cos (at-a\tau''),$$

A'' being the amplitude of the progressive portion of the tide. If this progress shoreward, the total offshore velocity is

$$u=\frac{A'a}{\mu} \sin (at-a\tau')-A''\sqrt{\frac{g}{h}} \cos (at-a\tau''). \qquad (264)$$

This becomes zero when

$$\tan at=\frac{\alpha \sin a\tau'+\beta \cos a\tau''}{\alpha \cos a\tau'-\beta \sin a\tau''}, \qquad (265)$$

where $\alpha=\frac{A'a}{\mu}$ and $\beta=A''\sqrt{\frac{g}{h}}$.

If $\tau''=\tau'=0$,

$$\tan at=\frac{A''}{A'}\frac{\mu}{a}\sqrt{\frac{g}{h}}, \qquad (266)$$

$\therefore$ if $A''=0$, slack water occurs at the time of high or low water, but if $A'=0$, three hours before or after.

Progressions result from such irregularities in the shore line as estuaries and narrow openings into bays, also from certain irregularities in the bottom, although the rise and fall of the outside waters is, of course, the cause of all such motion. The time of tide on the general shore line depends little upon the existence or absence of estuaries and straits leading inland. Hence, the time of high water in the entrance to such estuaries or straits can not differ much from the time of tide for the same shore line devoid of such irregularities. The difference generally becomes greater as the size of the estuary or other shallow arm of the sea increases; but it seldom exceeds one hour and is generally much less. Because of the existence of an antecedent wave (sec. 8, Part IV B), one can assume that somewhere not far off the mouth of the estuary or strait, the time of tide is the same as it would have been had no such opening been present. For this point the time of turning of the current will approximately satisfy (266); and conversely if the time of turning is known, the ratio A''/A' can be estimated. In fact, $\frac{\mu}{a}$ is often in the neighborhood of 15, and, for the shelving areas here considered, $\sqrt{\frac{g}{h}}$ generally ranges from one-fourth to unity or more. Since the observed delay of turning outside the estuary seldom exceeds one hour, it follows that A'' is there a small fraction of A'.

As the estuary is approached and entered, the τ'' terms in (264) become dominant and t approaches the values $\tau''\pm 3^{\text{h}}$. On the other hand, equation (265) shows that when h becomes sufficiently great, $t=\tau'$ or $\tau'+6^{\text{h}}$, as was to be expected.

49. *The combination of a progressive stream with a stationary one lying transversely to it.*

Let the velocities of the stationary and progressive motions be written

$$u=A' \cos \theta,$$
$$v=A'' \cos (\theta-l''y-\varepsilon'');$$

then

$$\frac{\partial(u^2+v^2)}{\partial\theta}=0$$

leads to the equation

$$\tan 2\theta=\frac{A''^2 \sin 2(l''y+\varepsilon'')}{A'^2+A''^2 \cos 2(l''y+\varepsilon'')}, \tag{267}$$

which gives the time of maximum or minimum current at any point x, y after the time of the maximum current in the stationary wave; A' and A'' are supposed to be functions of x, y, suited to the problem in hand.

There exists a point at which the component velocities are equal in amplitude and differ in phase by an odd multiple of 90°. For, the point x, y will cause the numerator of (267) to vanish if $l''y+\varepsilon''=0$ or $(2\nu+1)\frac{\pi}{2}$. This second value of y substituted in the denominator will cause it also to vanish, and so the time of maximum current to become indeterminate, if $A'=A''$. The value of x thus determined is the remaining coordinate of the point in question and which, as already noted, may be styled a "circular point."

In particular, suppose A'= constant and suppose A'' to be some such function of x as $A' e^{-p^2x}$ or $\frac{L-x}{L}A'$. Taking the circular point as the space-origin it is evident that all along the line $x=0$, the component velocities are equal. Since for simplicity ε' has been taken as zero, ε''/a denotes the excess of the current hour of the progressive wave at this point over that of the stationary wave. The velocity ellipse at any part x, y, will have its y-semiaxis numbered $l''\ y+\varepsilon''$ in excess of the numbering of the x-semiaxis. The latter number is the current hour of the stationary wave multiplied by a.

50. *Given the two component velocities, to find the time of occurrence of the maximum velocity, together with its value and direction.*

Let the velocities be written

$$u=A' \cos \theta,$$
$$v=A'' \cos (\theta-E),$$

where $E=l''y+\varepsilon''$. Then the time is given by the equation

$$\tan 2\theta'=\frac{A''^2 \sin 2E}{A'^2+A''^2 \cos 2E}. \tag{268}$$

If we have

$$z=A \cos \theta+B \cos (\theta+\beta),$$

the time of the maximum or minimum value of z is given by the equation

$$\tan \theta=-\frac{B \sin \beta}{A+B \cos \beta}$$

where β is the phase of B relatively to the phase of A, or

$$\tan \theta=\frac{B \sin E}{A+B \cos E}$$

if $E=-\beta$. Or,

$$-\tan \theta=\tan v'=\frac{B \sin \beta}{A+B \cos \beta}. \tag{269}$$

Hence Table 14 can be used directly as it stands provided we make the following substitution

For A, A'^2;
for B, A''^2;
for v', 2θ;
for β, $2E=2(l''y+\varepsilon'')$.

For distinction, v' is here used to denote the v of sect. 4, Part III.

Upon substituting in u and v the value of θ thus found, the value of the maximum current, $\sqrt{u^2+v^2}$, and of its direction, $\tan^{-1}\phi=\frac{v}{u}$, become known.

51. *Given the times and the magnitudes of two components at right angles to each other, to find the times, directions, and magnitudes of the maximum and minimum velocities.*

Let

$$u=A' \cos (at-aT')=A' \cos (\theta-\varepsilon'), \tag{270}$$
$$v=A'' \cos (at-aT'')=A'' \cos (\theta-\varepsilon''). \tag{271}$$

The required times are given by the equation

$$\tan 2\theta=\frac{A'^2 \sin 2\varepsilon'+A''^2 \sin 2\varepsilon''}{A'^2 \cos 2\varepsilon'+A''^2 \cos 2\varepsilon''}. \tag{272}$$

From the harmonic analysis of the observations the component amplitudes or H's and the local epochs or κ's are supposed to be known. Upon substituting these for the A's and ε's in the above formula, the required times, referred to the time of transit of the tidal body across the local meridian, become known.

Take one of the four values of θ and substitute it in the expression for u and v. The signs of u and v will show the quadrant of the corresponding maximum and minimum velocity; $\sqrt{u^2+v^2}$ will be the value of the velocity, and $\frac{v}{u}$ the tangent of its direction with the x-axis.

Tables 14 and 15 can be used in this connection if we take as time origin the time of maximum velocity in the x-direction and make the following substitution:

For A, A'^2;
for B, A''^2;
for v', 2θ;
for β, ε''.

52. *Given the times, directions, and magnitudes of the maximum and minimum velocities to find the velocity at any other time.*

Suppose that here u, v, A', A'', ε', ε'', refer to the given principal directions, and not to the arbitrary north and east or y- and x-directions.

The equations (270), (271), (272) still apply, but with the additional restriction

$$\varepsilon''=\varepsilon'\pm 90°.$$

The component velocities along the principal directions are the values u and v with the given value of t or θ substituted.

To find the velocity at any given time graphically, describe a circle with twice the maximum velocity as diameter. Divide the circumference into twelve equal hour spaces. Mark the required time and draw an ordinate to the diameter through this point. Diminish this ordinate in the ratio $\frac{\text{minimum velocity}}{\text{maximum velocity}}$. The line drawn from the center to the extremity of this diminished ordinate represents the velocity for the given time in both magnitude and direction.

53. *Given the times, directions, and magnitude of the maximum and minimum velocities of the periodic current also the velocity of the permanent current to find the times, directions, and magnitudes of the resulting maximum and minimum velocities.*

Let the velocity ellipse of the periodic current be written

$$\frac{u^2}{a^2}+\frac{v^2}{b^2}=1, \text{ or } \frac{x^2}{a^2}+\frac{y^2}{b^2}=1, \tag{273}$$

and let x', y' denote the extremity of the vector representing the velocity of the permanent stream taken in the reverse direction. Then the distance D from this point to any point on the ellipse satisfies the equation

$$(x'\sim x)^2+(y'\sim y)^2=D^2. \tag{274}$$

Substituting in the expression for D^2 the value of y from (273) and equating the x-derivative to zero there results the equation in x

$$(a^2-b^2)x+\frac{by'x}{\sqrt{1-\frac{x^2}{a^2}}}-a^2x'=0. \tag{275}$$

Writing $\sin\theta$ for $\frac{x}{a}$ this equation becomes

$$(a^2-b^2)\sin\theta+by'\tan\theta-ax'=0, \tag{276}$$

which is of the same form as equation (28), Part III; this is tabulated in Tables 17 and 44.

Having thus found the value of x, the value of y becomes known from (273); the required maximum and minimum velocities then become known in both magnitude and direction.

The velocity ellipse may be denoted either by the single equation (273) or by the two equations (270), (271), provided A', A'', ε', ε'', in the latter refer to principal axes. Hence the angle θ becomes known through them for any particular point, x, y or u, v. Consequently the times become known when the velocities attain their maximum or minimum values.

54. *Rectilinear tidal currents combined with a permanent current.*

By means of the parallelogram of velocities it is easily seen that the time of maximum tidal current is the time of maximum resultant current (sometimes of minimum current, if the resultant direction is more than 90° away from the tidal current considered). Hence, the observed time of maximum resultant current is the time of maximum tidal current.

Given the resultant or observed maximum flood and ebb arrows to find those representing the true flood and ebb and the permanent current.

Join the ends of the observed arrows and bisect the connecting line; join the origin and the point of bisection. This line represents the permanent current in position, magnitude, and direction. The two portions of the bisected line represent the true flood and ebb in magnitude and direction, but should be transferred to the origin, in order that the position may be correct. The value of an ordinary maximum current (slack) is the perpendicular distance of the bisected line from the origin. If ω represents the angle between the permanent current and the true ebb, then the time of slack before flood will be accelerated over its position midway between the two strengths by

$$\frac{1}{a}\sin^{-1}\left(\frac{C\cos\omega}{A}\right) \tag{277}$$

hours, A being the amplitude of the tidal-current velocity and C the velocity of the permanent stream.

If $\omega=0$, as in a tidal river, then this value becomes $\frac{1}{a}\sin^{-1}\frac{C}{A}$. If in such cases F denote the numerical value of the strength of flood and E that of ebb, then

$$\begin{aligned}A&=\tfrac{1}{2}(E+F),\\ C&=\tfrac{1}{2}(E-F).\end{aligned} \tag{278}$$

Where the tidal currents are not rectilinear, but elliptical, the heads of the radiating arrows representing the observed velocities (at each hour, say) will lie upon the perimeter of an ellipse. The major semiaxis found from the plotting represents in magnitude and direction (but not in position) the maximum tidal velocity, and the minor semiaxis, the minimum. The permanent current is represented by a line drawn from the origin of the plotting to the center of the ellipse.

55. *Circular points.*

Fig. 4 represents the case where

$$A''=\frac{L-x}{L}A',\ \epsilon'=0,\ \text{and}\ \epsilon''=90^\circ.$$

$$\therefore\ u=A'\cos\theta,$$

$$v=\frac{L-x}{L}A'\cos(\theta-l''y-90^\circ)=\frac{L-x}{L}A'\sin(\theta-l''y).$$

With a given θ and x, y, it is easy to find upon the diagram the u and v of the maximum velocity.

For a minimum, use the same equation but decrease or increase θ by 90° according as the velocity wanted is before or after the maximum. It will be noticed that in the figure the rotation of the current arrows is counterclockwise.

From (267) and the assumptions just made

$$\tan 2\theta=\frac{\left(\frac{L-x}{L}\right)^2\sin 2(l''y+90^\circ)}{1+\left(\frac{L-x}{L}\right)^2\cos 2(l''y+90^\circ)}, \tag{279}$$

$$\doteq -Ll''\frac{y}{x}+2\,l''y,$$

near the origin. In this vicinity

$$\frac{dy}{dx}=-\frac{K-2\,l''y}{Ll''-2\,l''x}\tan\phi$$

where K is written for $\tan 2\theta$. At the origin

$$\frac{dy}{dx}=-\frac{K}{Ll''}=\tan\phi \tag{280}$$

$$\therefore\ \tan\phi=-\frac{1}{Ll''}\tan 2\theta.$$

The cocurrent lines radiate from the origin; their numbering is clockwise and ranges from 0 to 6 hours.

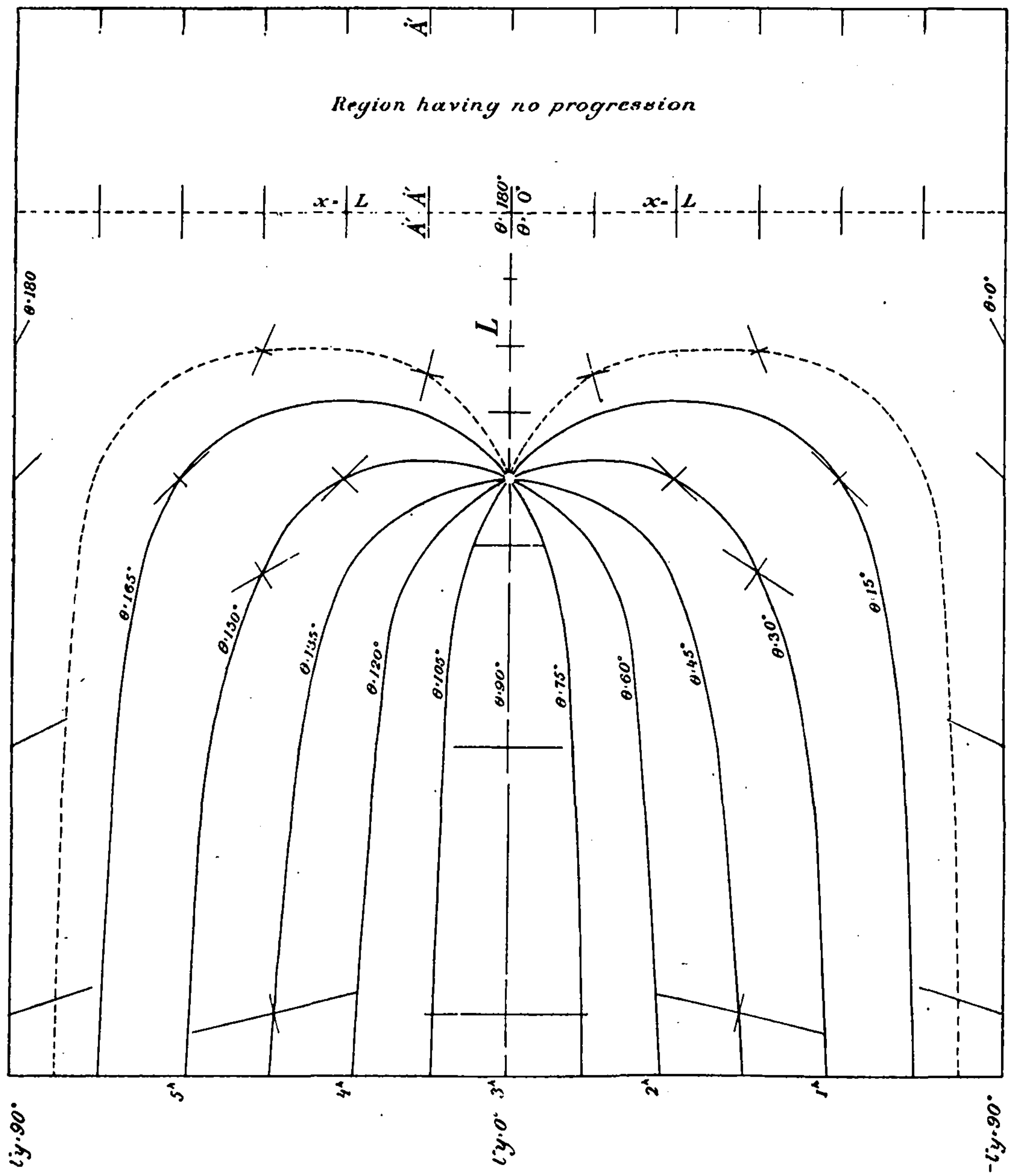
At the origin

$$u=A'\cos\theta,$$

$$v=A'\cos(\theta-90^\circ);$$

consequently the rotation of the current is counterclockwise, the period being 12 hours.

No. 4.



Region having no progression
A'
x-L
A' A'
θ·180° θ·0°
L
θ·180
θ·0°
θ·165°
θ·150°
θ·135°
θ·120°
θ·105°
θ·90°
θ·75°
θ·60°
θ·45°
θ·30°
θ·15°
5ʰ
4ʰ
3ʰ
2ʰ
1ʰ
i'y·90°
i'y·0°
-i'y·90°

Suppose $x=0$; then from (279)

$$\tan 2\theta=\frac{-\sin 2l''y}{1-\cos 2l''y}. \tag{281}$$

Fig. 4 shows a strip such that

$$-90°<l''y<90°.$$

For negative values of y, within these limits, $\tan 2\theta$ is positive, and for positive values of y, it is negative. For $l''y=-90°$, $\theta=0$, and for $l''y=90°$, $\theta=180°$.

If

$$A''=A'e^{-p^2x},\ \varepsilon'=0,\ \text{and}\ \varepsilon''=90°,$$

$$\tan 2\theta=-\frac{e^{-2p^2x}\sin 2l''y}{1-e^{-2p^2x}\cos 2l''y}. \tag{282}$$

Near the origin

$$e^{-2p^2x}\doteq 1-2p^2x$$

$$\frac{dy}{dx}\doteq-\frac{2Kp^2-2l''p^2y}{l''+2Kl''^2y}\doteq-\frac{Kp^2}{l''}.$$

$$\therefore\ \tan\phi=-\frac{2p^2}{l''^2}\tan 2\theta.$$

If

$$A'=Ce^{p^2x}$$

$$A''=D\frac{L-x}{L}e^{q^2y^2},$$

the stationary portion becomes dominant as x increases in value, while the progressive portion becomes dominant as x increases numerically in the negative direction.

$$\tan 2\theta=\frac{D^2\left(\frac{L-x}{L}\right)^2e^{2q^2y^2}\sin 2(l''y+90°)}{C^2e^{2p^2x}+D^2\left(\frac{L-x}{L}\right)^2e^{2q^2y^2}\cos 2(l''y+90°)}. \tag{283}$$

If $A'=C$, i. e., if $p=0$, also if $D=C$; then the line of equal component velocities (i. e., where $u=v$) is not the y-axis, but is a curve tangent to the y-axis at the origin, and the distribution or radiation is the same as that shown in the figure.

Circular points may frequently be regarded as resulting from the crossing of two tidal streams, the phase of one being nearly constant in respect to distance, the phase of the other varying rapidly (i. e., l'' is much greater than l, which depends directly upon the depth); the former may be spoken of as a stationary stream and the latter as a progressive stream. The velocity amplitudes in either or both may vary according to any regular law. At a circular point the component-velocity amplitudes must be equal and lie perpendicularly to each other, also the phases in these two directions must differ by 90° or three hours.

If two such streams intersect (not necessarily at right angles) there will generally be a line along which the two component-velocity amplitudes in these directions are equal to each other. For, the ratio of these two amplitudes may be supposed to vary in the region covered by the streams according to some law, and in particular, near any point at which they happen to be equal. Along a certain line drawn through this point the amplitude ratio will vary most rapidly, and along some one line it will not vary at all from unity.

Lay off from any point two arrows, each equal to the amplitude of either component velocity, their direction being the directions of the two streams. But the simply harmonic motions (displacements or velocities) along two intersecting paths, give as the resultant path or hodograph, an ellipse, whose center is this point and whose major or minor axis bisects the angle between the two paths. By varying the phase of one motion relatively to the phase of the other, all forms of ellipses will be obtained and all of these will be inscribed in a rhombus, the centers of two of whose sides are the outward extremities of the given paths. One of these ellipses must be a circle. Note the relative phase corresponding to the circle. If it is $\pm 90°$, the point is a circular point. If not, go along the line of equal amplitudes until the relative phase for the circular paths is $\pm 90°$.

56. *To find the time and amount of the greatest height difference for a strait connecting two tidal bodies.*

Let $\theta = at$ and suppose the time origin to be the time of high water at the end characterized by the single subscript. Then $z_{,} - z_{,,}$ or $A_{,} \cos \theta - A_{,,} \cos (\theta - \varepsilon)$ is to be a maximum or minimum. The time after the $A_{,}$ high water when this will occur is given by the equation

$$-\tan at = -\tan \theta = \frac{A_{,,} \sin \varepsilon}{A_{,} - A_{,,} \cos \varepsilon} = \frac{A_{,,} \sin \beta}{A_{,} + A_{,,} \cos \beta} = \tan v' \qquad (284)$$

where $\beta = 180° - \varepsilon$ or $\varepsilon = 180° - \beta$. § 4, Part III.

Now Table 15 gives the angle v', and the "HW phase" is the angle β. Hence if we take the argument β from 180° the tabular value of the table will, when reduced to hours, be the time whereby the time of the $A_{,}$-tide must be diminished in order to give the time when the $A_{,}$-height most exceeds the $A_{,,}$-height.

If the time is reckoned from the time of the $A_{,,}$-high water instead of to the time of the $A_{,}$-tide, the $A_{,,}$-height will most exceed the $A_{,}$-height at times given by entering Table 15 with $\varepsilon = \beta - 180°$, using the "HW phase" or β written at the bottom of the table. In this way Table 60, showing the time of maximum slope, has been constructed.

Either of these values of ε substituted in $A_{,} \cos \theta - A_{,,} \cos (\theta - \beta)$ gives $A_{,} \cos \theta + A_{,,} \cos (\theta + \beta)$ which is of the same form as the height due to two simple tide waves, equations (19), Part III. Hence if the columns of Table 16 be taken in the inverse order these results follow immediately. Table 61 shows the difference in surface elevation for the two ends of the strait.

In accordance with sections 35, 102, Part IV A, the time of strength of flood or ebb in a strait of length L connecting two tidal bodies is given by the equation

$$\tan at'' = \frac{A_{,} \cos l(L-x) \cos \alpha_{,} - A_{,,} \cos lx \cos \alpha_{,,}}{A_{,} \cos l(L-x) \sin \alpha_{,} - A_{,,} \cos lx \sin \alpha_{,,}}. \qquad (285)$$

If lL is but a small fraction of 2π, the above equation becomes

$$\tan at'' = \frac{A_{,} \cos \alpha_{,} - A_{,,} \cos \alpha_{,,}}{A_{,} \sin \alpha_{,} - A_{,,} \sin \alpha_{,,}} \tag{286}$$

Let $\alpha = 0$, then $\alpha_{,,} = -\varepsilon$, and

$$\tan at''' = \frac{A_{,} - A_{,,} \cos \varepsilon}{A_{,,} \sin \varepsilon}; \tag{287}$$

$\therefore at'''$ is 90° greater than at in (284),

and so the greatest velocity occurs three hours after the time of greatest slope. This is what would be expected in small slope motion through a straight sufficiently long for oscillatory motion to occur, and connecting two deep tidal bodies whose horizontal motions can be ignored. (Cf. sec. 11, Part IV A.)

Where the strait is so short and narrow that the motion is due to hydraulic effects, the time of maximum velocity approaches the time of greatest slope. (See secs. 34–37, Part I; sec. 106, Part IV A.)

The section of the strait at which the range becomes a minimum, upon the assumption that its instantaneous surface is a plane, may be found in the following manner:

Let L denote the length of the strait; x the distance of the required section from the end where the amplitude of the tide is $A_{,}$. The height at any section in the strait is (sect. 106, Part IV A)

$$\zeta = \frac{\zeta_{,} (L-x) + \zeta_{,,} x}{L} = \frac{(L-x) A_{,} \cos at + A_{,,} x \cos (at + \alpha_{,,})}{L} \tag{288}$$

the time being reckoned from the time of high water at the first end

From $$\frac{\partial \zeta}{\partial t} = 0, \text{ we have}$$

$$\tan at = -\frac{A_{,,} x \sin \alpha_{,,}}{A_{,} (L-x) + A_{,,} x \cos \alpha_{,,}} \tag{289}$$

and from

$$\frac{\partial \zeta}{\partial x} = 0$$

$$\tan at = \frac{A_{,,} \cos \alpha_{,,} - A_{,}}{A_{,,} \sin \alpha_{,,}}; \tag{290}$$

$$\therefore \frac{x}{L} = \frac{A_{,}(A_{,} - A_{,,} \cos \alpha_{,,})}{A_{,}^2 + A_{,,}^2 - 2 A_{,} A_{,,} \cos \alpha_{,,}}. \tag{291}$$

These values of x and t when substituted in the expression for ζ give the amplitude of the tide where it becomes a minimum.

In the expression for x/L it will be noticed that the denominator is the square of the side of a triangle opposite the angle $\alpha_{,,}$ whose including sides are $A_{,}$ and $A_{,,}$. The factor $A_{,} - A_{,,} \cos \alpha_{,,}$ in the numerator is the distance from the outward extremity of $A_{,}$ to a point upon $A_{,}$ below the point marking the outward extremity of $A_{,,}$.

Since $\frac{x}{L} < 1$, it follows that $A_{,,} > A_{,} \cos \alpha_{,,}$, if a minimum occurs in the strait.

CHAPTER V.

OBSERVATION AND REDUCTION OF TIDAL CURRENTS.

57. Observations of the directions and velocities of currents are usually attended with considerable difficulty and expense; for, the work being carried on in boats, is liable to interruptions caused by unfavorable weather and in many instances by the passing of boats. The installation and maintenance of a fixed self-registering current meter is probably out of the question; and so the amount of observation must depend upon the time during which the observers are on duty.

In whatever manner current observations are to be made, great care should be taken to ascertain and to give in the record the location of each station, not only by angles between three or more objects marked upon charts and hydrographic sheets, but also upon a tracing, sketch, or fragment of a chart, which should always accompany the record. Generally the position upon both flood and ebb should be shown. The work of the field party is not complete until the directions, azimuths, or bearings of all objects sighted upon in connection with the observations and all directions of the observed currents have been ascertained and given in the record. For locating stations, objects not too far away should be sighted upon, and these may be quite numerous; but for determining the direction of the current it is advantageous to use objects rather remote and few in number. If at some distance from land, positions should be given by latitude and longitude with as much precision as the means at hand will permit. In all cases soundings should be frequently made, as this aids in identifying the station and in judging of the probable nature of the current.

The record should be given in such a form as to show readily directions and velocities of the current, the depths at which the observations have been taken, the variation and deviation of the compass.

The kind of time used should always be specified, and care should be taken to write "a. m." or "p. m." at the top of each page and at the beginning of each half day.

The purpose of the survey will govern the distribution of stations and the length of time during which they are to be occupied. Owing to irregularities produced by the wind and the discharge of fresh water, each station should be occupied for several days, if possible. For such stations as may be chosen as principal stations in a hydrographic survey, the time of occupation should be 15 or 30 days. For determining the non-tidal currents, the same stations should be occupied at different seasons of the year.

58. *Floats.*

Current observations are usually made either by means of floats, or by means of meters having revolving vanes or cups.

The float or log is usually a cylindrical body 2, 3, or more inches in diameter and from 1 to 4 fathoms in length. If hollow, the amount of weight necessary to cause it to float vertically, and to project a small distance above the water is easily applied. In case the float is a solid log, then the loading is accomplished by pouring lead into a hollow extending upward from the bottom, or by tacking sheet lead around the outside.

If double floats are used for obtaining the velocity below the surface, the lower one should be large in comparison with the surface or upper one. The lower float (if it may be so called) may consist of a sphere, cylinder, or two intersecting plane sheets of galvanized iron. In the last instance it is desirable to have air cavities at the upper edges of the intersecting vanes, and to attach leaden weights to the lower edges. In this way the proper tension upon the connecting cord or wire can be secured and the vanes will keep a vertical position. The upper float may be either cylindrical or spherical.

Let the observed common velocity of the two floats be denoted by v_c, the observed surface velocity by v_s, then the velocity of the lower body (v_l) will be

$$v_l = \frac{v_c(R_s+R_l)-v_sR_s}{R_l} \tag{292}$$

where R_s and R_l denote resistances of impact upon the two bodies found by placing them successively in the same stream or drawing them through still water with the same velocities. The only assumptions implied in this formula are that the ratio of the force of resistance of the two bodies remains the same for all velocities (see secs. 12–14) and that the wire or cord connecting the two bodies is small.

The line, when thoroughly wet, should be divided by means of leather straps, suitably marked by perforated holes into divisions each 50.67 feet in length, representing knots. Each of these spaces should be subdivided by knotted cords into spaces 5.07 feet in length. If the interval used is 30 seconds, the number of large divisions run off will represent the velocity in knots per hour and the numbered smaller divisions the decimals of knots. If a run of 28 seconds be used, the principal divisions should be 47.29 feet in length. There should be at least 60 feet of stray line between the float and the zero division, in order that the float may drift beyond the influence of the vessel before the measurements commence. The length of the line should be frequently tested.

If a watch instead of a glass be used as the timepiece, the graduations of the line may be omitted. In using such a line the number of seconds consumed in paying out a given length is ascertained, preferably by aid of a stop watch. If 100 feet is the length of line so run off, the velocity in feet per second will be $\frac{100}{t}$, where t denotes the number of seconds consumed. But

$$\text{(feet per second)} \times \frac{45}{76} = \text{knots per hour,}$$

and so for 100 feet of line

$$v = \frac{45}{76}\frac{100}{t} = \frac{59.21}{t} \text{ knots}$$

$\therefore$ for a line $100 \times \frac{76}{45} (=168.9)$ feet long

$$v = \frac{100}{t}, \text{ and for a line 84.45 feet long, } v = \frac{50}{t};$$

and so on.

That is, by taking a line of suitable length the velocity becomes the reciprocal of t multiplied by a simple number like 100 or 50.

59. *Observations by means of floats.*

There are numerous ways of observing currents by means of floats, some of which consist in (1) noting the number of knots or marks upon a log line which are paid out in 30 seconds of time; (2) noting the time required for a given length of line to be paid out; (3) following up a free float with a boat and fixing the positions from time to time by angles upon three or more objects; (4) measuring angles between the float and fixed objects by means of two theodolites located upon the shore, or watching the float pass two parallel ranges a known distance apart; (5) ascertaining the amount by which a vessel has been displaced through the action of a current. As a rule observations upon free floats are objectionable because of the great labor connected with their reduction, and because they do not refer to a single point or station.

In making observations with a line and float (first method) one man holds the reel while another notes the time. When the log is cast, and the stray line is out so that the initial mark has appeared and has reached the fixed reference point on or near the reel, the person holding the reel cries "now;" the person with the watch notes the position of the second-hand, and when thirty seconds have elapsed, cries "stop." The person at the reel now notices what division of the line has reached the reference point. This is recorded, and if the length of the line be sufficient, it may be allowed to run out for another thirty seconds after any particular division or marking of the line has reached the reference point on or near the reel. A stop watch will give greater precision to all work of this kind. After the velocities have been noted, the log is still allowed to drift until its direction is ascertained. This may be done either by measuring with a sextant the angle between a fixed object and the float, or by directing the sights of a compass toward the float. If the float is to the right of the object of reference, the angle is marked "*R*," if to the left, "*L*." This rule should be invariably followed in the record. If observations are made with a compass, the direction should be recorded in degrees (not in points) and corrected for variation and deviation as indicated in the form for record. If circumstances permit, it is best to carry on simultaneously both sextant and compass observations. During the day, the float should carry a wind vane, small flag, or slender rod; and during the night, a lantern.

In comparatively narrow bodies of water the velocity of the current is often obtained by aid of two ranges transverse to the stream. The float is set adrift some distance above the upper range and picked up below the lower range. Observers stationed on the shore note the time when each range is passed. Greater precision can be attained if observers stationed on the shore make simultaneous observations upon the float by means of two theodolites. This is important wherever the lines of flow are not known, or are not fixed in position for the varying phases of the tide.

For convenience of reduction care should be taken to make current observations upon the exact hours and half hours.

The time of the current's turning (middle of slack) should be carefully observed and recorded wherever slack water occurs.

The direction and force of the wind, together with the appearance of rips, eddies, and other interesting phenomena, should be observed and recorded.

60. *Current meters.*

A current meter usually consists of a rotating meter wheel actuated by the impact of the water; a framework for supporting the wheel; a vane for causing the instrument to lie parallel to the lines of motion of the current; a counterpoise for causing the suspended meter to lie in a nearly horizontal position; a worm gear and wheels for recording the number of revolutions or preferably an electric connection with a recording apparatus located in the boat from which the meter is suspended.

A float may be used for determining the direction when observations are made near the surface. One of the chief requisites of current meters is uniformity of operation. Hence, all bearings and gears belonging to the meter proper should be tightly inclosed, if possible, thus placing them beyond the reach of the water and sediment.

Woltmann's mill, and the meters of Fteley, Revy, and Moore, have counting devices in the instrument proper. The Henry, Price, and Haskell meters are electrially connected with the observing or recording apparatus.

For making observations at considerable depths, the meter must be provided with some means of determining the direction of the stream, and it is important that this may be done without the necessity of hauling up the meter after each reading.

Pillsbury's meter gives both velocity and direction, but has to be hauled up for reading. The Ritchie-Haskell direction meter has a registering aparatus in the boat, but requires great care in manipulation.

If a revolving meter could be so constructed as to have its cups or small blades move with a velocity equal to that of the stream, then

$$v = 2\, n\, \pi\, r,$$

where n is the number of revolutions per second and r the radius or distance from the axis of rotation to the centers of the small cups or blades. The cup anemometer and the Price current meter partially fulfill these hypothetical requirements.

If small oblique vanes were placed upon the circumference of a skeleton wheel so that the whole wheel would in some respects resemble a wind mill, and if I denote the inclination of a vane to a line drawn parallel to the axis upon which the wheel revolves, then v denoting the velocity of the stream, the velocity of the rim of the wheel should be, in the case of no resistance, $v \tan I$. Here v does not equal $2\, n\, \pi\, r$, but $2\, n\, \pi\, r \cot I$.

These simple illustrations show why one should expect to find current velocities to vary almost linearly with the number of revolutions. In practice other small terms come into the expression for v or n, and so it is reasonable to assume that v is of the form

$$v = \alpha + \beta n + \gamma n^2$$

61. *Remarks on the use of meters.*

Shortly before using a meter it must be carefully rated for various velocities, and it should be tested from time to time. This is usually accomplished by driving it at uniform rates through still water, the meter being attached to the prow of the boat and well submerged. The course over which the boat is driven being accurately known, and the various times and readings for each run being noted, it is not difficult to compute a curve representing the rating. To do this, assume that observations or runs have been made giving directly the revolutions per second in each case, viz., $n_1, n_2, \ldots, n_m$, and from the known times of going over the known course, the velocities in feet per second, viz., $v_1, v_2, \ldots, v_m$. For convenience, write a, b, c for 1 $(=n^0)$, n, n^2, then if we assume that the velocity and number of revolutions per second are already connected by the relation

$$v=\alpha+\beta n+\gamma n^2 \tag{294}$$

where α, β, γ are constants to be determined, we have three linear equations for their determination, viz.

$$\begin{aligned} &\sum_{i=1}^{i=m} a_i(a_i\alpha_i+b_i\beta_i+c_i\gamma_i-n_i)=0, \\ &\sum_{i=1}^{i=m} b_i(a_i\alpha_i+b_i\beta_i+c_i\gamma_i-n_i)=0, \\ &\sum_{i=1}^{i=m} c_i(a_i\alpha_i+b_i\beta_i+c_i\gamma_i-n_i)=0. \end{aligned} \tag{295}$$

If the velocity is to be measured at a depth of only a few feet below the surface, the meter is attached to a pole; if at a considerable depth, it must be suspended by a strong, slender cord or cable, and to the lower extremity of the meter sufficient weight should be attached for keeping the axis of the meter in a nearly horizontal position.

In recording the observations the same form as that used in recording float observations can still be used. The number of revolutions should be written a little above the line with the corresponding velocity on the line. The depth at which the observation is taken should be written in the column of remarks.

For details concerning the rating of meters, see "Accuracy of Stream Measurements," by E. C. Murphy, pages 80 et seq. The current meter devised by Lieut. J. E. Pillsbury, U. S. N., is described in the U. S. Coast and Geodetic Survey Reports, 1885, pages 495–501; 1890, pages 459–620. It consists, in part, of a cup meter and an enclosed compass, both placed within an open frame. The frame terminates in a heavy ball and is hung in gimbals, so that the weight of the ball secures the uprightness of the instrument at all times. The revolutions are counted by means of a worm gear and wheel register. The compass needle is locked as soon as hoisting of the instrument begins.

Further references to measurements of the Gulf Stream made by this meter are the Survey reports for 1886, 1887, and 1889.

There is little or no difficulty connected with the construction and operation of an electric meter which measures the velocity only, for an insulated wire can be carried down inside of or alongside of the suspending cable to the axis of the meter wheel. A projection on the wheel near its axle comes into contact with this pole or end of the wire, one or more times for each revolution. This closes the circuit and causes the movement of an armature on an electro-magnet; the armature in turn actuates the recording apparatus. The meters of Price and Haskell are of this character.

Many greater difficulties arise in the determination of the direction of the current, especially if the meter is not to be hoisted in making the reading. The problem is to ascertain by electrical means the magnetic direction of the current. One means of accomplishing this requires that a suitably constructed needle, swinging over a horizontal circle or ring, be inclosed in the body of the instrument. One electro-magnet in the body of the instrument is in circuit with the observing apparatus in the boat. The armature of this magnet, when the latter is magnetized and demagnetized by the observer in the boat, mechanically moves or rotates the horizontal ring under the needle until a contact is made between a metallic point situated upon it and a similar point on the needle or the case inclosing it. This contact closes a second circuit, which in turn opens the first. The position of a pointer in the receiving apparatus shows the direction of the needle at the time of observation. The moving horizontal ring or circular arc is brought back to its initial position by means of a spring when the observation is ended. In a general way this describes the direction current meter devised by Ritchie and Haskell. A brief description of the meter is given on pages 343-345 of the U. S. Coast and Geodetic Survey Report for 1891 (II).

A meter for measuring the directions and velocities of ocean currents at various depths, invented by Prof. O. Pettersson, is briefly described in Vol. I, Svenska Hydrografisk Biologiska Kommissionens Skrifter.

62. *Miscellaneous apparatus and methods for observing currents.*

A method of observing currents below the surface has been employed by W. Bell Dawson in St. Lawrence Bay.* A fan consisting of two sheets of galvanized iron intersecting at right angles, suspended by sounding wire. The direction and inclination to the vertical of the wire near the surface are noted. The value of the velocity becomes known from a table constructed from actual observation.

The velocity of the current can be measured by noting the angle of deviation of a pendulumlike body from the vertical. An apparatus adapted to this mode of measurement is called a hydrometric pendulum.

Pitot's tube is an instrument which measures the velocity of the stream by means of the head of water sustained by the impulse of the stream. More or less elaborate types of this instrument are described in treatises on hydraulics.

In case of very low velocities, such as those found at sea, it seems probable that floats are the only reliable apparatus.

For a comparison of results obtained by means of different instruments and by different methods, reference may be made to Doctor Murphy's paper entitled "Accuracy of Stream Measurements," and especially to pages 47-59.

63. *Nonharmonic reduction of currents.*

Unless the current observations extend over several weeks of time, it is generally advantageous to plot them upon cross-section paper. This is done by taking the times as abscissæ and the velocities as ordinates of a curve. At the foot of each ordinate the direction is written, unless a second curve is constructed having times for abscissæ

*Survey of Tides and Currents in Canadian Waters; Report of Progress, 1897.

and directions for ordinates. Near the upper margin of the sheet containing the plotting or plottings, the times of high and low waters at some station to which it is proposed to refer the currents are indicated. In case no near-by or suitable station is available, the currents may be referred to the moon's transits, and these should be indicated near the upper margin of the sheet. For tidal rivers, straits, sounds, and other narrow bodies of water it is generally sufficient to tabulate the times of the maximum velocities and of the slack waters. In more open bodies of water, or wherever the current may be rotary in character, hourly values before and after the times of the high and low waters, or before and after the times of the moon's transit, should be tabulated. See tabulations in sections 95 and 96.

By using multiples of twenty-four hours for the length of the series tabulated, the diurnal inequalities will be nearly eliminated and the mean values of flood, ebb, etc., will be those pertaining to the semidaily wave.

If there is no permanent current, the semidaily values obtained can be reduced to their mean values by means of the factor Mn/Mn′, where Mn denotes the true mean range of tide at the reference station and Mn′ the mean range at the reference station for the period covered by the current series. In a short series, use in place of Mn′, the actual range of each particular tide at the reference station. If there is a permanent flow, this should be taken out in accordance with section 53 before applying this factor to the tidal current; it may then be restored. In the tables of current data, sections 83 and 90, both kinds of current are to be kept together as has generally been done. Only the harmonically analyzed currents are free from the permanent flow wherever such flow exists. On the maps (Figs. 5–17) the two kinds are kept separate.

64. *Harmonic reduction of currents.*

The advantage of harmonic over nonharmonic methods is even greater in the reduction of currents than in the reduction of tides, for current observations are much more irregular than tidal observations, and the quantities sought are frequently so small as to be completely hidden from view.

A fairly good analysis can be made for a series of hourly observations extending over fifteen or twenty-nine days. These may be plotted on cross-section paper in the manner already described, but omitting the times of the high and low waters and the transits. Whether plotted or not the hourly values of the current should be resolved into north-and-south and east-and-west component velocities. This can be done either by means of an ordinary traverse table or graphically, using cross-section paper upon which is drawn a large circle divided into degrees and over which moves a graduated arm, rotating about the center of the circle. The north-and-south values are written upon one sheet or set of sheets and the east-and-west upon another. To avoid negative numbers, one or more whole knots may be added to the true values.

Each set of sheets is then summed for the current constituents in the same manner as would have been done had they contained tidal ordinates. (See sec. 77, Part II.) The harmonic analysis as carried out here differs in no respect from that applied to the tides.

When a series is only a few days in length, the most that analysis can give directly is a semidiurnal part, a diurnal part, and possibly quarter daily part; these may be denoted by $\dot{\varDelta}_{2n}$, $\dot{\varDelta}_{2e}$, $\dot{\varDelta}_{1n}$, $\dot{\varDelta}_{1e}$, $\dot{\varDelta}_{4n}$, $\dot{\varDelta}_{4e}$. Now, about the only reasoning available is that in each of these waves the ratios between constituent amplitudes and the relative phases or ages are the same as the corresponding ratios and ages in the tide wave. Assuming these quantities to be known for the tide, they become available for inferring constituents of the currents from the observed Δ's.

We are thus led to the problem: Given the harmonic tidal constituents for a given station, required the amplitude and time or phase of the semidaily wave and of the daily wave for a particular day or for several days.

These can be readily obtained from reliable predictions or from tidal record covering the period of current observation by summing and analyzing as if for currents. If no predictions are available, they can be made by some of the methods mentioned in sections 57–67, Part III. For this purpose the predictions need not be very elaborate.

Having found the ζ and R of any tidal constituent, $\dot{C}$, the epoch and amplitude of the corresponding current constituent, C, are given by the relations

$$\dot{C}_n^\circ = \zeta(\dot{C}_n) + C^\circ - \zeta(C), \tag{296}$$

$$\dot{C}_e^\circ = \zeta(\dot{C}_e) + C^\circ - \zeta(C), \tag{297}$$

$$\dot{C}_n = C \frac{12\, R\,(\dot{C}_n)}{12\, R\,(C)}, \tag{298}$$

$$\dot{C}_e = C \frac{12\, R\,(\dot{C}_e)}{12\, R\,(C)}, \tag{299}$$

For obtaining the maximum and minimum velocities from the north and south components, see section 51.

65. *Prediction of currents.*

If the tidal currents have but a small diurnal inequality, they can generally be predicted by applying differences to the predicted times of tides at a near-by station and suitable factors to the heights reckoned from mean sea level. At such stations the times of currents can be predicted by applying intervals (varying somewhat during the synodic half month) to the times of the moon's transit.

Where the diurnal inequalities are considerable, the currents do not generally correspond well with the tides. If sufficient observations are available, they may be tabulated according to two arguments, viz., the moon's transit and the day of year. Such tabulations are available at once for making predictions. (Cf. sec. 59, Part I.)

From suitable harmonic analyses the entire current ellipse for stations having rotary currents can be predicted by means of tide predicting machines. (Sec. 78, Part II). An ordinary machine will give at one setting one of the component velocities for as long a period of time as may be desired. Another setting will give the other component velocity. The two can be combined without difficulty by means of a right-angled triangle.

If the machine have two sets of cranks and pulleys, and the two sets of cranks differ in phase by 90°, then by using principal directions the two motions can go on at the same time. If the summation chains after passing over the pulleys cross each other perpendicularly, the distance between two fixed points upon them can be made to represent the velocity of the resultant current in both magnitude and direction.

CHAPTER VI.

DESCRIPTIONS OF TIDAL CURRENTS.

66. *Remarks on current charts.*

Synoptical charts are referred to in the description of the tidal currents around the British Isles. They aim to show, without computation, the direction and velocity of the currents for the region covered, at each tidal hour. The fact that at least 6 or 12 charts are thus required, is in itself, a serious drawback. They are not convenient for showing how the times of the turning of the tide at different places compare with one another; for, several charts would have to be consulted, and hourly values do not give such differences very closely. Such charts are, however well suited to the wants of the navigator.

Mr. John Ross, of this Survey, has devised a form of chart for presenting current and tidal data, not over areas, but along a given path of commerce. The distance from an assumed point is one coördinate and the time with reference to a near-by tide the other coördinate. The tabular values are the velocity and sometimes the direction of the current; also, the time of local high and low water. A simple diagram accompanies each chart; the object of the diagram is to enable the navigator to readily apply the values found upon the chart. Examples of such charts are given in the Coast and Geodetic Survey Tide Tables, and Chart No. 1610 published by the United States Hydrographic Office.

A current hour is the Greenwich lunar time of a particular phase of the tidal current, say, of the maximum flood.

Generally speaking, the flood may be taken as the stream whose maximum velocity occurs after local low water and before or at local high water. In some rare cases where the maximum velocity occurs shortly after local high water, the stream may still be regarded as the flood.

In many localities a given stream if followed some distance will change its name from flood to ebb—the change occurring where the time of maximum flood is simultaneous with the time of local high water; similar remarks apply to the ebb.

The necessity for changing the designation of a stream from flood to ebb, or vice versâ, shows the advantage of using not exactly the times of actual maximum velocities, but the times of the maximum of the regular semidaily velocities; in other words, the times of the M_2 current stripped of the disturbing influences of the M_4- and M_6-currents. Some values of this regular semidaily current will be found in the table of harmonic constants given under section 97. These have been brought out by analyzing hourly values of the velocities generally resolved into north-and-south and east-and-west directions. A good approximation to the M_2-current hour can be obtained by taking the mean between the observed flood-current hour and the ebb-current hour, having first increased or decreased the latter by 6. Another way is to take the mean between two consecutive slack-current hours. A still closer approximation is to take the mean between the flood-current hour, the ebb-current hour, increased or decreased by 6; one slack hour, increased or decreased by 3; and the other by 9.

The ebb arrows are not generally shown upon the cocurrent charts, because they are simply the reverse of the flood arrows; when shown they are distinguished by a single barb. The permanent current is represented by the blunt-headed arrows. Where rotary currents are represented, the flood arrow is drawn in the usual way and the minimum velocity following the flood by 3 hours is shown by a line without barbs. Its length compared with the length of the flood arrow bears the ratio of the observed velocities. For convenience all flood arrows upon the same chart are of equal length; so, also, are the blunt arrows representing permanent streams. The velocities in knots in these two cases may be written upon or near the arrows.

The tabular values given under sections 95 and 96 contain whatever permanent current was running at the time when the observations were taken.

When the current at a given station is referred to a tide at some point more or less distant, it is to be assumed that a common time is used for both places.

When the current is referred to a transit of the moon, it may be assumed that the transit refers to the local meridian.

67. *Common characteristics of currents.*

The effect of the combination of a nearly stationary stream with one rapidly progressive has been considered in section 49. The former is often an on-and-off shore stream, the latter, one flowing nearly parallel to the shore line. Circular points occur most frequently where the stream divides, although not simultaneously, and much less frequently where two streams come together.

If the current turn clockwise, the order of the cocurrent lines is counterclockwise, and vice versâ.

Having a reliable map of cotidal lines, the time of turning, or of maximum velocity, of the tidal current through a strait of moderate length can generally be inferred with considerable accuracy. The two cases which lend themselves to computation most readily are: 1. A narrow strait of varying cross section and whose length is only a small fraction of λ (λ being reckoned according to the depth of the strait), and wherein the motion is hydraulic because the velocity is so great that too many particles leave the strait proper for permitting the motion to become oscillatory. 2. A strait of such considerable length and of sufficiently great cross section (implying reduced velocity), for preventing more than a small fraction of the particles from leaving the strait (i. e., the strait proper and its approaches), and so causing the motion to become oscillatory.

The motion pertaining to a narrow strait dies out rapidly in either tidal body connected, while the motion of a broader strait is shared by the water for some distance beyond one or both ends of the strait.

Where the current is hydraulic, the greatest velocity toward the body having temporarily the lower level occurs when the downward slope in that direction is the greatest; such times can be taken directly from Table 60.

Where the curernt is oscillatory, the greatest acceleration toward the body having temporarily the lower level occurs when the downward slope in that direction is the greatest; such times can be taken directly from Table 60, but the maximum velocity in the given direction occurs $\frac{1}{4}\tau$ (or three hours for a semidaily tide) later than the time given in Table 60. Many examples of these cases will be given in the descriptions of tidal streams.

A long shallow strait, especially if connecting shallow bodies, may have a progressive wave or current passing through it. If a strait have such dimensions that its current is partly progressive and partly stationary, the computation of the times of greatest velocity at various points along the strait becomes more difficult and unsatisfactory.

In small, sharp bays, in bays connected with the sea by means of tolerably broad straits, or in other small arms of the sea wherein the rise and fall of tide is nearly simultaneous with that outside, the slacks must occur at approximately the times of the tides. (See Chap. VIII, Part IV A.)

Another motion of a local character may be described here. This is what may be described as hydraulic-slope motion. If a stationary wave have an amplitude increasing (say) as one proceeds along a coast line, there is a tendency for any water along the shore not fully participating in the oscillatory motion, because of shore impediments, to seek its level. Moreover, the gravitational action tending to produce motion is direct; it acts upon the littoral strip of water and produces motion in this strip, and differs from hydraulic motions in straits where gravity acts upon the bodies connected. The motion thus set up in the strip may be simultaneous notwithstanding the shallowness of the water and so the slow rate with which pulses would travel; this is so because gravity acts similarly all along the strip and produces motion throughout such a body simultaneously. The effect of this action is to cause the water along the lateral boundaries of a stationary wave to turn earlier than the water along the axis or central portion.

Along the end boundaries of stationary waves (whether dependent or not), the current is weak and normal to the coast line.

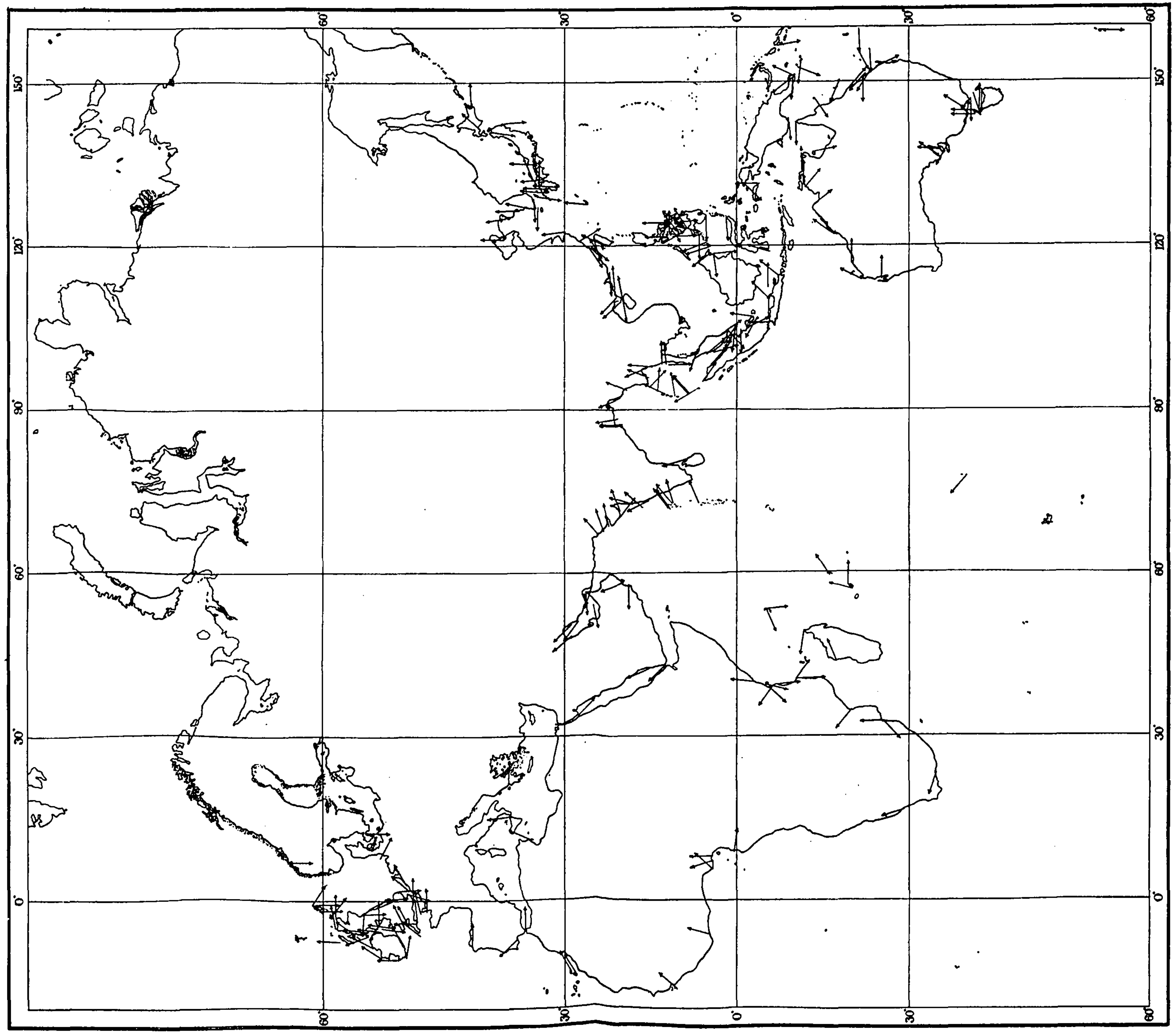
68. *Tidal currents for the world at large.*

Tidal currents have been observed only in comparatively shallow waters, such as the marginal strips next the coast lines, the waters overlying continental shelves and shoals, in sounds and other dependent bodies. For this reason the information regarding tidal currents is very meager. In Figs. 5 and 6 an attempt has been made to bring together, chiefly from the Admiralty charts, the principal observational data relating to the direction of the ocean tidal currents.

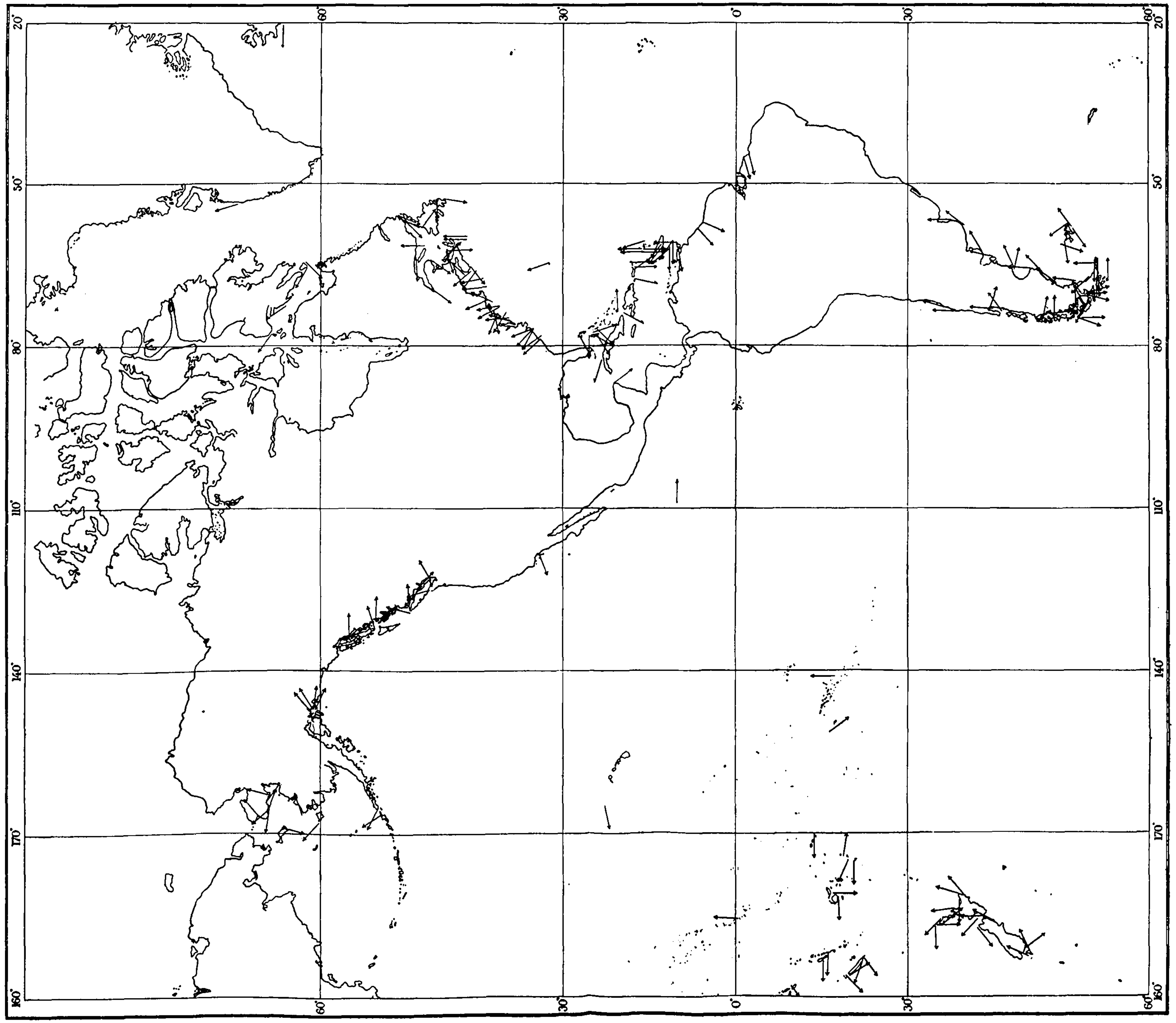
As remarked in section 30, Part IV B, the flood flows northerly at the Baluchistan end, and southerly at the Madagascar end of the half-wave area extending between these coasts. It was also noted that the flood flows southeasterly through the Seychelle Archipelago, indicating the superposition of an east-and-west motion upon the north-and-south motion of the area just mentioned. The currents of the Bay of Bengal are nearly normal to the coast, indicating the stationary character of the tide. The same is true for the waters northwest of Australia, south of Cape Colony, southeast of Brazil, southeast of the United States, northeast of Brazil, off Panama, off Alaska, and probably south of Australia. Some further evidence bearing upon this will be noted below, especially in connection with quotations from the Admiralty Coast Pilots.

Many localities have the controlling tidal streams running parallel to the shore. Such shores may be lateral boundaries of either a stationary or a progressive wave.

No. 5.



TIDAL CURRENTS.



TIDAL CURRENTS.

The eastern coast of Ceylon and Somaliland, and the outer coast of the Virgin Islands and California—all lying near nodal lines—are examples of the first case; while portions of western Europe, southern South America, western Oceanica, and many arms of the sea extending inland are examples of the second.

The harmonic constants of stations off the Atlantic coast of the United States (sec. 97) show how very feeble the tidal currents become away from land and near the end of a stationary wave; also how progressions into neighboring dependent arms of the sea cause transverse velocities often comparable with the velocities of the main oscillation.

69. *Coasts of Africa.*

On account of the regular outline of Africa and the comparative absence of off-lying shoals and chains of islands, it is fair to assume that the movements of the ocean extend to the very coast of the continent. The tidal currents as well as the tide should therefore be some index as to the character of the motion in the surrounding deep waters. The quotations given below are taken from Parts I (1899), II (1901), and III (1897), of the African Pilot published by the Admiralty. The matters relating to the times and heights of the tides are generally omitted, as such information can be obtained from the charts in Part IV B, this manual.

Evidence of the half-wave area extending from Mozambique Channel to Baluchistan and India is afforded by the southwesterly set of the flood current at the northern end of the channel.

The fact that at the southern end of the channel flood sets northerly indicates that here is a loop of one or more stationary waves extending in a southerly direction. (See Fig. 23, Part IV A, and Fig. 1, Part IV B.)

Evidence of an area whose motion is north and south with a loop near Cape Colony is afforded by the quotations which indicate small tidal streams around Table Bay and eastward.

The smallness of the stream in the Gulf of Guinea is in accord with the rather small ranges of tide and the fact that this gulf does not partake of the general oscillatory movement of the South Atlantic system.

The smallness of the currents off French Guinea and Sierra Leone indicates the proximity of a loop of the South Atlantic system.

The considerable northeasterly flood through the Canary Islands indicates the existence of the North Atlantic system.

A similar flood through the Azores indicates northerly progression due to openings northwest of Europe.

At the entrance to the Strait of Gibraltar the streams are weak while the range of tide is considerable; they turn at nearly the times of high and low waters.

The quotation relating to the Kongo River shows that the varying density of the water near the river's mouth has its influence upon the currents.

70. *Coasts of Africa, quotations.**

On the north shore of Mohilla the flood sets to the westward, but changes before the water has done rising, as does the stream to the eastward before low water.

* In the Admiralty Pilots, Directories, etc., the bearings are magnetic unless otherwise stated.

St. Lazarus Bank: A regular tide was observed when at anchor on the bank, the flood setting E.S.E. about 4 hours, and the ebb W.N.W. about 7 hours, with about half an hour slack water; the strength at springs was 2 knots; the rise and fall, approximately, 12 feet.

In the northern part of Pemba channel, near the coast of Pemba island, the flood stream setting to the southward neutralizes and at times overcomes the constant north-going current, and the ebb accelerates it.

It is high water, full and change, in Kokotoni harbor, at 4h. 10m.; springs rise 15 feet, neaps 10 feet. As a rule the flood runs southward, and the ebb northward.

Zanzibar Channel: The tidal streams, as a rule, are as follows: The flood runs southward in the northern part of Zanzibar channel, and in a contrary direction at the southern end, thus meeting at high water at a point near the center, the position of which depends much upon the wind.

Dar-es-salaam Bay: As a general rule, the flood runs north-westward, and the ebb in the contrary direction, but amongst the islands and reefs the streams will often be found setting to the opposite points.

Mafia Channel: The tidal streams are strong in all the channels, and along the shore; the flood stream running southward and towards the shore, the ebb to the northward and off the shore.

The direction of the tidal stream northward of Ras Kisimani is ebb to the northward and eastward, and flood to the southward.

It is high water, full and change, at Kilwa Kivinje, at 4h. 0m.; springs rise about 12 feet. There is but little tidal stream at the anchorage.

It is high water, full and change, in Lindi river, at 4h. 5m.; springs rise 11 feet. The tidal streams in the bay, outside the bank of soundings are not strong.

It is high water, full and change, at Mgau Mwania at 3h. 45m.; springs rise 12 feet; off the entrance the flood runs to the northward, and the ebb to the south-eastward, with a force of from 2 to 3 knots.

It is high water, full and change, in Mikindani harbor at 3h. 50m.; springs rise 12 feet. The tidal stream in the harbor is scarcely perceptible.

It is high water in Rovúma bay, full and change, at 4h. 10m.; springs rise 12 feet; the ebb running to the northward and flood to the south-eastward.

In Maiyapa bay, the flood sets north-westward, and the ebb south-eastward at the rate of 2 to 4 knots at springs.

Nyuni Pass: The flood sets north-westward from 2 to 3 knots at springs, but is scarcely perceptible at neaps.

Nameguo Pass: The tidal streams within the outer reefs are irregular.

It is high water at Kero Nyuni, full and change, at 4h. 15m.; springs rise 13 feet.

It is high water, full and change, at Mozambique, at 4h. 15m.; springs rise 12 feet. The streams run strong in the harbour—the flood to the westward, the ebb to the eastward.

The tidal rise in the mouths of the Zambezi is about 12 feet at springs; this amount is reduced to about 5 feet at Mchenga, situated about 25 miles above the entrances and 5 miles above the junction of the Chinde; the time of high water at Mchenga is 2½ hours later than at the mouth of the Chinde, or 6h. 50m., full and change.

Inhamissengo Mouth: It is high water, full and change, at 4h. 30m.; springs rise about 12 feet. The ebb tide at springs runs 4 to 4½ knots in the entrance.

Pungue River: The tidal streams are very strong, especially when the river is high; as much as 5 knots at springs have been observed at the junction of the Pungue and Buzi.

It is high water, full and change, at Innambán at 5h. 38m.; springs rise 11 feet, neaps 7 feet The stream runs strong in the river; off the town it sometimes amounts to 4 knots an hour.

Delagoa Bay: Seaward of the shoals, the flood sets to the northward at the rate of 2 knots.

Port Natal: In the port, the time of high water at full and change is 4h. 30m., springs rise 6 feet. The velocity of the ebb at springs is about 3 miles an hour in the Bluff channel and of the flood about 2½ miles.

In the road, outside the bar, the flood stream sets nearly north and the ebb in the opposite direction.

Kei River: It is high water, full and change, at Kei river at about 4h. 0m.; springs rise about 5 feet. The flood stream sets north-eastward close in shore, and the ebb south-westward.

It is high water, full and change, at Port Elizabeth at 3h. 10m., and the rise is 6 feet; the tides are often irregular, being acted upon by the wind. The surface stream is uncertain in direction and inappreciable.

It is high water, full and change, in Table bay at 2h. 40m.; springs rise 5 feet, neaps $3\frac{1}{2}$ feet. The duration of slack at high water varies considerably, and greatly depends on the prevailing wind; the water is never stationary more than 30 minutes, and frequently it begins to fall immediately on reaching high water There is no sensible stream of tide, either in the bay or on the adjacent coast. The time of high water and its rise is nearly the same at Simons bay, and at all the bays along the coast from the Cape of Good Hope to Cape Agulhas.

Congo River: The observations appeared to show that the fresh water of the Congo extends from the surface to the bottom until the head of the Congo cañon just below Kissanga, when it encounters a body of salt water filling this deep gully. It then runs over this denser water with decreased depth and increased velocity, the layer of fresh water being deeper with the ebb tide and shallower with the flood, both decreasing the broader the river becomes, until, from being from 3 to 5 fathoms deep just below Bull island, it is only a few feet deep after passing Bulambemba point.

This deep body of salt water is either perfectly still, or has a very slight tidal flow (two-tenths to half a knot per hour) up river with the flood, and down with the ebb tide.

Ambas Bay: The tidal streams appear to run both ways for an equal period; the flood setting to the south, and the ebb to the north out of Ambas bay between Ambas island and Pirate rocks

New Calabar River: The ebb stream sets over Baleur bank, the flood stream sometimes sets over the western shoals, but if the outside current is setting strongly to the eastward, the flood stream will be but little felt. Near Sand island both ebb and flood streams set toward that island.

Off Bonny town the ebb stream runs from 3 to $3\frac{1}{2}$ knots an hour in a S.W. by W. direction.

It is high water, full and change, in Ramos river at 4h. 20m.; springs rise 5 feet. The ebb runs for 9 hours.

Forcados River: On the bar, the flood tide sets across it to the northward, the ebb in the contrary direction, which must be allowed for.

Benin River: The tidal stream in the river is said to sometimes run at a rate of 4 to 5 knots an hour.

On the bar, the ebb stream sets to the westward and the flood about E. by N., but a set, toward the northern breakers, has been experienced on the flood.

Banana Islands: The flood sets East and E.S.E.; the ebb W.S.W. and W. by N.; rate 1 to $1\frac{1}{2}$ knots.

Isles do Los: The flood stream sets to the N.E., and the ebb in contrary direction, with a rate of from $1\frac{1}{4}$ to $1\frac{1}{2}$ knots an hour at spring tides.

At the entrance of the Nunez river the flood sets N.E. and ebb S.W. at rates of from 2 to 3 knots an hour. West of Talabuncha point the flood sets in a northerly, and ebb in a contrary, direction.

Orange Channel: The ebb stream seldom exceeds $2\frac{1}{2}$ knots and the flood $1\frac{1}{2}$ knots an hour in velocity, except after heavy freshets in the rivers, the general direction of the flood stream being to the N.E., and the ebb to the S.W.

The ebb stream in the Cacheo, as also off it, sets to the N.E., and the flood to the S.W.

It is high water, full and change, in the Kasamanze river at 9h. 55m.; springs rise $5\frac{3}{4}$ feet.

In the Great pass the flood stream has a tendency to set towards the north, and the ebb toward the south bank; the rates vary from 2 to 3 knots an hour.

The tidal streams are felt so far as point Piedras, about 60 miles from the bar.

Salum River: At Kaolack it is high water, full and change, at 6h. 5m. the rise and fall of tide is about $3\frac{1}{4}$ feet.

The tidal streams run very strongly on the bar and in the narrow parts of the river, the stream of both flood and ebb continuing from 2 to $2\frac{1}{2}$ hours after high and low water, during which period there is no appreciable rise and fall until the stream turns. The flood tide entering at West pass sometimes attains a velocity of 3 knots an hour, and splits after crossing the bar.

It is high water, full and change, between Sta. Lucia and Branca islands at 7h.; springs rise about 5 feet.

The flood stream sets to the westward, and the ebb to the eastward with a velocity of 2 knots an hour during springs.

Near the shore, at Cape Verde, the tidal streams are very appreciable, the flood dividing into two branches, one setting to the northward, the other toward Almadi point; the flood stream occasions strong and irregular currents in Yof bay; the ebb stream sets off shore.

Senegal River: Abreast of this river, and for a space of several miles to seaward, the powerful tidal streams, both in and out, affect the general uniformity of the southerly current, and are often so strong as to bring vessels, anchored in the outer road, with their broadsides to the wind in the strongest breezes. These outer tidal streams have no very regular set; the flood stream, however, generally runs E.N.E. and the ebb W.N.W.

It is high water, full and change, in Ouro river at oh. om.; springs rise 8 or 9 feet.

Off the entrance the flood stream sets nearly east, and the ebb west, with a velocity of about 2½ knots an hour

Lanzarote Island: The flood streams run to E.N.E. and ebb stream in a contrary direction, the rate, at spring tides, being about 1 knot an hour.

Lobos Island: The flood stream sets E.N.E. and ebb W.N.W.

It is high water, full and change, in Santa Cruz bay at 1h 30m.; springs rise 8 feet, neaps 6 feet.

The tidal streams set by the Dezerta islands during spring tides, at the rate of 1½ to 2 miles per hour; the flood in the direction of N.E. by E., and the ebb S.W. by W. Springs rise 7 feet.

It is high water, full and change, in Funchal bay at oh. 48m.; prings rise 7 feet.

The tidal wave strikes these [Madeira] islands nearly at the same time as the Azores, the flood stream running to the north-eastward at the rate of 1½ miles per hour at spring tides, and in the narrow channels between Dezerta islands and off San Lourenzo point, it sometimes attains the velocity of 2 miles per hour.

It is high water, full and change, in Mogador harbour at 1h. 18m.; springs rise 10 or 12 feet. The tides are generally regular in their rise and fall, but the direction of the tidal stream varies with the wind, and its strength is at all times weak.

The flood stream in the offing north of Tangier bay runs from east to west, and the ebb in the reverse direction, turning in mid-channel at high and low water by the shore.

In Fayal channel the flood stream sets N.E., and the ebb S.W., with a velocity of from 1 to 2 knots an hour.

It is high water, full and change, at Corvo and Flores islands at oh. 20m.; springs rise 3½ feet.

The stream of flood tide runs to N.E. by N. and the ebb S.W. by S., with a velocity of 1½ knots per hour at springs; these tidal streams, when opposed by gales, create a most confused sea off the north and south extremes of both islands.

The currents in the Straits of Gibraltar and Messina, and the Euripus, are described in sections 84–86, Part IV A.

On account of the large rise and fall around the coasts of Spain, Portugal, and France, the currents are very strong in the tidal rivers. For brief accounts of these currents see Sailing Directions for the West Coasts of France, Spain, and Portugal, published by the Admiralty; also Étude Pratique sur les Marées Fluviales, by M. Comoy.

71. *The British Isles and the North Sea.*

The behavior of the tidal currents in this region has long been understood. For instance, Barlow, on a map facing page 140 of his Exact Survey of the Tide (1717), shows the general direction taken by the flood stream in these waters, although he here aims at showing the advance of the tidal wave. A similar map for the northern part of the Irish Sea occurs between pages 152 and 153 of his treatise.

The charts of Captain Beechey are briefly referred to in section 126, Part I, and two of these are reproduced as Figs. 27 and 28, Part IV A.

The character of the tide wave, whether progressive or stationary, is indicated upon a chart opposite page 125 of a book entitled "The Tides;" Society for Promoting Christian Knowledge (1857).

In connection with the below descriptions it will be found advantageous to frequently consult section 44 and Figs. 20–22, Part IV B, in order to see the relations between the currents and the tides.

The English Channel and the Irish Sea contain stationary waves whose particles are at elongation inward at about the time of high water at Dover, or at about XI Greenwich lunar time (Fig. 20; Part IV B). At this time the water is slack over nearly all of the Irish Sea, including the axis of the North Channel, and over a portion of the English Channel north of Cherbourg. Three (lunar) hours before high water at Dover the flood is running strongly in the regions just mentioned, and three hours after high water the ebb is running strongly. The tendency of the apparently progressive part of the wave between the northwestern corner of France and the southern part of Ireland is to cause the inward stream to have its maximum velocity at IV instead of at XI − 3 or VIII. As a matter of fact, the greatest inward velocity here occurs about 4 hours after Dover high water, or at III. This indicates that the tidal wave in this region is partly stationary, as is generally the case in a marginal strip of shallow water lying between the deep water of the ocean and the land. In both the Bristol Channel and the Gulf of St. Malo, there is evidence from the cotidal chart of a stationary wave; for, in either case the rate of advance is greater than that due to depth. But toward the inner ends of these arms of water, where the tidal hour is VI, the greatest velocity of the flood stream occurs at about 2½ hours before the time of high water there, or at about III½, Greenwich time. The effect of Bristol Bay upon the currents off the Scilly Islands is evidently to stop the northeasterly flood stream before the easterly stream slackens at this part of the English Channel. Hence the currents are here rotary in character and clockwise in rotation. The reverse must be true of the currents north of Cotes du Nord. The following quotation and table are taken from the Admiralty Tide Tables for the British and Irish ports for the year 1907, and illustrate what has just been said:

> Off the mouth of the English Channel the stream, although materially influenced by the indraft and outset of the Channel, will be found running to the *northward and eastward,* while the water is *falling* at Dover; and to the *southward and westward* while it is *rising* at that port. The particular direction given to the stream in this part of the sea, by the meeting of the Channel and of the offing tides, will be shown in the table [1st below]; and it is only necessary to mention here, that to the southward of the parallel of Scilly, the tidal streams of the Channel and offing blend together with varying force and direction, and occasion the direction of the stream to be constantly changing, and in some places even to make the entire circuit of the compass in one tide, without ever remaining long upon any one point; so that any written description of their course is rendered almost impossible, and the table alone must be consulted for the direction at any particular hour. From this rotatory motion of the stream, it has been asserted that a vessel can never be carried far in any direction by it. Such, however, is not the case; for, although it may be true that while at anchor in a particular spot the vessel's head will turn to every point of the compass, yet directly she is loose she will be carried away upon a rhomb depending upon the state of the tide at Dover.

Westward of a line joining Ushant and the Land's End.

Hours	North side of latitude 49° N.						South side of 49° N.	
	West part	Rate	Near Scilly	Rate	Seven stones L. V.	Rate	West part	Rate
						Knots		
H. W.		Greatest rate, springs, 1½ knots		Greatest rate, springs, 1½ knots	WSW. to WNW.	0 to 1	......	Greatest rate, springs, 1½ knots
After high water, Dover 1	NW. by W.		NW. by N.		NW. to NNW.	0 to 1	WNW.	
2	N. by W.		N. by W.		N. by E.	0 to 1¼	NNW.	
3	NE.		N. by E.		NE. by N.	0 to 1½	ENE.	
4	ENE.		NE.		NE.	¼ to 1½	ENE.	
5	ENE.		NE.		ENE.	¼ to 1½	NE. by E.	
6	Ely.		E.		ENE. to ESE.	0 to 1	Ely.	
Before high water, Dover 5	ESE.		......		SE. to SSE.	¼ to 1	SE.	
4	S.		Sly.		S.	¼ to 1¾	Draining.	
3	SSW.		SW.		SSW.	¼ to 1¾	SSW.	
2	SWly.		SWly.		SW.½ S.	¼ to 1¾	SW. by S.	
1	WSW.		SWly.		SW. by W.	¼ to 1¼	SW. by W.	

Entrance of Gulf of St. Malo on a line joining Brehat Island and southwest end of Guernsey.

Hours	Westward from Sept Isles		12 miles from Brehat Island		12 miles from Guernsey		Near SW. point Guernsey		4 miles W. by S. from Casquets		4 miles WNW. of Cape La Hague	
	Course	Rate	Course	Rate	Course	Rate	Course	Rate	Course	Rate	Course	Rate
H. W.	WNW.	Greatest rate, springs, 2 knots	NNW.	Greatest rate, uncertain	WNW.	Greatest rate, uncertain	Wly.	Greatest rate, uncertain	W. by N.	Greatest rate, springs, 5 to 7 knots	WSW.	Greatest rate, springs, 5 to 7 knots
After high water, Dover 1	W. by S.		WNW.		Wly.		Wly.		W. by S.		SW. by W.	
2	WSW.		SWly.		SWly.		SSW.		SW.		SW. by W.	
3	SW. by W.		Sly.		Sly.		SSW.		SW.		SW. by W.	
4	SSW.		SE.		SE. by S.		SE.		S.		SW. by S.	
5	S.		SE.		ESE.		ESE.		SE. by S.		SW. by S.	
6	SE.		SE.		ESE.		ESE.		SE. by E.		NE. by E.	
Before high water, Dover 5	E. by S.		SE. by E.		ESE.		{ESE. / E. by N.}		E. by N.		NE. by E.	
4	E. by N.		NEly.		Ely.		{ESE. / E. by N.}		NE. by N.		NE. by E.	
3	NEly.		NW.		NNE.		....		NE. by N.		NE. by N.	
2	Turning.		NW.		NNW.		NNW.		NE. by E.		NE. by N.	
1	NW. by N.		NW. by W.		W. by N.		NNW.		N.		NE. by N.	

It should be remembered that the directions in the quotations from the Admiralty Tide Tables are magnetic.

Concerning the streams near the Channel Islands the Tide Tables say:

Near Guernsey and to the northward of that island the true Channel stream prevails; the great body of the water running about E. by N. whilst the tide is *rising* at Dover, and about W.S.W. when it is *falling* at that place; but near Roches Douvres to the southward, the stream sets S.E. into the Gulf of St. Malo, from 2 hours after high water at Dover to 4 hours before high water there, and N.W. during the remainder of the tides.

Thus what is called *tide and half tide* prevails at Guernsey and amongst the islands to the northward; whilst at Jersey and along the southern shore of the gulf, and out to the westward toward Roches Douvres, the stream is more uniform and regular; the former resulting directly from the action of the Channel stream, the latter from an interruption of the southern portion of that stream by the coast of France, and its diversion into the Gulf of St. Malo.

The center of Deroute channel (between Roches Douvres and Guernsey) may be considered to mark the separating boundary of these two streams; for along this line and to the eastward they successively run together side by side, blend, and separate in alternating direction and force, depending on the state of the tide.

It should here be noted that the tidal stream around and between the Channel islands has a rotatory motion (evidently caused by the different action of the above-described two streams and the peculiar form of the shores of the gulf) from right to left, going right round the compass in little more than 12 hours.

* * * * * * *

In the offing westward of Guernsey, the stream seldom attains a rate of 3 knots until the island is approached within 4 or 5 miles, where it increases to 4½ knots; in the Rûssel channels it exceeds 5 knots, and it runs about the same rate between Jersey and the Minquiers; in the center of Deroute channel, between Jersey and Sark, its strength is barely 4 knots, and 3 knots farther westward between Guernsey and Roches Douvres; near Roches Douvres the rate appears to be 3½ knots; in the offing north of Alderney and the Casquets, 5½ knots is not an uncommon rate for an ebb spring tide, and on similar occasions the Race and Swinge streams run more than 7 knots.

The rapidity with which the tides rise and fall and their velocity are greatly influenced by strong north-eastern and south-western gales; the former retarding and the latter accelerating their progress in a remarkable degree; the latter will also cause the Race stream to run three-quarters of an hour longer to the north-eastward than usual, although the former has not a similar effect upon the stream when running to the south-westward.

About one mile south of the bill of Portland, at half flood by the shore, or 4½ hours after high water at Dover, the stream sets from S.S.E. to S.E. by E., and the opposite stream about W.S.W.; the velocity of both streams, at springs, being from 5 to 6 knots; but although they run with such violence near the Race, about one mile S.W. of the bill they are weak.

Off Portland Bill the easterly velocity of the main stationary wave should have its greatest value at about XI − 3 or VIII. But the observed tidal hour for Portland Bill is VI. As a matter of fact, the greatest easterly velocity occurs at about VII½, according to the Admiralty Tide Tables.

The times of the greatest eastward velocity through Dover Strait can be inferred from the tides by noting the tidal hours and ranges off either end of the strait proper and adding 3 hours to the values given by Table 60. The tide off the west end of the strait occurs at X½ hours, the mean range being 20 feet; the corresponding quantities for the east end are XI½ and 12. Hence the time of maximum eastward downward slope is X½ − 1.066 = 9.434; this increased by 3 hours gives XII.43 for the time of the maximum eastward current in the strait, which practically agrees with the results of observation.

As already remarked, the principal current in the Irish Sea has its maximum inward velocity at XI − 3 or VIII. Just off St. David's Head this velocity is from 2 to 4 knots and around the Skerries from 2 to 5. West of the Isle of Man this velocity is very small.

At the northern end of North Channel the tidal hour and mean range in feet are V.5 and 7, while for the southern end they are X.7 and 12. Using these values in Table 60 the time of maximum downward northward slope is X.98, and so, subtracting 3 hours from this value, the result is VII.98 for the time of the maximum southerly stream. Observation gives VIII as the current hour of the stream.

The cotidal lines in the North Channel, and also those in the Irish Sea and English Channel, are much influenced by the transverse slope due to the deflecting force of the earth's axial rotation. Not so with the cocurrent lines; for, the transverse velocity is small in comparison with the velocity along the strait or channel. Hence, *in a channel* *only moderately wide, and having a current of some magnitude, the cocurrent lines are frequently more simple in character than are the cotidal lines.* The reverse of this is often true along the irregular borders of open bodies of water and where the current is generally small.

The following quotations from the Admiralty Tide Tables partially describe the tides in the Irish Sea and adjacent waters:

72. In the Irish channel, as before observed, experiments have shown that, notwithstanding the variety of times of high water throughout the channel, the turn of the stream over all that part which may be called the fair navigable portion of the channel is nearly simultaneous; that the northern and southern streams in both channels commence and end in all parts (practically speaking) at nearly the same time; and that that time happens to correspond nearly with the time of high and low water on the shore at *the entrance* of Liverpool and of Morecambe bay,* a spot remarkable as being the point where the opposite streams coming round the extremities of Ireland terminate. So that it is necessary only to know the times of high and low water at either of these places, to determine the hour when the stream of either *tide will commence or terminate in any part of the channel.* For this purpose the Liverpool tide table may be used, subtracting a quarter of an hour from the times there given, in consequence of the high water at George pier being later than the point which is considered as the head of the tide.

The tidal undulation from the Atlantic enters the Irish channel by two channels; of which Carnsore point, the S.E. point of Ireland, and St. Davis head, the S.W. point of Wales, are the limits of the southern one; and Rathlin and the Mull of Cantyre the boundaries of the northern.

The axis of the in-going stream runs nearly in a line from a point midway between the Tuskar and the Bishops, to a position 16 miles due west of Holyhead; beyond which it begins to expand eastward and westward; but its main body preserves its direction straight forward toward the Calf of Man, which it passes to the eastward with increased velocity as far as Langness point, and then at a more moderate rate on toward Maughold head. Here it is arrested by the southern stream from the North channel coming round the point of Ayr, and is first turned to the eastward by it, and then goes with it at an easy rate direct from Morecambe bay; thus changing its direction nearly eight points.

* * * * * * *

The western part of the stream, after passing the Saltees, runs nearly in the direction of the Tuskar, sets sharply round it, and then takes a N.E. direction, setting fairly along the coast, but over the banks skirting the shore, so that vessels tacking near the inner edge of the sands with the northeast-going stream, and on the outer edge on the opposite stream, have been carried upon them and lost, especially upon the Arklow and Codling banks. Abreast of Arklow is situated that remarkable spot in the Irish channel, where the tide scarcely either rises or falls. The stream notwithstanding sweeps past it at the rate of 4 knots at springs, and reaches the parallel of Wicklow head. Here it encounters an extensive projection of Codling bank; and while the outer portion takes the circuit of the bank, the inner stream sweeps over it, occasioning an overfall and strong rippling all round the edge, by which the bank may generally be recognized. Beyond this point the streams unite and flow on toward Howth and Lambay, growing gradually weaker as they proceed, until they ultimately expend themselves in a large space of still water situated between the Isle of Man and Carlingford. There we have not been able to detect any stream; for there another remarkable phenomenon occurs--the water rising and falling without apparently any perceptible stream. This space of still water is marked by a bottom of blue mud. Such is the course of the flowing water of the Southern channel.

In the North channel the stream enters between the Mull of Cantyre and Rathlin island simultaneously with that passing the Tuskar into the Southern channel, but flows in the contrary direction. It runs at the rate of 3 knots at springs, increasing to 5 knots near the Mull, and to 4 near Tor point, on the opposite side of the channel. The eastern branch of this stream turns round the Mull toward Ailsa

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*The entrance of Liverpool and of Morecambe bay are, as before stated, 18 minutes earlier in their time of high water than those given for Liverpool in the tide tables.

At N. W. L. V., Liverpool bay, the flood stream sets in an ESE. direction, with a maximum rate at springs of 2½ knots; the ebb WNW., 2 knots. At neaps the flood sets at the rate of 1 knot, the ebb three-quarters of a knot.

and the Clyde, a portion passing round Sanda up Kilbrennen sound and loch Fyne. The main body sweeps to the S. by E., taking nearly the general direction of the channel, but pressing more heavily on the Wigtonshire coast. Near the Mull of Galloway the stream increases in velocity to 5 knots; the eastern portion turns sharply round the promontory toward the Solway, and splits off St. Bees head, one portion running up the Solway and the other toward Morecambe bay.

73. The currents on the west coast of Scotland turn soon after the times of local high water, indicating that the wave is there chiefly stationary. Through the larger channels the current is nearly oscillatory, but through the short and narrow straits it is nearly hydraulic. (See Chap. VIII, Part IV A.)

For example, the tidal hour just off the western end of Corrievrekin Strait is V.4 and that just off the southeastern end IV.5; the mean ranges off these two ends are 7 and 4 feet, respectively. Using these values in Table 60, it follows that the greatest southeastward downward slope occurs at VI.2; observation gives about VI.5 as the hour of the southeastward stream. Hence, the Corrievrekin is nearly hydraulic in character. The velocity of the strength of current varies from 4 to 8 knots.

Before making very satisfactory computations of this kind, it will be necessary to have the times and the heights of the tide carefully observed.

The currents in the Little Minch are oscillatory. The tidal hours off the north and south ends of the strait are VI.5 and V.5, while the ranges in feet are 11 and 8. By Table 60 the greatest southward downward slope occurs at VIII. Subtracting 3 from this, the theoretical hour for the north-going stream is V. Observation gives V½.

Scott, in The Lord of the Isles, thus speaks of the currents among the islands along the western coast of Scotland:

O'er look'd dark Mull! thy mighty Sound,
Where thwarting tides, with mingled roar,
Part thy swarth hills from Morven's shore.
* * * *
All day with fruitless strife they toil'd,
With eve the ebbing currents boil'd
More fierce from strait and lake;
And midway through the channel met
Conflicting tides that foam and fret,
And high their mingled billows jet,
As spears, that, in the battle set,
Spring upward as they break
* * * *
Or that your eye could see the mood
Of Corryvrekin's whirlpool rude,
When dons the Hag her whiten'd hood.

The following quotations from the Admiralty Tide Tables refer to the streams along the west coast of Scotland:

While the laws of the streams are thus of more importance than the laws of the rise and fall of the tide, they are also much more simple. The times of high and low water are very different at different parts of the coast, while the times of slack water are nearly the same throughout the whole region in question. In a great part of this region the stream has no distinct title to be considered either a flood or an ebb stream, although at any point it generally flows for six hours in one direction, and for six hours in the opposite direction.

* * * * * * *

Between the Mull of Cantyre and the north-east coast of Ireland, the most westerly part of the north-going stream turns to the west, and runs through the sound of Rathlin along the north coast of Ireland; the central part flows to the north-west past the Rhynns of Islay; the easterly part, which has flowed partly through the sound of Sanda, turns sharply round the Mull of Cantyre, and flows to the northward, pouring with great velocity through the narrow openings in the chain of islands, viz.: the sound of Islay, between Islay and Jura, the gulf of Coirebhreacain between Jura and Scarba, the little Coirebhreacain between Scarba and Lunga, the Slate isles and Cuan sound; of these, the little Coirebhreacain is quite impassable; and Coirebhreacain and Cuan sound are seldom attempted except near slack water.

Great complication arises from describing the time of change of the stream by reference to the time of high and low water on the shore; thus we should have to say that in the sound of Sanda, the ebb stream begins two hours before high water; at the Mull of Cantyre, one hour before high water; a little north of this, again two hours before high water. Southward of Gigha, we might say indifferently, that the flood tide runs to the south and begins three hours before low water, or that it runs to the north and begins three hours after low water; in the sound of Islay and in the gulf of Coirebhreacain that it begins an hour before low water; and in describing the streams along the north coast of Ireland we have even greater complication.

The direction of the tidal streams on the rest of the West coast of Scotland may be thus described: Outside of Islay and Iona the streams turn at the time of high and low water at Liverpool, running southward with the rising and northward with the falling tide at that place. At the northern end of the passage of Tiree the streams change at 1½ hours, at the southern end of the Little Minch at from three to four hours, and at the northern end at from four to five hours after high and low water at Liverpool; the time of the turn of the streams being thus gradually retarded as we proceed north. In the sound of Mull there is the same retardation, the streams turning at the southern end at one hour before, and at the northern end half an hour after, high and low water at Liverpool, and flowing in the same direction as above mentioned.

Round the north end of the island of Lewis, the stream bends into the Minch and meets the stream from the southward, the course of both streams being nearly the same as if there were an embankment from loch Shell in the island of Lewis to Ru Rea on the coast of Ross-shire. At the same time, another branch of the stream which has rounded Ardnamurchan point flows through Sleat sound, and being an hour earlier than the tide which has rounded the north end of Skye, it pours with great velocity through Kyle Rhea, but owing to the undulations round Skye meeting near Kyle Akin there is very little stream through that narrow opening; the flood stream, as it is stated, sometimes flowing in one direction and sometimes in the other, according to the prevailing winds.

74. The tide wave along the eastern coast of Scotland and England as far south as Flamborough Head is progressive in character as might be inferred from the cotidal charts, Figs. 21, 22, Part IV B. Now, observation shows that the currents follow this coast and attain their maximum flood velocities at about the times of local high water.

The corner of the sea lying between England and Holland and Belgium is characterized by a stationary oscillation (sec. 44, Part IV B) which is very apparent in the currents. Being an arm of an almost tideless sea sustained by the rise and fall in the Dover Strait, the northeastern stream should occur at XI + 3, or II, a fact agreeing with observation.

The tidal hours of the estuaries of the Schelde and Meuse ranges from XII to II. The east-going stream in the offing occurring at II, it follows that since the estuaries must contain tide waves, stationary in part, the times of greatest influx must be somewhat earlier than the times of tide. Observation shows that the greatest influx occurs from XII to I o'clock, or from 2 to 1 hours earlier than the greatest easterly stream in the offing.

Van Der Stok finds that at Schouwenbank L.V. the currents are rotary and counterclockwise as they should be in a case of this kind. (See table under sec. 97.)

The southeastern corner of the North Sea contains a tide wave stationary in part. This might be inferred from Fig. 22, Part IV B; but the greatest flood stream around Helgoland Island occurs 1⅔ hours before local high water.

The tidal streams in the approaches to the Baltic Sea are everywhere weak.

The famous Malström or Moskenström in the Lofoten Islands can possess no very unusual strength, because the mean range of tide is there only 6 feet, and the time of high or low water must be about the same for the whole region concerned in the production of the whirlpool. (Fig. 23, Part IV B.) Barlow gives a map (opposite p. 196 of his treatise) showing the streams of this region and the whirlpool itself. The Malström is described at some length in Part II of the Norway Pilot, 2d ed., pp. 400–401, 422–424.

References to recent charts and discussions of the currents around the British Isles and in the North Sea.

Hydrographic Office, Admiralty: Tidal Streams, English and Irish Channels (1899); Tidal Streams, Coasts of Scotland (1899); Tidal Streams, North Sea (1899); Tide Tables, Charts, and Pilots, or Directories or Sailing Directions.

M. Hédouin: Current charts published by the Service hydrographique de la marine, 1891.

J. P. Van der Stok: Études des phénomènes de marées sur les Côtes Néelandaises, Koninlijk Nederlandich Meteorologisch Institut, 1905.

Deutsche Seewarte: Atlas der Gezeiten und Gezeitenströme für das Gebiet der Nordsee und der Britischen Gewässer, 1905.

75. *The Gulf of St. Lawrence and outside waters.*

As already explained in section 73, Part IV A, and sections 34–40, Part IV B, the tides along the coast of America from Cape Race, Newfoundland, to Florida, result from a stationary wave extending from this coast in a southeasterly direction. The tidal hour of the American loop of this wave being XII, it follows that well off the coast the current hour should be IX. As the northwestern edge of the ocean basin is approached this hour changes little or considerable, according to circumstances. From New York entrance to Savannah, observations made a few miles off the coast indicate, with scarcely an exception, that the northwesterly or westerly component of the current is running with the greatest velocity at a little after IX. Stations off New Jersey, Maryland, Virginia, North Carolina, and South Carolina are given in the accompanying table. Since the first nodal line of the stationary tidal oscillation terminates near Guadeloupe Island, it follows that the times of tide for the northern coasts of Cuba, Haiti, Porto Rico, and the Virgin Islands can not differ very much from XII. (See Fig. 11, Part IV B.)

If the Gulf of Mexico and the Caribbean Sea be regarded as tideless bodies, it follows that the greatest southward downward slope through Florida Strait, Windward Passage, and Mona Passage must occur at about the time of high water outside. Straits of these dimensions, especially if connecting deep bodies of water, must contain stationary waves. Consequently the maximum southward velocities must occur about 3 hours after the time of high water off their northern openings. The inward current hour (ebb) should therefore be in the neighborhood of XII + 3, or III. Observation gives for Florida Strait off Fowey Rocks II.3, and near the western end of the strait III.0 as the current hours. For Windward Passage the observed hour is III.4, for Mona Passage II.7, and for Vieques Passage III.1. The same thing is nearly true of the tide in the Lesser Antilles. Between Barbados and Tobago the current hour of the westerly stream is XI.78 and between St. Vincent and St. Lucia the hour is X.34. The tidal hour is VII. This being increased by 3 hours gives X for the current hour, assuming the oscillation to be stationary.

The principal part of the tide in the Gulf of St. Lawrence is a fractional stationary wave whose node is north of the Magdalen Islands and whose loop is the St. Lawrence Estuary. (See sec. 91, Part IV A.) The tidal hour of this loop is about VI; hence if there were no progression the current hour for the in-going stream should be III. An inspection of the map (Fig. 13, Part IV B) will show that high water for the northeastern arm of the gulf occurs at a trifle before II; consequently water must be most rapidly flowing northeastward at a little before XI, or II − 3; hence the current hour shown on Fig. 7. Just outside of Cabot Strait the ocean wave is partly stationary, with a tendency to a maximum northwesterly velocity at IX, and partly progressive, owing to the irregularities in the shore line and the progression existing in the gulf, with a tendency to a maximum velocity at XII. The observed maximum velocity in the strait occurs at XI. But, as already stated, the westerly velocity of the stationary wave north of Magdalen Islands is about III. So far as velocities are concerned, a progressive wave affects a stationary wave least near a nodal line, and most at the end from which the progressive wave seems to come. Hence the tendency for the cocurrent lines to bunch up toward Cabot Strait rather than at the node. The hours for the west-going stream change from XI at Cabot Strait to a little less than III off the Magdalen Islands. The rapidly changing stream is intersected by the stationary stream filling or emptying the northeastern corner of the gulf. They intersect at right angles, have equal velocities, and phase difference of 3 hours at the point shown in Fig. 7, from which the cocurrent lines radiate. The hour of the stationary stream is X½ or IV½, and of the progressive I½.

The current in the Strait of Belle Isle is oscillatory. At the outer end the tidal hour is X and at the inner end II; the mean ranges are 2½ and 3½ feet, respectively. These values, substituted in Table 60, give, when increased by 3 hours, XI.8 o'clock for the time of maximum inward velocity. Observation makes the hour off Armour Point a trifle over XII½. As already noted, the stream flowing out of the northeast angle of the gulf in a southwesterly direction is swiftest at IV½; consequently off the inner end of the strait the current hour must change from I to IV½ if the west-going stream be followed. The mean maximum velocity off Armour Point is about 1¼ knots.

Above its estuary, the St. Lawrence River has a tidal wave nearly progressive in character, and so the flood continues a considerable time after local high water and the ebb, after local low water.

In comparing the chart of cotidal lines (Fig. 13, Part IV B) with the cocurrent chart (Fig. 7, Part V) it must be remembered that here and elsewhere the cotidal lines refer to actual (not the M_2) high water, while the cocurrent lines refer to the time obtained by using the maxima of both flood and ebb (adding 6 lunar hours to the latter) or to the M_2-current. Where river stations are involved, an M_2 cotidal map would be preferable to one referring to actual high water for making comparisons with the currents. At Quebec, the M_2 high water is nearly one-half lunar hour behind the actual high water.

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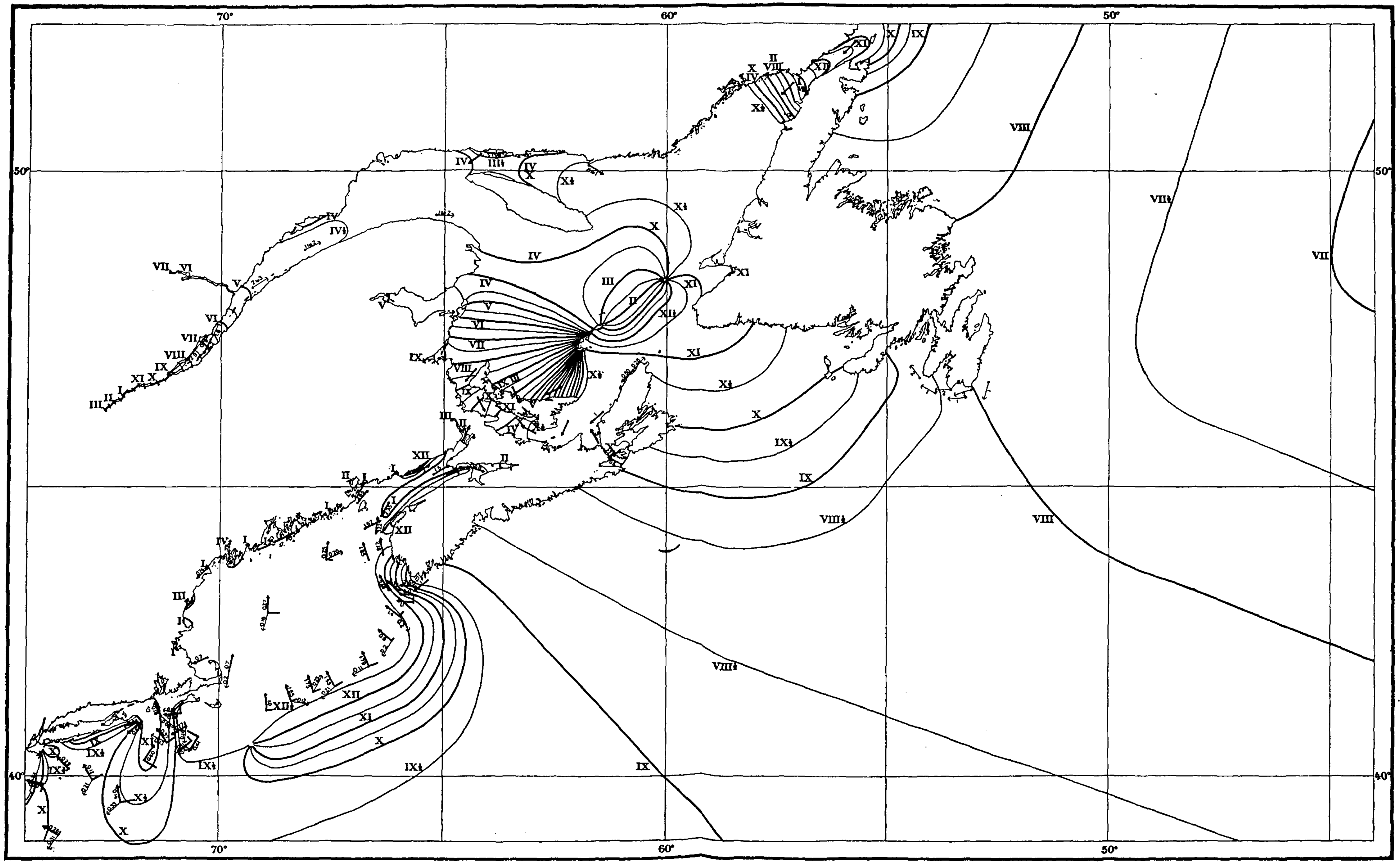

COCURRENT LINES FOR THE GULF OF ST. LAWRENCE AND VICINITY.

Tidal hours: Quebec, X. 61, V. 58; St. John, III. 16, IX. 22; Boston, III. 82, IX. 86.

The spring velocity of the tidal current in the narrows of the South Traverse is 7½ knots.

The tidal current between Anticosti Island and the mainland north of it is a stationary oscillatory stream. The tidal hours off the east and west ends of this strait are II.5 and V.6, respectively, while the mean ranges of tide are 3 and 5 feet. The time ascertained by Table 60 when decreased by 3 hours gives III.6 as the current hour of the west-going stream.

The current in the narrow part of Northumberland Strait is also oscillatory, as can be seen by noting the tidal hours and ranges at the ends and applying Table 60. The values II¼ and 5 for the east end and XII½ and 2 for the west end give, upon subtracting 3 hours from the value in Table 60, XII o'clock for the time of greatest eastward current. Near the narrowest part of the strait the flood stream turns to ebb and the cocurrent lines, if drawn, would bunch up together. The numbers between XI and IV have been omitted on the map. North of Prince Edward Island the transition from flood to ebb is less sudden.

Through the Gut of Canso the streams are hydraulic. The hours and ranges in feet for the two ends being XI.5, XII.7, and 4, 2½; the value from Table 60 is X.3. Off Cape Porcupine the rate of flood or ebb is 4 knots.

References to tidal currents in Canadian waters:

Admiralty: Newfoundland and Labrador Pilot; Sailing Directions S. E. Coast of Nova Scotia and Bay of Fundy; St. Lawrence Pilot.

W. B. Dawson: Survey of Tides and Currents in Canadian Waters, Reports 1901, 1902; The Currents at the Entrance of the Bay of Fundy, Ottawa. 1905.

76. *Gulf of Maine.*

As explained in sections 34, 91, Part IV A, and section 39, Part IV B, the ocean tide wave supports an oscillation of approximately critical length in the Gulf of Maine and Bay of Fundy by means of an intermediate progressive wave which is in evidence at Georges Bank. Here, where the range of the stationary dependent wave is small, the progressive wave greatly influences the times of the resultant observed tides. In approaching this bank from deep water, and by the time the maximum flood reaches the center of it, the current hour changes from IX½ to XII½, the change taking place chiefly at the loop of the oceanic oscillation.

Observation shows that the time of current increases less than half an hour between Georges Bank, where it is XII½, and the regular shore line 175 miles to the northwest. This is shown in Fig. 7. In the central portion of the Bay of Fundy the current hour is I. Along the shores of the bay the current turns earlier because its motion being there partially arrested by the irregularities of the shore line, the hydraulic tendency to flow into or out of the bay in accordance with the surface slope comes into existence.

Because of the narrow channel above the city of St. John, the tides produce two falls each way daily, the slack waters occurring when the river and the bay are upon the same level. The flow is strong in consequence of there being an average maximum head of nearly 10 feet. (See Fig. 13, Part IV B.)

In the center of the passage to the Basin of Mines, the spring maximum velocity is 5 to 6 knots, while near Cape Split it is 7 or 8 knots.

In so far as the currents in the Gulf of Maine are rotary, the rotation is clockwise.

East of Cape Cod Peninsula the cold permanent current setting southward is apparent.

77. *Nantucket Shoals to Narragansett Bay.*

From what has been said concerning the westerly ocean currents at about IX o'clock and the northerly current into the Gulf of Maine at about XII½, it is reasonable to expect a circular point in the neighborhood of Nantucket Light Vessel (or where the stream, in a sense, divides), and that the rotation of currents on Nantucket Shoals should be clockwise as a rule. So far as observations have been made they go to verify these conclusions. Easterly from this point, the progression of the hours is northward, and westerly from the point, the progression is southward. This indicates that the progression upon Georges Bank controls in the first region, while the progression over the shoals southeast of Nantucket controls in the second. In other words, we are to imagine about half of the scheme illustrated by Fig. 4 to be in each locality; in either case the north and south motions are simultaneous across the lines marked XII and IX. All observed currents off Nantucket which are rotary turn clockwise.

The fact that the current intervals increase in going southward and southwestward along the coast of Nantucket Island, while the tidal intervals increase rapidly in the opposite direction, was noted by Schott more than 50 years ago, on page 163 of a paper relating to the currents on Nantucket Shoals and published in the Coast Survey Report for 1854.

Upon referring to Fig. 8 it will be seen that the current hour for the easterly going stream increases through Vineyard Sound to a late region northeast of Cape Poge; farther east the hour of the main stream continues to decrease to a little east of Great Point; still farther east the hour of the main current increases, but the direction of flood veers to northward. Along the eastern shore of Monomoy Peninsula is a region about 2½ hours earlier than that east of Great Point. This is caused by the hydraulic effect along the coast, the downward northerly slope of the water being greatest at about the time of low tide at Provincetown or IX½. One may therefore go westerly from this early region to the late region marked I, northeast of Cape Poge, and find the current hour invariably increasing. Other early regions are located inside of Great Point and of Monomoy Point. These bays are simply filled and drained nearly simultaneously with the rising and falling of the tide in the main body of the sound. The currents (filling) have their greatest velocity 2 or 3 hours before the times of high water. The west-going stream of the sound occurs only 2 or 3 hours after these times of influx into the dependent arms or bays. Consequently, their times of most rapid filling must gradually merge into the times of the swiftest west-going stream in the main body of the sound.

The currents through Muskeget Channel and Edgartown Harbor (when open to the south) are hydraulic, as can be seen upon substituting the ranges and tidal hours off the ends of these channels, as found on Fig. 15, Part IV B, in Table 60. The tidal hours for Muskeget Channel are XII.5 and IV.2, while the ranges are 3 and 2½ feet; therefore the north-going stream should be XI.5. Observation gives XII –. In Quicks Hole and other openings between Buzzards Bay and Vineyard Sound, the currents are hydraulic. Because of these openings and the proximity to the entrance to Vineyard

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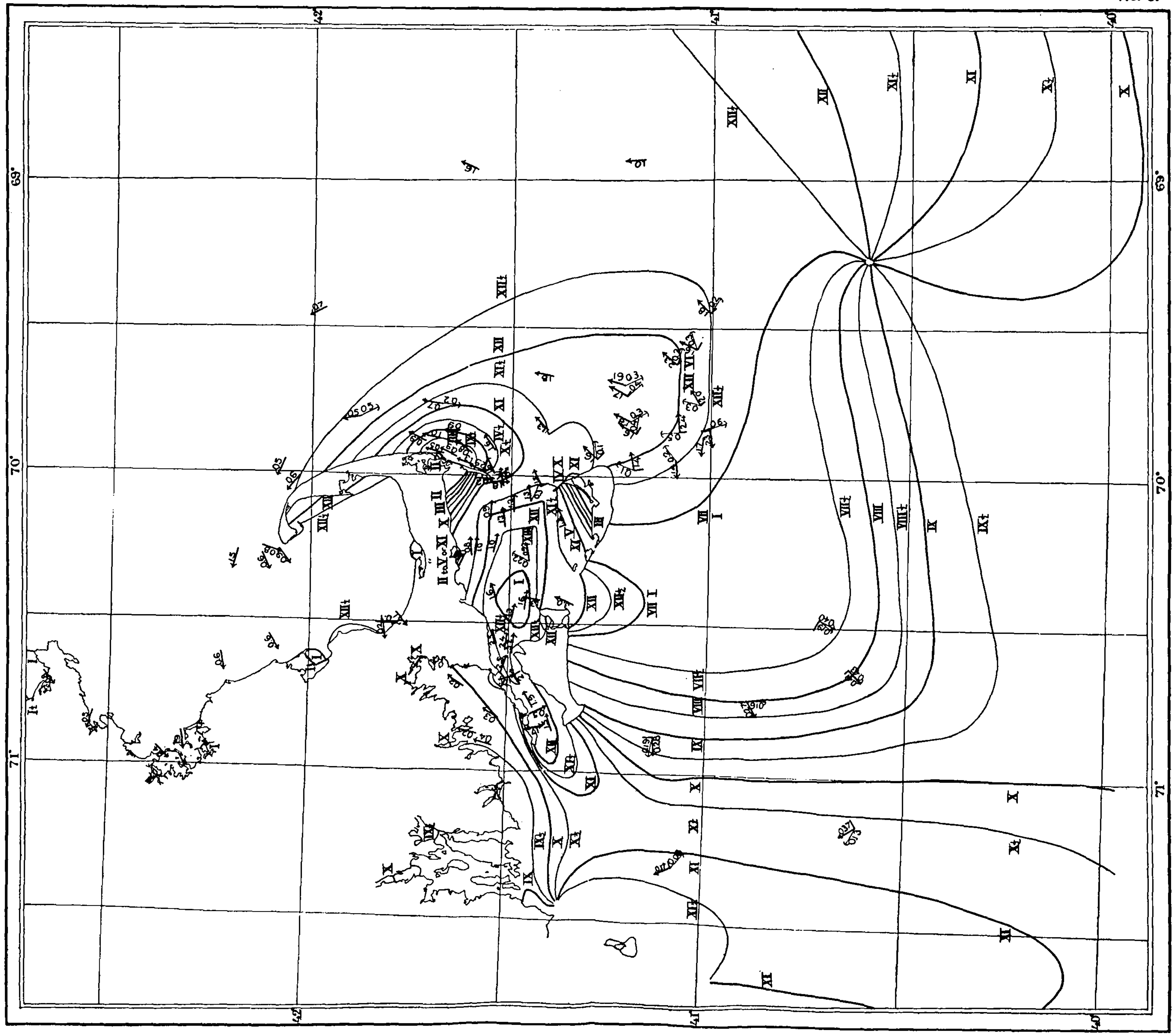
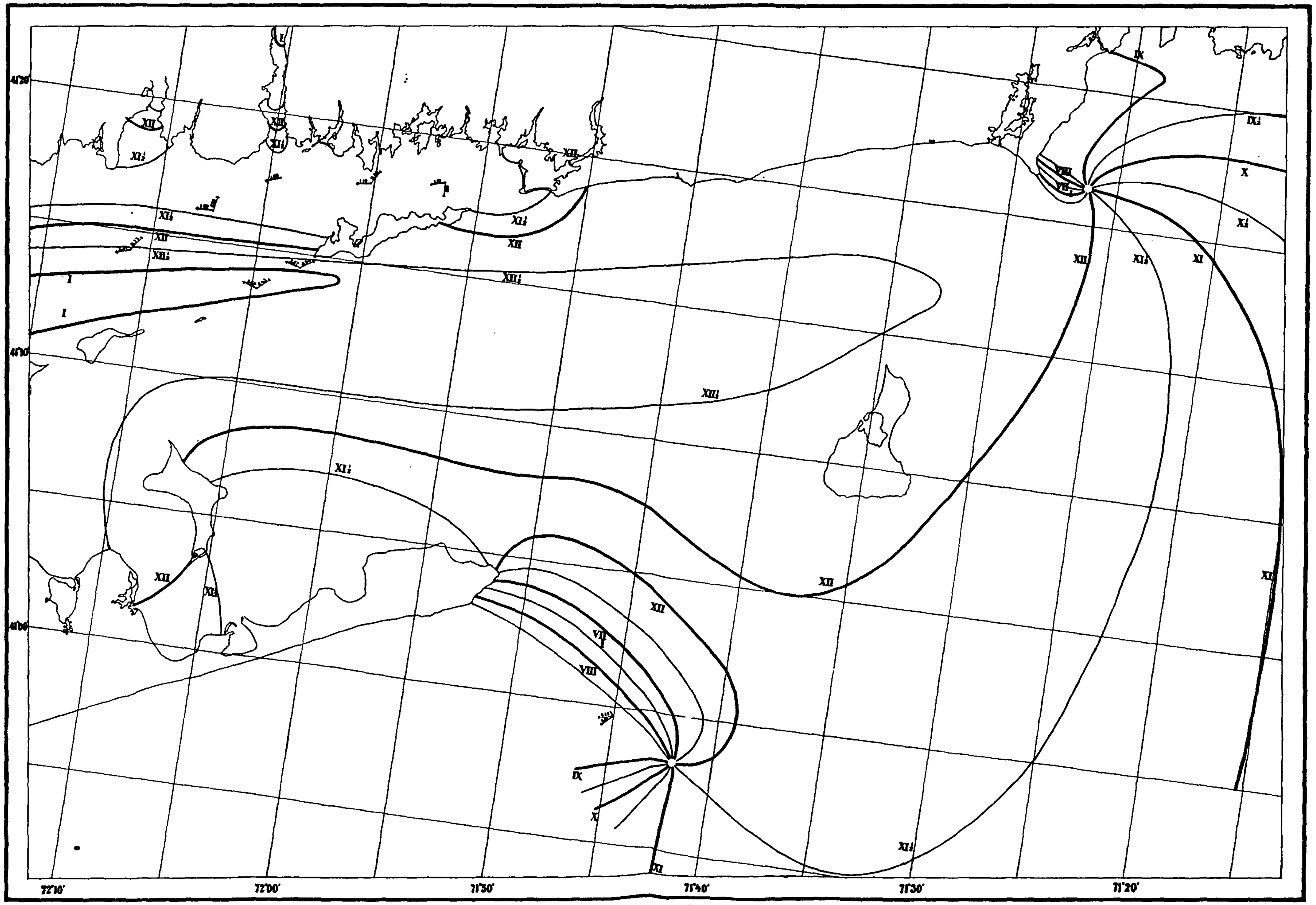


COCURRENT LINES FOR NANTUCKET SHOALS AND VICINITY.

Tidal hours: Boston, III. 82, IX. 86; Newport, XII. 23, V. 51; Sandy Hook, XII. 26, VI. 33.



COCURRENT LINES FOR THE EASTERN PORTION OF LONG ISLAND SOUND.

Tidal hours: New London, I. 92, VIII. 19; Falkners Island, III. 38, IX. 31; Sandy Hook, XII. 26, VI. 83.

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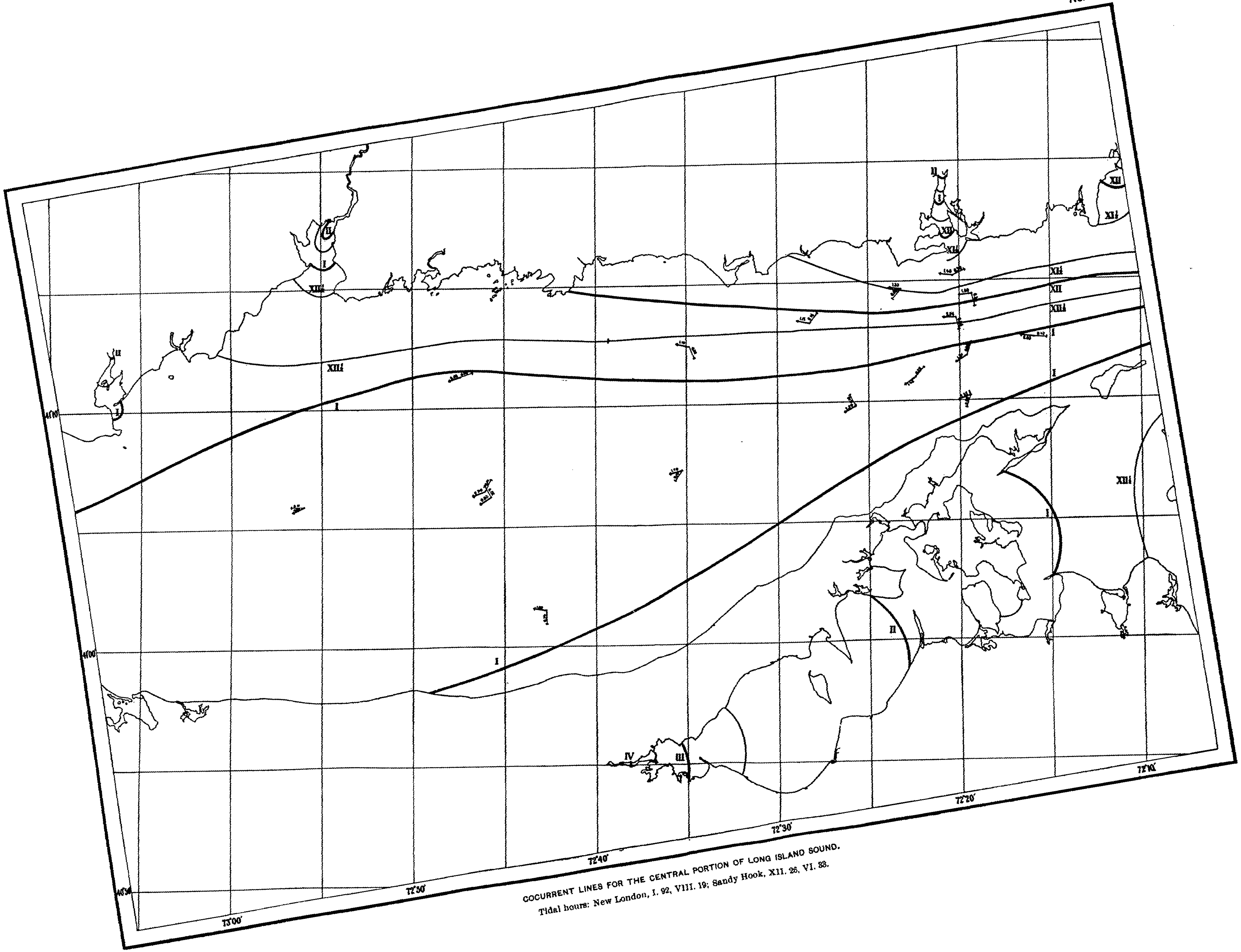

COCURRENT LINES FOR THE CENTRAL PORTION OF LONG ISLAND SOUND.

Tidal hours: New London, I. 92, VIII. 19; Sandy Hook, XII. 26, VI. 33.

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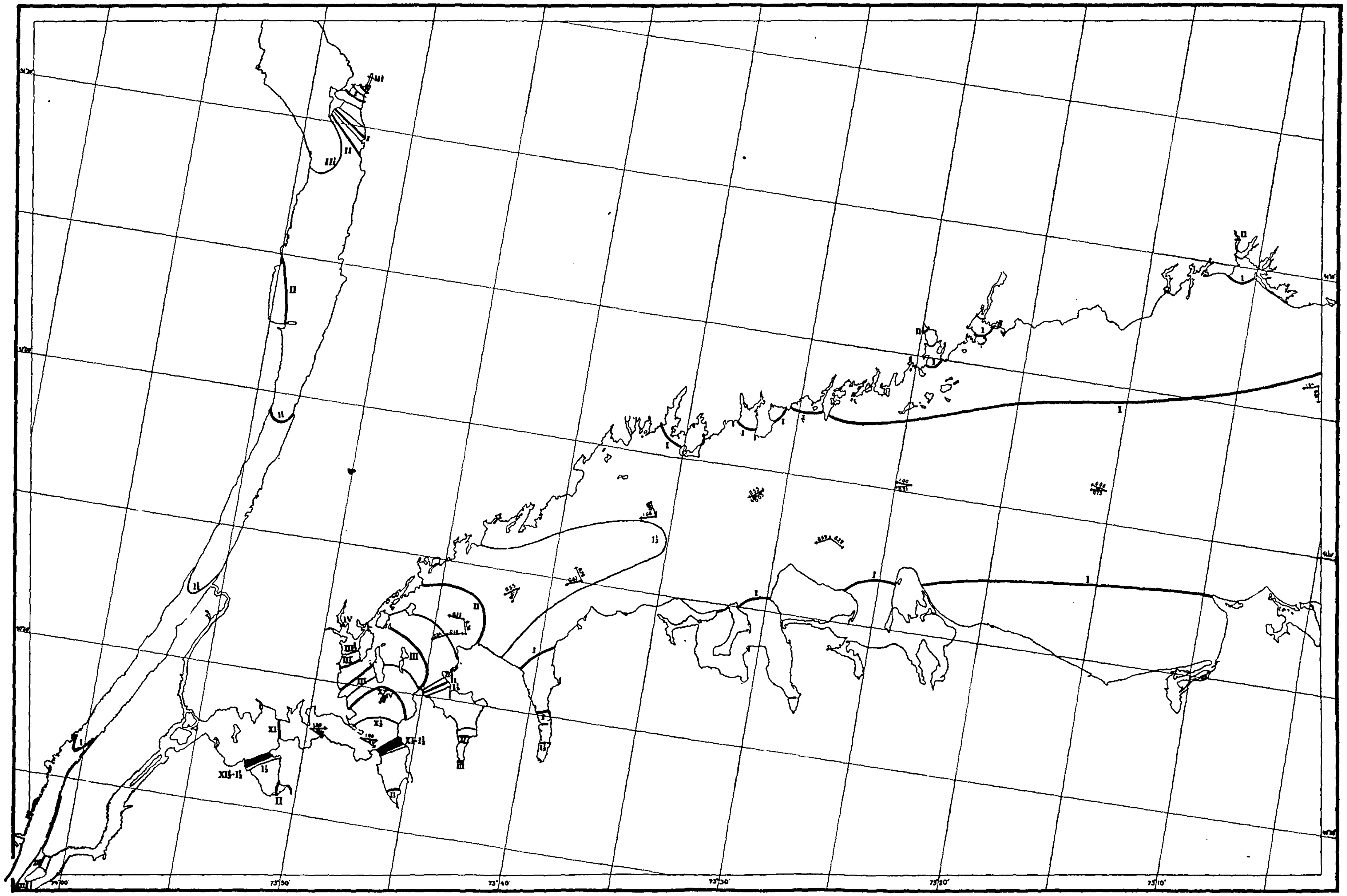


COCURRENT LINES FOR THE WESTERN PORTION OF LONG ISLAND SOUND.

Tidal hours: Stamford, III. 61, IX. 70; Willets Point, III. 69, X. 10; Governors Island, XII. 73, VI. 95.

Sound, the current hour increases from the northwestern shore of Buzzards Bay, where it is about IX½, toward the southeastern shore, consisting of islands, where the hour varies from X to XI.

Narragansett Bay has a nearly stationary tide wave, and has few belating dependencies or connections; hence the time of current must be about 3 hours before the time of high water, and this observation shows it to be the case; the tidal hour for the bay varies from XII to XII½ and the current hour from IX to IX½.

78. *Long Island Sound.*

The tide of Long Island Sound consists chiefly of a stationary wave approximately $\frac{1}{4}\lambda$ long. The tidal hour for this wave as inferred from the time of tide near the loop is IV. Observation shows that the current hour for the sound is I or a trifle over. The transition of the stationary Atlantic wave to the dependent wave of the sound is apparent many miles southward of Montauk Point, because here the ocean is comparatively shallow and because the time difference between the ocean and sound is considerable. The late current entering the sound joins, near the nodal line, two early stationary waves or currents, one being that of the ocean to the south, the other, that of Narragansett Bay to the northeast. Hence the two circular points near the entrance to the sound. Near the southern point the rotation of the current is clockwise, and near the northern point counterclockwise.

It may be noted that even in the region south and southeasterly from Montauk Point, where the current is as late as XI o'clock, there is a westerly component at about IX; this part of the current belongs to the Atlantic oscillation.

A cocurrent line marked IX extends from southern Nova Scotia southeasterly probably to a point eastward from Porto Rico. Observations made east of Désiderade Island show a northwesterly current at VIII.29. This agrees with the horizontal motion belonging to the stationary wave which causes the tides along the Atlantic coast of the United States. A line marked IX½ extends from Nova Scotia, outside of Georges Bank, to the circular point off Virginia, and is shown in Figs. 7 and 17. The character and extent of the cocurrent lines between the lines just referred to and the land, can be ascertained by means of the accompanying maps. The belating effect of Long Island Sound is very apparent, while the similar effect for New York Harbor is not great, because the time of the tide in the Lower Bay is not much later than that of the ocean.

At the eastern end of Long Island Sound the current is considerable, because a north-and-south line $\frac{1}{4}\lambda$ from the head of the sound would fall not far to the east of Montauk Point. Moreover, Plum, Great Gull, and Fishers Islands partially obstruct the passageway, thus necessitating increased velocities for maintaining a given rise and fall at the head of the sound. In the Race the velocity is 3 knots. The current hour for the greater part of the sound lies between I and I½. Near the northern shore the current hour is less than I. In Fishers Sound it is XI½. This acceleration is due to the direct action of gravity upon the shore waters when possessing an eastward or westward slope. The similar effect is not equally great near the south shore of the sound, because the regularity of the shore line there permits the oscillation to extend very near to the land; but in the bays on that side the current is early, owing to the fact that they must be filling most rapidly 3 hours before high water.

In entering tidal rivers where the tide wave soon becomes nearly progressive the current hour must change rapidly. (See Figs. 9–11.)

79. *East River.*

The tidal hour at and just east of Throgs Neck is III.8; in New York Upper Bay the tidal hour is XII.7. The mean range in the former locality is 7.2 feet, in the latter 4.4. By means of Table 60 it follows that the maximum eastward current should occur at X.8. Observation shows that from Throgs Neck to the eastern side of Governors Island the time of current changes by only 1 hour, viz., from X½ to XI½. Just east of the line marked X and IV, the former for the east-going stream, the latter for the one going west, the stream changes in name from flood to ebb, or vice versâ, according as in passing beyond this line the maximum stream follows high water or low water instead of preceding it, as a true flood or ebb is supposed to do. Off either shore of the northerly end of Blackwells Island the velocity of flood or ebb is 4 knots. Eddies occur in Pot Cove, Astoria Cove, and Wallabout Bay.

The times of current in the sharp bays bordering the East River are governed by the times of their high and low waters, the current preceding the tide by 3 hours.

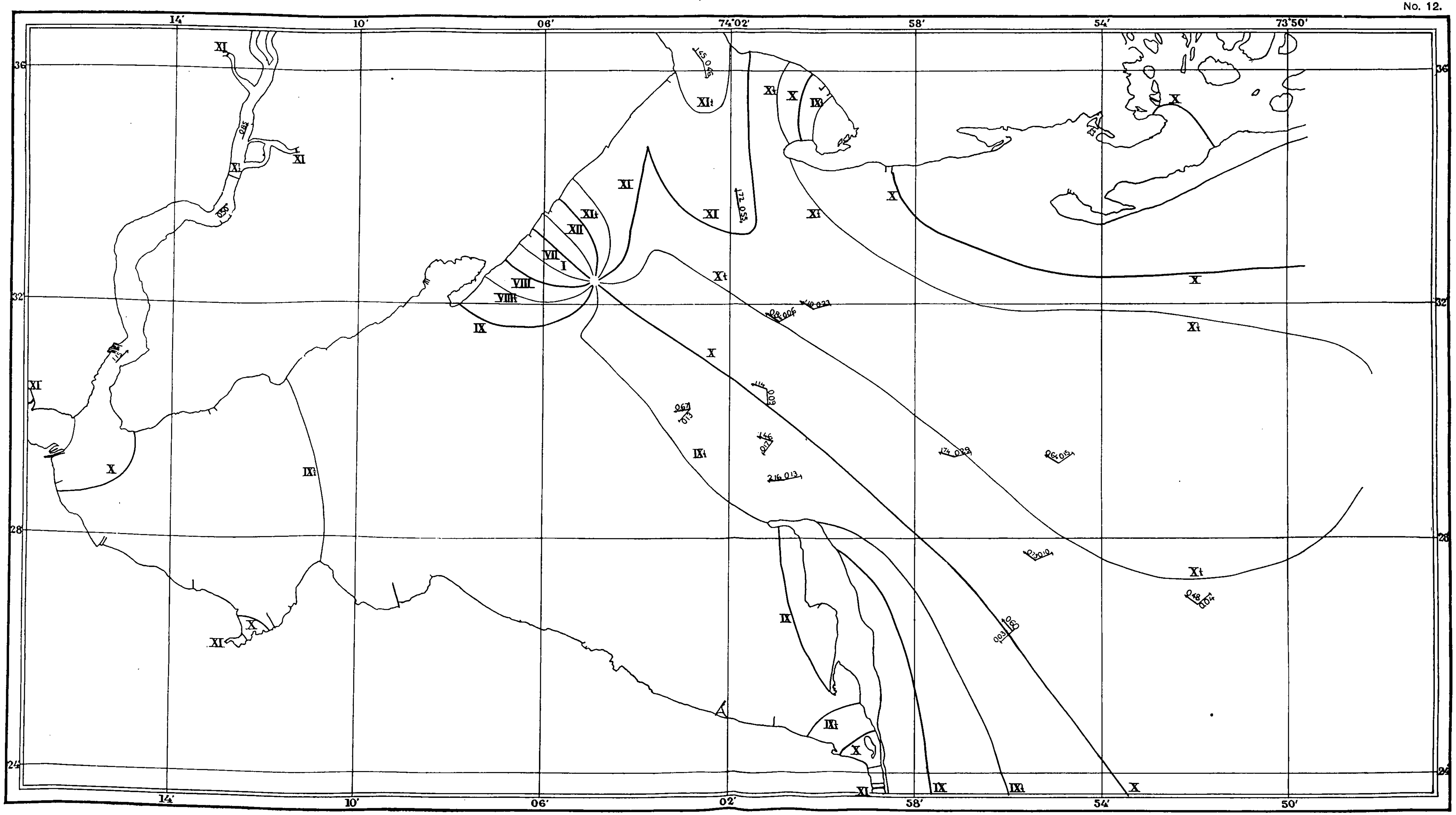
80. *New York Harbor and Hudson River.*

Both coasts of Sandy Hook have early currents (even earlier than IX), due to the direct effect of gravity tending to cause the greatest motion when the slope of the surface of water along the coasts is greatest. There is probably a circular point very near the New Jersey coast north of Barnegat Inlet, at which the IX and IX½ lines lying off the coast terminate. The X line from the circular point off Virginia probably also terminates here.

In passing through Fire Island Inlet the current hour changes from less than IX outside to more than X at the inner end of this strait. But, as can be seen from Fig. 12, the current hour changes little in going through Rockaway Inlet into Jamaica Bay. Because of rapid change in time in going through Fire Island Inlet and the opposite directions of the flood current without and within the inlet, the complete representation of the current at the mouth of the inlet requires a circular point around which the numbering of the lines is counterclockwise, and so the rotation of the near-by currents must be clockwise. At the entrance to Rockaway Inlet the current simply splits, there being a wedge of dead water between the two branches.

No recent observations have been made close to the point of Sandy Hook; but Mitchell found there an almost continuous outward tidal current caused by the fact that an eddy was formed just within the hook on the flood stream, but none was formed there on the ebb. It seems probable that a similar condition exists now notwithstanding the variations which the hook has since undergone.

The tide in Raritan Bay consists chiefly of a stationary wave increasing in range to the westward. Hence the greatest downward and northeastward slope along the Staten Island shore occurs not far from the time of high water. The direct effect of gravity is to produce a northeasterly going stream at about this time, or a little later. The stationary character of the Raritan Bay tide causes maximum flood to occur at about IX½ while the progressive character of the Upper Bay and Hudson River tide causes current hour off Coney Island to be XI. Hence, the times of the northeasterly going stream must vary from XI to III½ along the Staten Island shore, while the onshore stream occurs at X; hence, the circular point.



COCURRENT LINES FOR THE ENTRANCE TO NEW YORK HARBOR.

Tidal hours: Sandy Hook, XII. 26, VI. 83; Governors Island, XII. 73, VI. 95.

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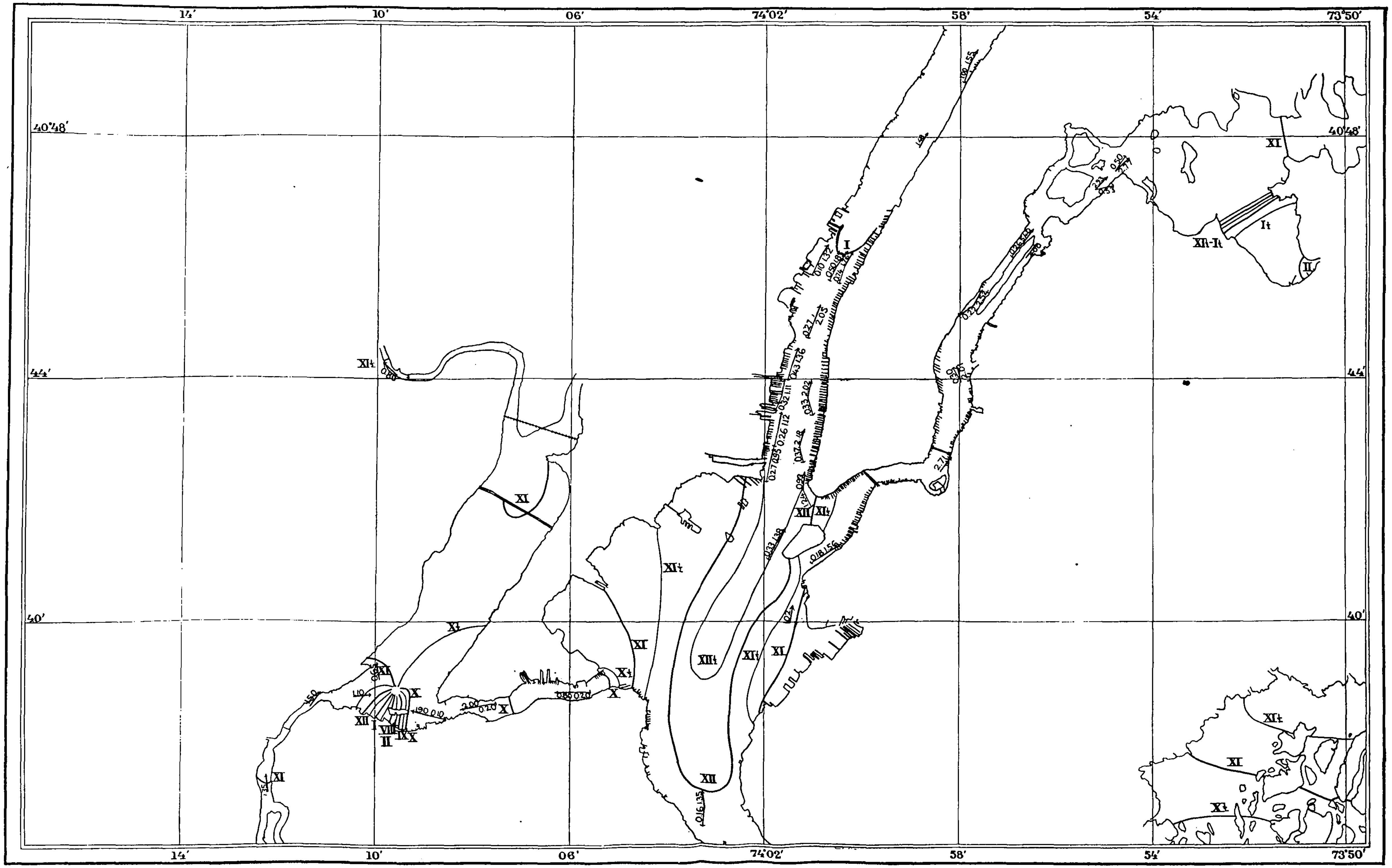

COCURRENT LINES FOR NEW YORK UPPER BAY AND VICINITY.

Tidal hours: Sandy Hook, XII. 26, VI. 33; Governors Island, XII. 73, VI. 95; Willets Point, III. 69, X. 10.

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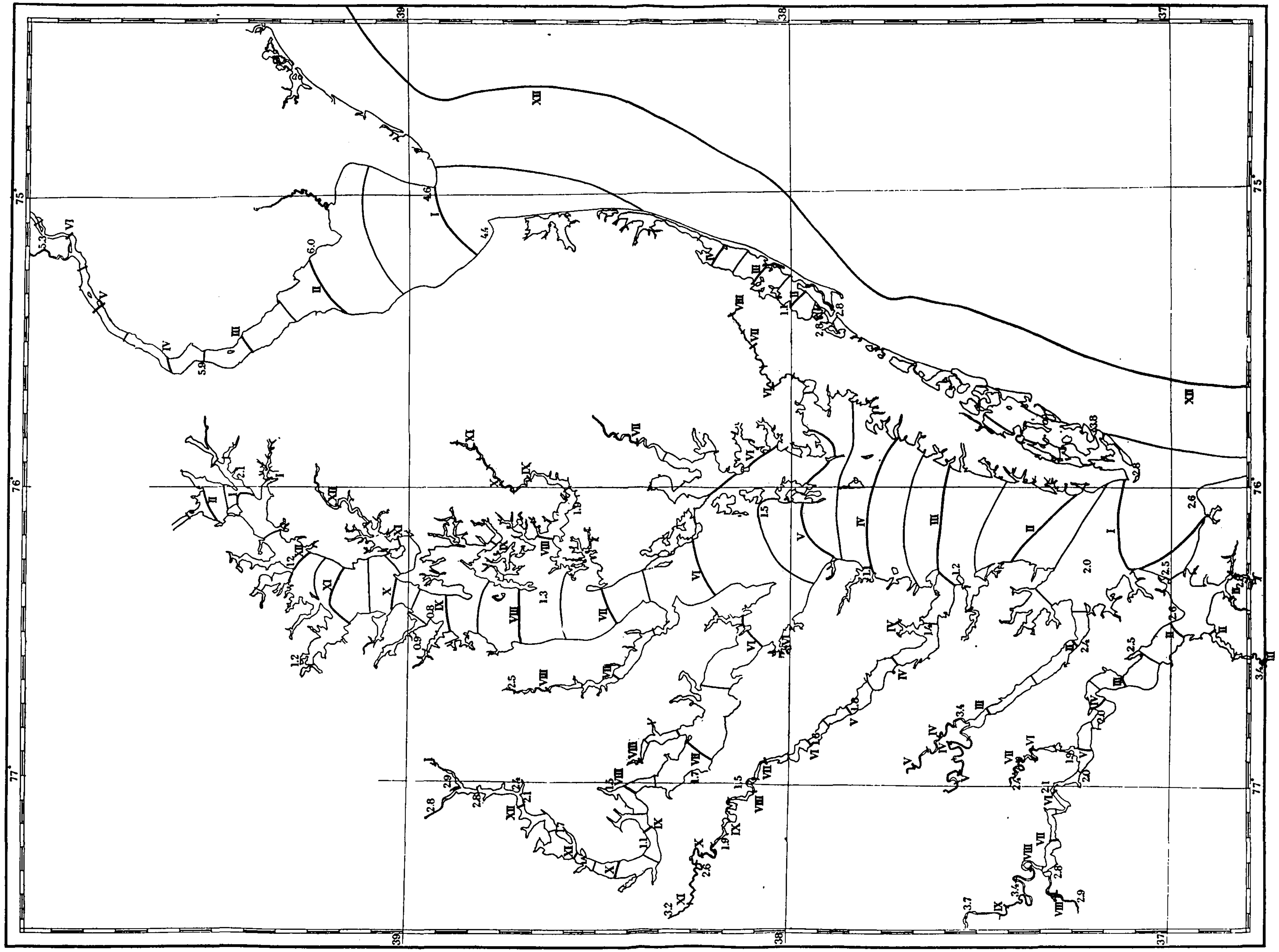
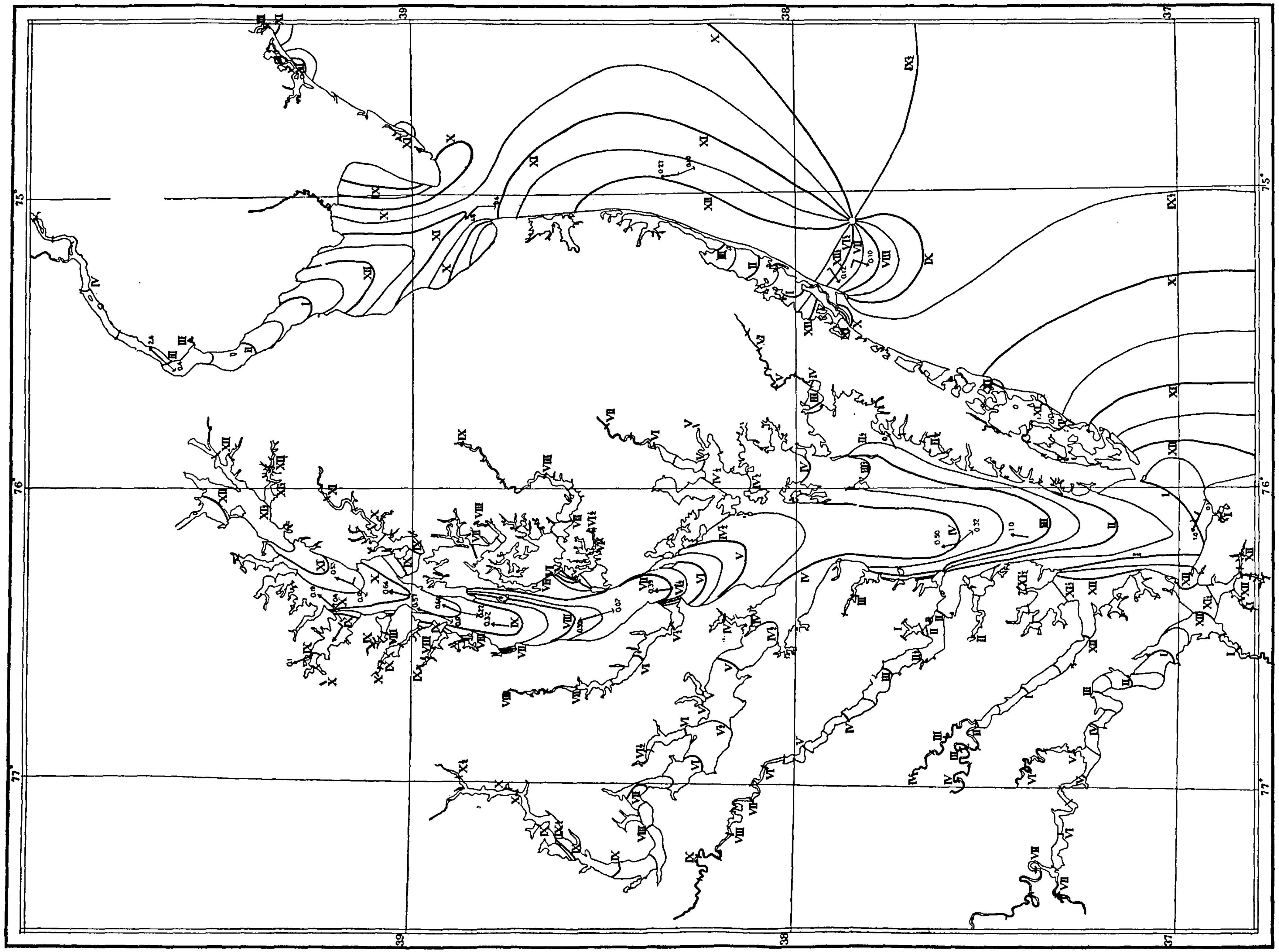


COTIDAL LINES FOR DELAWARE AND CHESAPEAKE BAYS.



COCURRENT LINES FOR DELAWARE AND CHESAPEAKE BAYS.

Tidal hours: Philadelphia, VI. 46, I. 74; Old Point Comfort, I. 58, VII. 26; Baltimore, XI. 45, V. 85; Washington, XII. 69, VII. 08.

The feeble currents in Gravesend and Gowanus bays are earlier by from 1 hour to 2 hours than are the currents in the middle of the channel.

Just south of Battery Park is a wedge of nearly tideless water, lying between the Hudson and East rivers. Because of this fact, the permanent flow of the Hudson generally dominates the current.

In the Kill van Kull the current is 2½ hours earlier than in the channel of the Hudson opposite the mouth of this stream. The fact is of some importance with reference to any sewerage which may be discharged into the Kill van Kull on the ebb tide; for, it will, in the first place, be carried southward a considerable distance. The currents through both kills are hydraulic as can be seen upon noting times and ranges of tide in Newark Bay and the waters outside of it. The circular point in Newark Bay indicates that, following one stream, the times (current hours) of this stream vary much within a short distance. In other words, the streams coming from opposite directions are approximately simultaneous. The currents of Newark Bay, following in the general direction of the eastern and western shores has X½ as its hour in the southern part of the bay.

The flood current in the lower Hudson has its greatest velocity at about the time of local high water, indicating the progressive character of the tide wave. Where the fresh and salt water meet there is a tendency for the light fresh water to lie at and near the surface while the more dense salt water occupies the lower layers of the stream. Hence the observed surface current may have a strong permanent current, while near the bottom this permanent current will be much weaker. Hence the times of slack water may be greatly disturbed at the surface and remain comparatively regular near the bottom. The observations of Mitchell and Marindin have shown that the flood slackens early at the surface in comparison with its time of slackening at the bottom. The reverse occurs at the slackening of the ebb stream.*

In the upper Hudson the tide wave becomes partially stationary so that the greatest flood velocity finally occurs two or more hours before the time of local high water.

81. *Delaware and Chesapeake Bays.*

The greatest velocity of the flood current in lower Delaware Bay occurs about 2½ hours before the time of local high water. This gives further evidence that the tide wave of the bay is nearly stationary in character. In the river, on the other hand, the tide must be nearly progressive; hence, the crowding together of the cocurrent lines in the upper portion of the bay. Along the sides of the lower part of the bay, the time of the current is influenced by the direct effect of gravity upon these waters which only in part partakes of the oscillatory motion. Hence, its early time of turning or of running flood or ebb.

Off Cape Henlopen the mean maximum velocity is 1.8 knots, at New Castle 2.6, and at Philadelphia it is 1.4. In following the coast southward from Cape Henlopen the current becomes later. As the Virginia line is approached the velocity along the coast and that normal to the coast are very small. Observation shows the current in this region to be rotary and in the clockwise sense. This implies that the order of the cocurrent lines about the near-by circular point be counterclockwise, or opposite to the order for the circular point just east of the New Jersey coast.

* U. S. Coast and Geodetic Survey Report, 1887, pp. 301–312

The IX½ line setting out from the circular point of the Virginia coast passes near the outside of Georges Bank thence to southern Nova Scotia.

On account of the progressive character of the tide in Chesapeake Bay, the times of the currents are delayed for some considerable distance outside of the capes. Between the capes the current-hour is XII½, while in the water beyond its influence the hour is probably a little under IX½. Hence the crowding up of the cocurrent lines in approaching the entrance to the bay. The bay being a propagative body, the maximum flood velocity occurs at nearly the time of local high water. Many of the dependent arms of water intersecting the general shore line must have tides of a partially stationary character. Hence, there occur many localities such that the current hour increases toward the bay, and generally inland as well. These may be styled "early regions." They are made apparent through the convention of always writing the numbers on the later sides of the lines. The following are examples: Pocomoke Sound; Fishing Bay; Honca River; Choptank River, near entrance; Eastern Bay; Chester River, near entrance; Sassafras River, near entrance; Gunpowder River; Patapsco River; Magothy River, near entrance; Severn River; South River; Herring Bay; Patuxent River, near entrance; St. Mary River; Great Wicomico River, near entrance; Rappahannock River, near entrance; Piankatank River, near entrance; Mobjack Bay; entrance to York River; Hampton Roads; Elizabeth River.

The intervals and ranges indicate that near the head of the bay the tide wave is in part stationary. The early currents at this end of the bay give further confirmation of this hypothesis. At Baltimore harbor the tide wave is entirely stationary; for, current observations made by F. A. Kummell near Fort McHenry show that the northwesterly velocity is there greatest 3 hours before the time of high water.

In the acute angle between the axes of the Patapsco River and of upper Chesapeake Bay the currents are rotary; but this fact has not been represented upon the map because of the small extent of the locality in question.

The current near the heads of the James, Rappahannock, and Potomac Rivers is made early by the sudden changes in cross section and elevation of the river beds. The same is true of the lower Susquehanna, and of the Delaware at Philadelphia.

The velocity of the current between the Capes is about 1 knot. Off the mouth of the Rappahannock the velocity is 0.50 knot; off the Patuxent, 0.39 knot; off Herring Bay, 0.32 knot; off Sandy Point, 0.66 knot.

82. *Florida Strait.*

As already noted, the current in Florida Strait of the semidaily tide indicates that the tide wave is here partly stationary. The diurnal tide should here be a stationary wave, and with greater reason, because the length of the strait is a smaller fraction of λ in the latter case than in the former. Consider the diurnal tide at Fernandina and Key West, Fla.

From section 97, Part IV A, we have at the two places

$$K_1 = 0.34,\ K^\circ_1 = 120^\circ;\ K_1 = 0.27,\ K^\circ_1 = 274.$$

The O_1's at the two places compare in about the same manner and will, for convenience, not be considered. The longitude of Fernandina is 5.43 hours and of Key West 5.45. The K_1 tidal hours at the two places are therefore XIII.43 and XXIII.72, respectively.

These differ by 10.29 hours. Hence, there should be almost a nodal line for the K_1-tide in Florida Strait. An harmonic analysis of 191½ days at Cape Florida, beginning February 15, 1857, gives the following constants, not corrected for imperfect elimination:

$$K_1 = 0.0857 \text{ foot}, \; K_1^\circ = 189^\circ.09, \qquad K_2 = 0.0408 \text{ foot}, \; K_2^\circ = 286^\circ.89.$$
$$M_2 = 0.7654 \text{ foot}, \; M_2^\circ = 244^\circ.36, \qquad O_1 = 0.0714 \text{ foot}. \; O_1^\circ = 205^\circ.91,$$
$$S_2 = 0.1337 \text{ foot}, \; S_2^\circ = 279^\circ.47.$$

It is thus seen that at this point the diurnal tide is small in comparison with the semidiurnal. This fact was anticipated before the analysis was undertaken.

To infer the K_1-current, take the tidal hours and amplitude ratio for Fernandina and Key West, and make use of Table 60. The time of greatest southward, downward slope is thus found to be XII.7; consequently the tidal hour of the maximum south-going stream is XII.7 + 6 = XVIII.7. From the reduction for the observations off Fowey Rocks, longitude 5.33 $\dot{K}_1^\circ$ (north) is $14^\circ = 0.93$ hour. Hence, the observed current-hour for the south-going K_1 current is $5.33 + 0.93 + 12 =$ XVIII.26, which agrees well with inference.

The diurnal current flowing into the Gulf of Mexico through the Yucatan Channel should have its greatest velocity 6 hours before diurnal high water over the Gulf, or at II − 6 = XX. (See Nos. 113–148, Section 97, Part IV A.) Observation gives 248°.6 for the epoch of the K_1 north-going current at a point whose longitude is 5.75 hours. Hence, the current hour is XXII.32.

83. *Papers in Coast Survey Reports relating to tidal currents of the Atlantic Coast of the United States:*

C. A. Schott: On the currents of Nantucket Shoals, Report 1854, pp. 161–166; Currents in Muskeget Channel and off the northeast coast of Martha's Vineyard, Report 1854, pp. 166–168; Tidal currents of Long Island Sound and approaches, Report 1854, pp. 168–179.

H. Mitchell: Tides and tidal currents of New York Harbor and its dependencies, Report 1856, pp. 264–266; Tides and currents in Nantucket and Martha's Vineyard sounds, and in East River at Hell Gate with remarks on the revision of levelings on the Hudson River, Report 1857, pp. 350–354.

A. D. Bache: Tidal currents of New York Harbor near Sandy Hook, Report 1858, pp. 197–203.

H. Mitchell: Currents in the East River at Hell Gate and Throg's Neck, the sub-currents of New York Bay and Harbor and levelings on the banks of the Hudson River, Report 1858, pp. 204–207; Tides and currents of Hell Gate, N. Y., Report 1867, pp. 158–169; harbor of New York, 1873, Report 1871, pp. 109–133; Middle-ground Shoal, New York Harbor, Report 1872, pp. 257–261; Circulation of the sea through New York harbor, Report 1886, pp. 409–432; On the movements of the sands at the eastern entrance to Vineyard Sound, Report 1887, pp. 159–163; Report on the results of the physical surveys of New York Harbor, Report 1887, pp. 301–311.

H. L. Marindin: Tide levels and flow of currents in New York Bay and Harbor, Report 1888, pp. 405–408; Tides and currents in the harbor of Edgartown and in Katama Bay, Martha's Vineyard, Report 1892, pp. 225–241.

84. *Coasts of South America.*

Like Africa, South America is exposed to the direct action of the deep ocean tide; and so observations made upon tides and currents have an important bearing upon the general problem of the tides.

The quotations given below are taken from the Admiralty Pilots for South America, Part I (1893), Part II (1895), and for the West Indies, Vol. I (1893).

They indicate the ending of one stationary wave against the southeastern coast of Brazil, and another against the northern coast. They also indicate a loop of a stationary wave in the Gulf of Panama.

They show how in dependent stationary arms of the sea, like those along the eastern coast of Patagonia, the velocity of the tidal streams may be small while the range of tide is exceptionally great.

There is good evidence from the tides, and possibly some evidence from the currents, of the ending of a stationary wave along the Chilean coast. Both currents and tides indicate the southerly and southeasterly direction of the flood as Cape Horn is approached.

Both currents and tides indicate that the general direction of the flood along the eastern coast of South America from Staten Island to Rio de la Plata is northerly. One remark concerning the tides off the mouth of the Rio Negro indicates that their establishments change rapidly in going a comparatively short distance. (Cf. Fig. 29, Part IV B.)

85. *Southeast coast of South America, quotations.*

It is high water, full and change, at cape St. Roque at 4h. 14m.; springs rise from 8 to 10 feet. In the St. Roque channel the flood sets to the south, and the ebb to the north, at about one mile an hour.

The establishment of the whole eastern shore of Brazil varies but little as the coast lies nearly in a straight line, and parallel to the tidal wave which traverses the Atlantic ocean from E. S. E. to W. N. W.

It is high water, full and change, at Bahia, at 4h. 26m., and the spring rise is 8 feet. The flood runs 5 hours to the north-ward, and the ebb 7 hours to the south-ward. The velocity of the tide is about 1½ miles an hour, increasing to 2¼ and 3 miles during springs.

It is high water, full and change, at Caravellas, at 4h. 15m., spring rise about 10 feet. The tidal stream varies from 2 to 3 knots, the flood sets to the south, and the ebb to the north, outside the bar; but this direction varies very much with the locality, and force and direction of the wind.

It is high water, full and change, at Rio de Janeiro at 3h.; springs rise 4 feet and neaps 3 feet. The usual rate of the tide is about three-quarters of a mile an hour, springs run 1½ miles.

It is high water, full and change, off Estrella bay at 0h. 30m.; springs rise 5 feet, and neaps 4 feet and at Parati 1h. 43m., springs rise 5½ feet. There is little or no stream.

Santos Harbor: It is high water, full and change, at 2h. 50m., springs rise 5 feet. The tides are strong, particularly the ebb.

It is high water, full and change, at Saõ Francisco at 2h. 30m. a. m.; springs rise 7 feet, and neaps 5 feet. At springs, the stream from the river runs from 3 to 4 miles an hour, and is only overcome by the strength of the flood, soon after resuming its course; this is called half tides (meias marés).

It is high water, full and change, at Anhatomirim islet at about 2h. 45m.; springs rise 6 feet and neaps 4½ feet. The tides are tolerably regular in Santa Catherina channel; they enter from the northward and southward at the same time, and meet off the town, where they also separate. The strength seldom exceeds a third of a mile an hour, but near springs it sometimes runs 1½ miles.

There are no appreciable tides in Maldonado bay.

Monte Video: It is high water, full and change, at 2h. 30m. (approx.); astronomical tides range about 18 inches.

Rio de la Plata: In the vicinity of the Cuirassier and Chico light vessels in ordinary weather, the average rise and fall is 4 feet, the ebb setting to the southeast at the rate of from one-half to 3 miles an hour, and the flood to the north-west at from one-half to 1½ miles an hour.

It is high water, full and change, off Andres head at 10h., rise 8 feet. The flood sets to the northward and the ebb to the southward.

It is high water, full and change, in El Rincon about 5h. The tidal streams set strongly, the flood to the north, the ebb to the south, nearly 6 hours each way; off Asuncion point the flood sets to the eastward.

It is high water, full and change, in Union bay at 3h. 10m.; springs rise 12 feet, neaps 9 feet. The flood-tide at the entrance sets to the northward across the banks about 2 miles an hour.

Rubia Head: The tides run along this coast with dangerous strength, from 2 to 4 miles an hour.

Rio Negro: It is high water, full and change, on the bar, during settled weather, at 11h.; springs rise 14 feet, neaps 10 feet. In the offing, it is 3 hours later. The tidal stream runs parallel to the coast from 2 to 4 miles an hour.

The tidal wave comes up the coast from the southward, and rushes round Valdes peninsula with much strength, causing violent and dangerous overfalls off Valdes creek and Norte point. Part of the body of water thus going northward, separates, and runs round Norte point; thence to the port of San Josef the tide sets strongly, with ripplings and races, dangerous for boats, or very small vessels. The main body continues its progress to the northward, inclining to the west, until near Belen bluff, when it divides; one stream running to the north-west, the other to the eastward. Eastward of Belen bluff, the ebb sets faintly to the south or south-eastward; westward of the bluff it sets to the south-eastward.

West of the meridian of Norte point, the south point of entrance to the gulf of San Matias, and northward of latitude 41° 50′ S., but little stream of tide is felt; though the water rises 24 feet. With a weather tide there is a very cross short sea in the entrance of the gulf.

Between Villarino point and the Reparo bank the tide runs from 3 to 5 miles an hour.

It is high water, full and change, within port San Josef at 10h. 0m. The tide rises from 20 to 30 feet, and the stream rushes between the heads from 3 to 5 miles an hour.

It is high water, full and change, at port Melo at 3h. 40m., springs rise 15 feet. The tides off this part of the coast are strong, running along the land at the rate of 2 or 3 miles an hour. Off the projecting points, and in confined passages, their strength is of course increased, and causes heavy ripplings when opposed to the wind.

At full and change, the flood or northerly tide ceases in the offing about 4h. 15m., but near cape Blanco and among the shoals, the tides may be less regular; they produce strong ripplings and set from 3 to 4 miles an hour round cape Three Points.

It is high water, full and change, at port Desire at 0h. 10m., springs rise 18½ feet. The tides set in and out of the port with regularity, and at the rate of 5 knots an hour.

It is high water, full and change, in Sea Bear bay at 0h. 45m., rise 20 feet. The tide off the entrance is very rapid. The flood sets to the N. N. E., and has been observed as much as 3 knots against a strong northerly wind. The ebb sets nearly in the opposite direction and about the same rate. Off Penguin island the northerly stream ceases at about 4 hours after high water by the shore.

It is high water, full and change, in the river Santa Cruz, at 9h. 30m.; springs rise 40 feet, neaps rise 29 feet, with a velocity of from 3 to 6 miles an hour. In the offing the tides flow regularly 6 hours each way, but turn 2 hours later than the time of high water in-shore. The flood runs to the north-eastward and the ebb to the south-westward.

It is high water, full and change, in the entrance of port Gallegos at 8h. 50m.; springs rise 46 feet, the stream runs at the rate of 5 miles an hour.

General description: Along that dreary and almost unbroken coast, extending from cape Corrientes to Bahia Blanca, the stream of the tide is very weak, although the water rises and falls about 10 feet. The great tidal wave from the southward here appears to end, after sweeping along the southern half of South America. In the archipelago of Tierra del Fuego the flood-tide comes from the N. W., passes round cape Horn, and through the strait of Le Maire, and then, from cape St. John, sets strongly to the eastward and north-eastward. From thence the flood runs to the north-east, along the north side of Staten island and Tierra del Fuego, occasions very high tides at the entrance of Magellan strait, where it unites with the stream which has come directly through the strait, and passing onward along the coast of Patagonia, produces high water at each place in succession until it is lost near cape Corrientes.

Near the coast between the dangerous banks of San Blas and Bahia Blanca, the flood and ebb streams set nearly north and south, from one to 4 miles an hour, according to the wind and the age of the moon. Between the banks of San Blas and the Rio Negro, the tides are regular, running a little more than 6 hours each way, if not affected by the wind, with a velocity of 2 to 5 miles an hour; these strong and dangerous tides are not much felt at the distance of 15 miles from the land. Between San Blas and cape Bermeja the tidal stream sets N.E. and S.W., about equally strong each way.

In the depth of the gulf of San Matais there is very little stream of tide, but a rise and fall of from 20 to 30 feet.

In the gulf of St. George there is not much stream of tide. Off capes Dos Bahias and Blanco, particularly the latter, the tides are again strong, and there are races off cape Blanco almost as dangerous as those off the peninsula of San Josef.

Off the peninsula of San Josef there are dangerous tidal races; and so high and so violent are the waves at particular times of tide that a small vessel might be most seriously injured if not totally destroyed by getting into them.

East Falkland Island: The flood runs to the north-east, past the Wolf rock, and becomes stronger as it approaches cape Pembroke, round which its rate is from 2 to 3 miles, according to the age of the moon. The flood runs directly to the northward of the Seal rocks to Volunteer point, while very little tide is felt within the heads of port William or Berkeley sound. The ebb runs with equal strength to the southward, and when there is a strong breeze, a heavy tide rip extends 2 miles off shore.

The tide sets to the westward during the flood along the whole south shore of East Falkland; its strength is from one to 2 miles an hour, but near Porpoise point, the south-west horn of the bay of Harbours, it is nearly 3 miles, and with westerly gales forms a strong race. The stream turns when it is high water by the shore.

It is high water, full and change, on the shore at Race point, at the northern entrance of Falkland sound, at 6h. 45m.; the velocity of the tide here is about 4 miles an hour, but in Grantham sound its rate diminishes to about 1½ miles. At the southern entrance of the sound it is high water, full and change, at 7h.

The time of high water, full and change, in the harbors in Falkland sound, is given on the chart.

The tides in both entrances of the sound, and between the islands, run from 3 to 5 knots at springs, but in the wider portions they are moderate. The stream of tide at the north entrance makes into the sound about 3 hours before high water on the shore, or about 4 hours at full and change. Among the islands in the south-eastern part of the sound the tides are very irregular in their set and velocity.

There appears to be tide and half tide all through Falkland sound. The flood stream commences by running to the northward when it is half ebb by the shore, and runs until half flood; it then turns and runs to the southward until it is half ebb again. But the tides among these islands require further investigation; Captain Fitz-Roy states that the tide flows into both ends of Falkland sound, and that the two streams meet near the Swan island.

It is high water, full and change, in Pebble sound at 8h. 45m.; springs rise 8 feet. Running along the north coast of the islands to the westward, part of the flood rushes through Tamar and Whaler passes, and part sweeps round the West Pebble islet into Keppel sound, filling that sound, and port Egmont, 2 hours before it has ceased running to the westward. This latter portion rushes eastward through the North-west pass at the rate of 5 to 8 miles an hour; it sweeps through a part of Pebble sound, meeting the flood-tide that comes in with equal velocity through Tamar pass, and thus causes whirls and eddies in several quarters. The water having attained its height remains quiet only a little while, and then ebbs with similar fury.

Biscoe Islands: From the observations which have been made, it is inferred that the flood and ebb streams in moderate weather run eastward and westward for a distance of about 6 miles from the outer points of the land, taking the sweep of the bays.

86. *Northeast Coast of South America, quotations.*

Paranahyba River: The tides run at the rate of 4 or 5 miles an hour in the passage; outside the bar the ebb sets to the northward.

Within 3 or 4 miles of Santa Anna reefs the tidal influence from Rio Preha is felt, the flood sets to the south-west and the ebb north-east. It is high water, full and change, at 5h. 45m, rise on the reefs 13 feet.

It is high water, full and change, in San Luiz harbour at the custom-house quay, at 7h. 0m.; springs rise 16½ feet, and neaps 10¾ feet. At the anchorage outside the harbour, the flood sets S.S.W. and the ebb N.N.E.

It is high water, full and change, at Manoel Luiz reef, at 5h.; and the rise is 12 feet. The tide runs regularly six hours each way, the flood to the S.W., and the ebb to the N.E., one mile an hour.

From Maranham to the Para River: The flood tide generally runs S.W. near the coast and W.S.W., or more westerly, at some distance from it; it has a mean rate of 2½ miles an hour near the land, which diminishes as the distance from the coast increases. The ebb tide sets about E.N.E. near the coast at the rate of 1¾ miles an hour.

From the Para to Cape North: The flood tide, which runs to the S.S.W. near the mouth of the Amazon, inclines toward the S.W. and W.S.W. in proportion to the distance from the land; and the ebb tide, which sets first N.E., inclines toward the N. and N.W. before it is united with the general current. A difference of 2 or 3 hours in the establishment of two places far from land and only 12 miles apart, and a rise of only 6½ feet 12 miles from a point, where at the preceding tide 29 feet had been observed, are two anomalies in the tides quoted as most remarkable among others less striking, though numerous on this coast.

The Bore or Pororoca is a tidal phenomenon which sometimes occurs in the western branch of the Amazon at about spring tides.

The bore confines itself to the shallows and affluents, and is not felt in depths over 4 fathoms, except by an increase in the velocity of the stream, so that there is no danger to vessels keeping the main or deep channels.

When it makes its appearance, which is at the lowest of the tide, a roaring sound is heard at a distance of from 3 to 6 miles; as it approaches the noise increases, and soon a head of water, estimated to vary from 5 to 12 feet in height with a breaking face, is seen occupying the whole of the shallow water off Maraca island and Araguary river out to about a depth of 4 fathoms. Its velocity is estimated at from 10 to 15 miles an hour, being strongest and most dangerous in the months of January to June, and at the equinoxes, when the wind is north-eastward, and it carries away in its course everything that is opposed to it.

It is high water, full and change, at the entrance of Cayenne river at 4h. 37m. At the equinoxes the rise is 10 feet, at ordinary springs 7 feet, and at neaps from 4 to 5 feet. Near the coast the flood stream, combined with the current, sets north-westward with a velocity of 2 to 4 knots an hour, varying with the seasons, being greatest during the summer months; the ebb stream sets north-eastward with a velocity of one knot an hour.

The flood stream outside the bar of Maroni river sets north-westward; the ebb stream in the river has a tendency to set towards Dutch bank.

Surinam River: In the offing, the flood stream sets to the westward, the ebb to the eastward.

It is high water, full and change, at the entrance to Berbice river at 4h. 30m.; springs rise 8 to 10-feet, and neaps 5 to 6 feet. The flood stream in the river sets about S.W. and the ebb North.

The flood and ebb streams off the mouths of Demerara and Essequibo rivers set S.W. by S. and N.E. by N., respectively, and extend to the distance of about 20 miles from the land, or to a depth of about 10 fathoms, on the inner edge of the permanent north-westerly current. The flood stream at this distance runs with and somewhat increases the strength of the current, whilst the ebb retards it.

Waini or Guayma River: The flood stream sets south-westward across the entrance, and the ebb straight out of the river.

Orinoco River: The tidal streams for a short distance off the land run about 6 hours each way, the flood to the westward.

87. *Western Coast of South America, quotations.*

Le Maire Strait: It is high water, full and change, in Good Success bay, at 4h. 3m.; springs rise 6 to 8 feet; it is slack water in Le Maire strait at or near the time of high and low water in Good Success bay. In Le Maire strait the flood stream makes to the northward about one hour after low water, and the ebb to the southward about the same time after high water, and the strength of the stream is from 2 to 4 knots near cape San Diego and from 1 to 3 knots in mid-channel; more or less, according to the wind.

In Barbara channel the flood-stream was found to set to seaward, or to the southward, as was also the case in Cockburn channel; but the whole system of tides in this great archipelago requires a careful and patient investigation.

To the northward of cape Virgins the streams set north-west and south-east along the coast; the same will be found on the outer edge and outside the Sarmiento bank. The north-west-going stream, which runs from 3 hours before to 3 hours after high water at cape Virgins, appears to sweep up the eastern shore of Tierra del Fuego to the south end of Sarmiento bank, where it divides, one stream running into the strait, while the other continues northward along the outer edge of the bank. In the same way the east-going stream is met coming out of the strait, and turned to the southward, by the stream sweeping down the coast to the south-east, and across the entrance in the same direction. The seaman must not be deceived by this, which makes the west-going stream on the north end of the bank appear to run out of the strait, while toward the south end it varies with the time of tide.

Thus it will be seen that in the vicinity of capes Virgins and Espiritu Santo, it is high water, full and change, between 8h. 30m. and 9h. A. M., while the west-going stream is still running into the strait and to the northward past cape Virgins. The main stream continues running to the westward at full and change until near noon, though the water is falling everywhere. About noon the direction of the stream changes (there being no appreciable slack water in the channel), and until near 3h. P. M. the water continues falling, while the stream of tide is running to the eastward until after 6 o'clock.

Magellan Strait: It is high water, full and change, in the First narrows at 8h. 57m.; and the strength of the stream is from 5 to 8 knots; there is no slack water. The stream changes 3 hours after high and low water.

It is high water, full and change, in Philip bay at 9h. 29m.; springs rise 17 feet. The western-going stream makes three hours before high water by the shore and runs till three hours after.

It is high water, full and change, in Laredo bay at 11h.; springs rise 7 feet. When to the southward of Laredo bay, the tidal streams are scarcely felt; but to the northward they are strong, and must be carefully guarded against during the night, or in light winds.

It is high water, full and change, at port Famine, at noon; springs rise 6 feet, the ebb setting to the northward, and the flood to the southward.

It is high water, full and change, in this part of the strait at 1h. 40m. The rise in port Tamar is 6 feet, and a little less in port Churruca. The flood stream sets to the eastward, and may attain a rate of 1½ knots.

The flood stream sets to the southward, or to seaward in Cockburn channel, but was not found to run with sufficient strength to affect a vessel working through. The rise is 6 or 8 feet at spring tides.

In Barbara channel the flood stream was found to set to seaward, or to the southward, as was also the case in Cockburn channel.

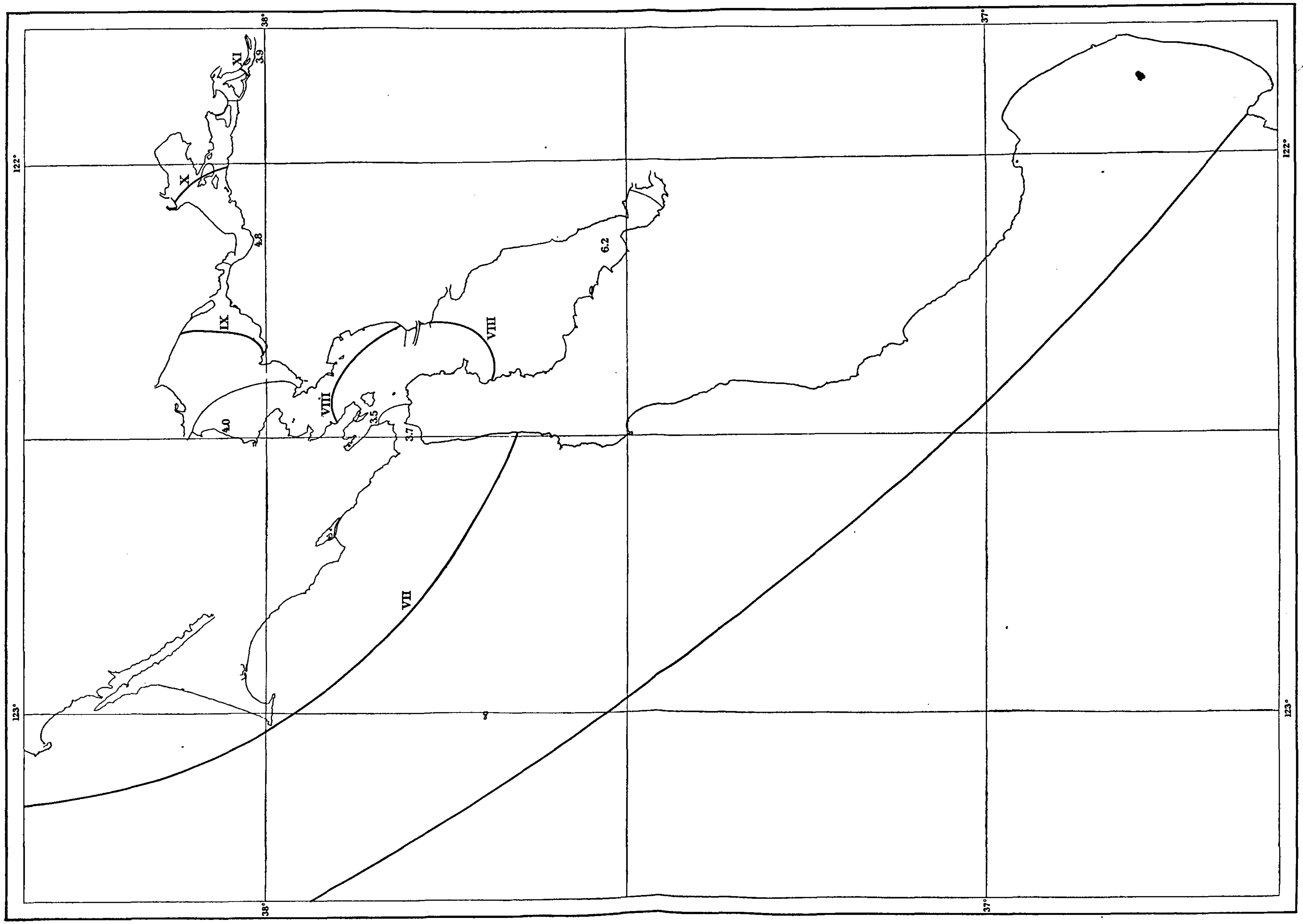
Guia Narrows: It is high water, full and change, at 12h. 0m.; springs rise 8 feet. The flood stream in the Narrows runs to the eastward, ebb to the westward, at the rate of 2½ to 3½ knots an hour at springs.

It is high water, full and change, in Brassey pass about noon. At spring tides the streams run through the pass 1½ knots per hour; flood to the eastward, and ebb to the westward.

It is high water, full and change, in Alert harbor at 12h. 15m.; springs rise 7 feet. No stream is felt.

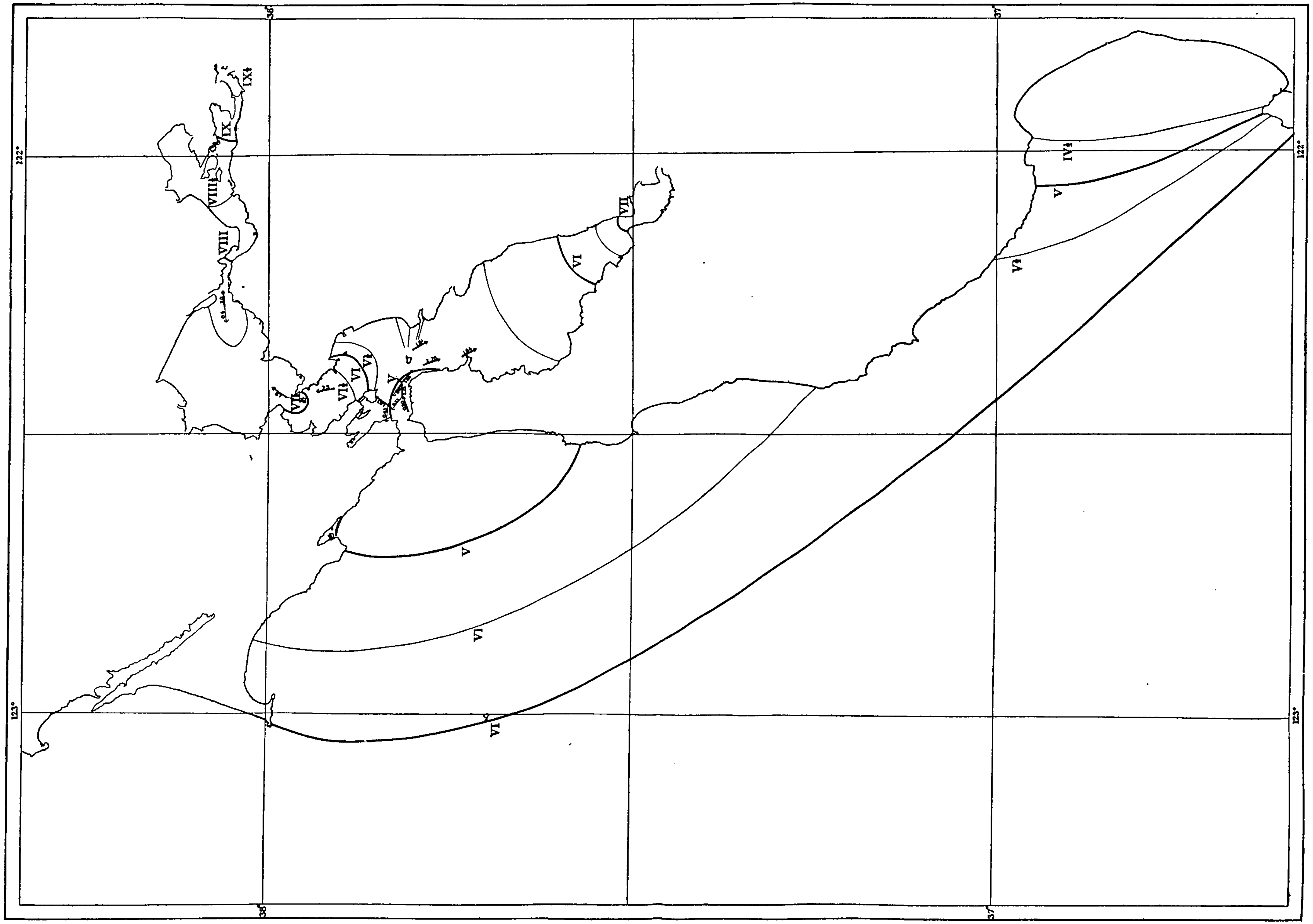
It is high water, full and change, in Trinidad channel about noon; springs rise about 6 feet. The flood-stream runs to the eastward and the ebb to the westward.

It is high water, full and change, in Eden harbour, at 0h. 15m.; springs rise 6 feet. The flood sets S.S.E., the ebb N.N.W.



COTIDAL LINES FOR SAN FRANCISCO BAY.

No. 17.



COCURRENT LINES FOR SAN FRANCISCO BAY.

Tidal hours: Fort Point, VII. 42, I. 04; Mission Street, VII. 87, I. 54.

Magellan Strait to Cape Tres Montes: High water on most parts of this coast takes place within half an hour on either side of noon, at full and change. The stream is inconsiderable, and the rise and fall rarely more than 6 feet.

Chonos Archipelago: In the channels which have an east and west direction, the flood sets to the eastward, and ebb to the westward. In those having a north and south direction the flood generally sets to the northward, and ebb to the southward.

It is high water, full and change, in Chacao narrows at 0h. 50m.; springs rise 16 feet, neaps 7 feet. The strength of the streams between Huapacho and Doña Sebastiana islet is from 3 to 4 knots, and gradually increases in rate until the maximum of 9 knots at springs is attained off Remolinos point.

In Chacao bay an eddy sets in a contrary direction to the stream in the narrows from 1 to 3 knots; the line of separation is that drawn from Tres Cruces point to Remolinos point.

It is high water, full and change, at port Huite at 0h. 55m.; springs rise 20 feet, neaps 13 feet. The flood tide off the port sets to the northward, and strongly at springs.

Chatham Island: At Wreck bay springs rise 8½ feet. Across the entrance to the bay the flood stream sets N.E. by N. at 1½ knots, and the ebb S.W. by S. at 1¾ knots an hour.

Pedro Gonzales Island, Gulf of Panama: It is high water, full and change, in Perry bay at 3h. 50m.; springs rise 16 feet. The tidal stream is not felt in the anchorage, but there is a considerable set off the island, the flood running to the northward, the ebb to the southward, the latter being generally the stronger.

It is high water, full and change, in Panama road at 3h. 50m.; springs rise from 15 to 22 feet, neaps from 10 feet to 16 feet. The ebb sets south from one to 1½ miles an hour, and is stronger than the flood, which runs to the North-west.

From charts published by the United States Hydrographic Office the following velocities of the tidal currents are obtained: Off Cape San Diego, La Marie Strait, 3 to 4 knots (tide race); off Cape Virgins, 2 knots; First Narrows, Magellan Strait, 5 to 8 knots; Second Narrows, Magellan Strait, 3 to 6 knots; entrance to Nuevo Gulf, 2 knots; east of Valdes Peninsula, 3 knots (overfalls).

The charts indicate, by the absence of arrows, the probably small velocities of the tidal currents along the unbroken coasts against which stationary waves have endings.

88. *Pacific Coast of North America.*

The Gulf of California has a tide wave stationary in the main. Through passages formed by the islands in the gulf, the currents are very strong. Between Tiburon Island and the main land the flow is hydraulic, with a velocity of perhaps 7 knots.

Off Point Fermin, San Pedro Bay, California, a few current observations indicate that the tidal flow is for the most part along the Californian coast and not perpendicular to it. Moreover, the observed current hour for the western stream is V, which about agrees with the time of northwesterly current in the stationary oscillation, one of whose loops is in the Gulf of Alaska, where the tidal hour is IX (see Fig. 23, Part IV A); that is, the flow along the coast is probably much greater than the flow normal to it due to the South Pacific system (sec. 75, Part IV A).

Knowing the time of tide for San Francisco Bay to be about VIII, it follows that time of greatest influx must be about V. Observation shows that this inference is nearly correct. Northeasterly from the city the current is rotary in the counterclockwise sense. This agrees with Airy's rule in such matters; for, observations upon both tides and currents prove that the tide wave of the southern branch of the bay is nearly stationary, while considerable progression occurs toward San Pablo Bay. Near the mouth of Richardson Bay, on the northern side of the strait, the currents are rotary in the opposite sense and for a similar reason. Although not based directly upon observation, there are good reasons for believing that beyond the influence of the bay the tidal streams must flow about parallel to the coast and here have VI for the hour of maximum flood.

If San Francisco Bay were only a deep reservoir whose level surface rose and fell with the water outside it would be reasonable to expect that for equal ranges of tide the diurnal velocities through the Golden Gate would be one-half those of the semidiurnal.

By comparing the values as $\dot{K}_1/K_1$, $\dot{O}_1/O_1$ with $\dot{M}_2/M_2$ it will be seen that for San Francisco the ratio is even less than half. This indicates that more wave motion goes on with reference to the semidiurnal tide than with respect to the diurnal, and this would naturally be expected in so limited body of water as San Francisco Bay.

Off the southeastern extremities of Vancouver Island the current has a velocity of from 3 to 6 knots.

The currents are strong at the entrance to Burrard Inlet.

The tidal currents in Seymour Narrows, Discovery Passage, have a velocity of from 4 to 8 knots (see Fig. 32, Part IV A). They are chiefly hydraulic, as can be seen by substituting the tidal hours and ranges taken from Fig. 32, Part IV A, in Table 60, and comparing with the observed times of turning. According to Lieut. Commander E. K. Moore, U. S. Navy, the slack waters in the Narrows occurs $3^h\ 48^m$ after Sitka high water and $3^h\ 51^m$ after Sitka low water, in absolute time. The former slack is that preceding the north-going stream; the latter, the south-going.

The same authority gives as the time by which slack water in Sergius Narrows precedes the high and low waters at Sitka, $2^h\ 00^m$ and $1^h\ 41^m$, respectively.

That currents are also hydraulic in Sergius Narrows and in Clarence Strait, can be seen upon consulting the maps just referred to and substituting the values taken from them in Table 60.

The turning of currents soon after the high and low waters in most of the canals of Alaska indicate waves chiefly stationary.

Through the narrow passes of the Aleutian Islands the currents are hydraulic.

For further details concerning the tidal currents in Alaskan waters, see Pacific Coast Pilot, Alaska, published by the Coast and Geodetic Survey.

89. *New Zealand.*

The tidal streams (Fig. 6) indicate a species of progressive wave traveling entirely around this group of islands. As has been explained in Part IV A, the origin of this movement is the loop of a stationary wave north of the North Island. The fact that a tide wave progresses through Cook Strait in a northwesterly direction from a region where the mean range is only 4 feet to a region where it is 8, suggests at once the probability of the oscillation in the strait being stationary.

From Fig. 40, Part IV B, it is seen that the tidal hour and range for the southeastern entrance to Cook Strait, New Zealand, are IV.4 and 4 feet, while the corresponding quantities for the northwestern entrance are IX.5 and 8 feet. Table 60 gives IX.8 for the hour of greatest southeastward downward slope through the strait. This increased by 3 hours gives XII.8 as the ebb (southeasterly) current hour. This value agrees fairly with the values given upon B. A. Chart No. 695. This chart shows overfalls and heavy tide ripplings in the strait due to the uneven bottom. The flow through Tory Channel is probably hydraulic.

The following quotations are from the New Zealand Pilot (1901):

90. *Coasts of New Zealand, quotations.*

On the eastern coast of North island the flood stream runs to the northward, and the ebb to the southward, at the rate of about one knot per hour; but in Hauraki gulf they take a contrary direction, the flood running south and the ebb north. The body of the flood stream, entering from the southward between cape Barrier and cape Colville, separates about False head on the west side of Great Barrier island, and sweeps round to the southward, filling the Thames and Waitemata rivers through the different channels leading to Auckland. The ebb tide runs from one to 1½ knots to the southeast between Great Barrier island and cape Colville, but inshore much stronger. The range of tide in Hauraki gulf is from 4 to 10 feet.

In Whangaparaoa passage the tides run from one to 2 knots; in Waiheke channel, half a knot; but from 2 to 3 knots in the adjoining narrow channels.

It is high water, full and change, at Long point at 6h. 0m.; springs rise 5 feet; neaps 4 feet. The tides in Hawke's bay are slack in the bay, but strong in the river mouths. The flood sets inward to the northward, and the ebb to the southward.

It is high water, full and change, at port Napier at 6h. 15m.; rise, 3 to 4 feet. The flood stream runs in 1½ hours after high water, and at the time of slack has fallen from 1½ to 2 feet; similarly with the ebb, the water begins to rise 1½ hours before the outward stream ceases.

In the narrow part of the channel the ebb runs 6 to 7 knots, and from the entrance sets northeastward. In the bay the flood comes in from south-eastward, and the ebb runs out northeastward.

It is high water, full and change, in Lambton harbor, port Nicholson, at 4h. 17m., springs rise 3¼ feet, neaps 3¼ feet; the strength of tide in the Narrows at the entrance of the port, is from half a knot to 2 knots, but within it is much less.

The flood stream outside the entrance sets to the northward, and the ebb to the southward; each tide runs about six hours.

It is high water by the shore at the southern entrance of Cook strait at 6h. 0m.; but the flood or northerly stream commences at 3h. 0m., or three hours before, and runs until three hours after high water by the shore.

The narrowest part of Cook strait is formed by cape Terawhiti and Wellington head, the latter bearing from the former N. 80° W. 12 miles. It is high water, in the center of the strait here, on full and change days at 8h. 0m.; the flood or northerly stream commences at 4h. 0m. and runs until 10h. 0m., the strength of the tide varying from one to 3½ knots.

Heavy tide ripplings are experienced in the central part of the strait between these two heads, where there is uneven bottom, the depths varying from 80 to 122 fathoms sand. Tide ripplings also extend off cape Terawhiti 2 miles, and for nearly 3 miles off Karori rock; eastward of Sinclair head these ripplings cease.

Wanganui Heads: Off the adjacent coast the flood runs to the northward, and the ebb to the southward, from 1 to 2 knots.

Between Wanganui and cape Egmont the flood tide sets to the westward, and the ebb to the eastward, at a rate of from one to 2 knots per hour.

It is high water, full and change, at New Plymouth at 9h. 30m.; springs rise 12 feet, and neaps 9 feet. The flood sets to the westward, the ebb to the eastward about one knot.

It is high water, full and change, at the east entrance of Tory channel at 8h. 15m.; springs rise 8 feet and neaps 6 feet. At the eastern entrance to the channel the tidal streams run 5 to 7 knots, opposite Jackson bay 2 to 4 knots, and in the rest of the channel one to 3 knots.

The flood stream begins to run at 1¾h. after low water by the shore, and continues for 5h. 35m.; the ebb stream begins at 1½h. after high water, and runs 6h. 25m.

Off Stephens island it is high water at 8h. 0m.; the flood or north-westerly stream begins 3¼ hours after low water; and the ebb or south-easterly 3¼ hours after high water.

French Pass: It is high water, full and change, at 10h. 0m.; the rise is 5 to 12 feet. The tide streams in French pass run 5 to 7 knots, and instead of setting directly through the narrow channel, set across more in a line from Rock Cod point to Channel point, and the contrary, and a tidal irregularity which though not of rare occurrence is especially remarkable in this pass, viz., that the ebb stream running to the eastward commences at 2 hours before high water by the shore, the tide at the same time rising in

Current basin and French pass; the extraordinary nature of the bottom, in connection with the narrowness of the channel, is quite sufficient to account for the whirling of the current, the depth varying from 7 to 53 fathoms, without reference to the distance from the shore or rocks.

Kaipara Harbor: The tides outside the harbor follow the direction of the coast, the flood running south and the ebb north.

Manukau Harbor: Tidal streams above Puponga, both in the Wairopa and Waiuku channels, average 2½ knots at springs. In the narrow part of the channel off Paratutai they run 4 knots, and on the bar outside from one to 2 knots; on the outer coast the flood sets to the south and the ebb to the north.

It is high water, full and change, on the bar of Whaingaroa harbor at 9h. 50m.; springs rise 12 feet, neaps 9 feet.

The strength of the tides between the heads is from 4 to 6 knots; a mile above, from 2½ to 3 knots; and at the anchorage off Matakokako point from 1½ to 2 knots.

Newhaven Harbor: It is high water, full and change, at 2h. 30m.; springs rise 7 feet, neaps 5½ feet, strength of tide 2 to 3 knots, both ebb and flood. The flood stream runs in for 50 minutes after high water.

The flood tide sets through Foveaux strait from west to east, and is strongest between Bluff harbour and Ruapuke island; its influence is felt as far as Long point, 45 miles eastward of that island. Between Ruapuke and Stewart island it sets to the south-eastward, running parallel with the shores of the latter. The ebb takes an exactly contrary direction.

It is high water, full and change, in the western entrance of Foveaux strait, that is, between the north point of Stewart island and Pahia point, at 12h. 15m.; the flood stream commencing from half an hour to 2 hours after low water, according to the winds, being earlier with those from the westward.

Both the ebb and flood streams run for 6 hours. At the eastern entrance of the strait, it is high water at 1h. 0m.; the flood stream commencing at 10h. 0m., or 3 hours after low water.

Along the northeast side of Stewart island the flood or south-easterly stream runs one hour and 20 minutes after it is high water at port William, or until 2h. 0m., on fall and change days. The strength of the tide varies from one half to 2½ knots; in the narrow part of the strait, between Ruapuke and the Bluff, it is 3 knots.

The flood tide coming from southward strikes the south end of Stewart island and divides, one part running northward along its western side, and then eastward through Foveaux strait; the other runs north-east along the south-east side of the island, as far as port Adventure, where the streams meet again and flow eastward.

The strength of the tides off the coast is from one half to 1½ knots, except in the narrow passages.

Chatham Island: Tidal streams are felt over an area of from 10 to 15 miles from the islands. The flood splits at the south point and runs north along the east and west sides, to join again at the north end; similarly the ebb divides at the north and rejoins off the south end. A single tide has been known to take a sailing vessel from off the southeast point of Chatham island into the vicinity of The Sisters.

Auckland Islands: The tide-rips off the north point of Enderby island extend a long way to the north-east, at times to a distance of 12 miles, and to a stranger have a most alarming appearance. The flood sets north-north-east and the ebb to the southward.

91. *Coasts of Australia.*

The tidal currents along the eastern coast of Australia are, as a rule, not strong. Those within the Great Barrier Reef seem, from the nature of the case, to be of no great importance in connection with the general problem of ocean tides; but any observed facts relating to the outer edge of the reef, or to the outlying islands must be of value. These indicate that the tides of the Coral Sea belong to a dependent wave nearly stationary in character.

Through Torres Strait the tidal streams are considerable.

Near the head of the Gulf of Carpentaria the semidaily tide nearly disappears.

The easterly and southeasterly direction of the tidal streams northwest of Australia indicate the stationary character of the tide. In the comparatively shallow waters bordering this coast, the currents sometimes have a rotary character.

There is probably little current along the western coast of Australia between Houtmann Rocks and Geographe Bay.

The current is probably small in the Great Bight.

Near the heads of Spencer Gulf and of the Gulf of St. Vincent the currents are weak and irregular, as is usually the case at the end of a stationary dependent wave.

On the southwestern coast of Tasmania the streams are weak, indicating a partial end boundary of the oceanic stationary oscillation from the southwest.

In the western end of Bass Strait the currents are strong (see Fig. 34, Part IV A).

The following quotations are taken from the Australian Directory, Vols. I (1897), II (1898), and III (1895):

92. *Coasts of Australia, quotations.*

It is high water at St. Paul island, full and change, at 11h. 0m., springs rise 3 feet.

At the outer anchorage in 30 fathoms, with Ninepin rock bearing W.N.W., distant 8 cables, the stream sets N.W. from low water to 2 hours ebb on the shore, or for 8 hours; and sets S.E. from 2 hours ebb until low water.

Cape Arid: The tides are very weak and inconsiderable in this neighborhood, and are much influenced by the wind.

Coffin Bay: At the bar the streams make an hour after low and high water, respectively.

It is high water, full and change, in Boston bay at 1h. 50m.; springs rise 6 feet. There is very little tidal stream in any part of port Lincoln. At 2 or 3 miles off the coast outside, the stream sets to the northward during the rising tide, and to the southward during the falling tide, its greatest strength being from 1½ to 2 knots an hour.

Spencer Gulf: It is high water, full and change, at the entrance to Franklin harbour at 4h. 0m.; springs rise 5 feet 6 inches. The streams begin a few minutes after high and low water respectively.

It is high water, full and change, in port Victoria, at 2h. 40m.; springs rise 5 feet. The tidal streams set North and South; about 1½ knots to the northward during the rising tide.

The stream sets N.N.E. during the rising tide, and S.S.W. during the falling tide, at the rate of 2 knots an hour over Tipara reef; outside it the streams set more North and South.

The stream divides off cape Spencer during the rising tide, one branch setting along shore, E.N.E., and the other to the north-westward and northward.

The tides in the northern part of Spencer gulf are very irregular.

Investigator Strait: During the rising tide the stream sets N.N.E. 1½ miles an hour into Foul bay; and during the falling tide it sets S.W.

Kangaroo Island: The north-going tidal stream runs during the rising, and the south-going during the falling tide.

It is high water, full and change, in port Wakefield, at 4h. 40m.; springs rise 11 feet; neaps 5 to 6 feet.

On the bar at the sea mouth of the Murray river high tide occurs in the night or morning from September to March; and from March to September in the day or afternoon. Also the time of high water only varies 2 hours from the time observed on full and change days (0h. 50m.), ranging from 11h. when the moon's age is 10 or 26 days; to 3h. when the moon's age is 20 or 7 days.

In the Murray mouth the ebb tidal stream runs strongest at low water, the ordinary rate then being 3 knots on the surface in the deep part, and 4 knots on the bar.

There is no tidal stream in Lacepede bay.

It is high water, full and change, at all places on this coast at nearly the same time, namely, Portland bay, 0h. 30m.; port Fairy, 0h. 31m.; Warrnambool, 0h. 37m.; New Year islands (King island), 0h. 48m.; Surprise bay (south part of King island), 0h. 43m.; Sea Elephant bay (King island), 0h. 50m.; springs rise 3 feet.

The tides and tidal streams are much affected by the winds and are uncertain.

It is high water, full and change, at New Year islands at 0h. 48m.; springs rise 3 feet. The stream turns, in fine weather, at high or low water, but is greatly affected by prevailing winds.

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It is high water, full and change, in Sea Elephant bay at 0h. 50m.; springs rise 3 feet. The flood stream runs to the northward and the ebb to the southward, at springs 1½ knots.

Port Phillip: The streams turn from 2 to 3 hours after high and low water on the shore.

The in-going stream comes from the southward and eastward, increases in strength as it nears the heads, sets right into the entrance, across and through the reefs, with great force, and spreads toward Shortland bluff and point King.

Between the heads the stream runs from 5 to 7 knots; in the West and South channels between 2 and 3 knots; and about 1½ knots in the broad space above the channels.

At the eastern part of the fairway of Bass strait, the flood stream sets to the southwest and the ebb to the northeast.

Kent Group: The flood stream comes from the N.E., the ebb from the S.W. In fine weather it is slack water at the time of high and low water.

At the eastern entrance of Franklin sound the flood streams meet, one coming from the N.N.E. and the other from S.E. The flood stream sets to the westward through Franklin sound, and from thence about W.N.W. on the north side, and W.S.W. on the south side of Chappell islands; and the ebb in the contrary direction. In the north channel the streams run 2 to 2½ knots.

Banks Strait: The flood stream is the west-going stream, and the ebb the east-going; the streams are each of 6¼ hours duration at springs; but during neaps the flood runs 7 hours and the ebb 5½ hours. The interval of slack water never exceeds a quarter of an hour; the west-going stream begins 30 minutes after low water at springs, and 50 minutes after it at neaps; the east-going stream begins 40 minutes after high water at springs, and 10 minutes before it at neaps.

In the narrowest part of the strait (8½ miles wide) between Swan isles and Clarke island, the tidal streams run at the rate of 3 knots at springs; westerly winds accelerate the east-going stream, which occasionally attains a rate of 5 to 6 knots.

The tidal streams are strong at port Frederick, attaining a rate of 5 to 6 knots an hour both with the flood and ebb.

Outside the port, the flood is the west-going stream; it is not felt beyond 5 miles from the coast.

Tidal streams set through midchannel between King island and Hunter group from one to 3 knots the flood to the north-east, and the ebb to the south-west.

It is high water, full and change, at cape Grim at 10h. 30m.; springs rise 8 feet; the south-west-going stream has a rate at springs of 5 knots, and at neaps of 3 knots.

Macquarie Harbor: There is little or no tidal stream in Pine cove, and the rise and fall does not usually exceed 1½ feet.

The tidal streams are weak and practically imperceptible, but after a heavy gale from the south-west a distinct set was felt into Frederick Henry bay, and in Flinders channel toward Norfolk bay.

In the Lachlan channels the flood stream runs to the north, the ebb to the south.

Swain Reefs: In the offing, 20 miles eastward from Hixson cay, the ebb sets East three-quarters of a knot, and the flood West one knot, the stream turning later than low water, and earlier than high water, on the reef.

At Claremont light-vessel the streams set, generally, to the south-westward during the rising tide and to the northward with the falling tide.

North of cape Sidmouth the flood runs to the northward, and the ebb to the southward.

It is high water, full and change, at Hannibal islands, at 9h. 50m. springs rise 10 to 12 feet, neaps 9 to 10 feet; neap range 6 feet. The flood stream sets north and the ebb south, but the result during the strength of the south-east trade or north-west monsoon, is generally to increase or diminish the prevailing current. The flood begins 4 or 5 hours before high water, and the ebb one to 2 hours after high water.

Tern Island: The tidal streams generally run parallel to the coast, flood to the northward, ebb to the southward.

It is high water, full and change, at Frederick point at 11h. 0m.; mean springs rise 10 feet, mean neaps rise 8½ feet, and neaps range 6½ feet. The diurnal inequality, amounting at times to 4 feet, chiefly affects the high waters.

The streams are rapid in Albany pass, attaining at springs a velocity of 5 knots an hour, and cause a confused sea when running in an opposite direction to the wind.

Off Fly point there is always a very heavy tide rip, dangerous to boats, on the flood at springs, caused by the stream from Newcastle bay meeting the stream on the east side of Ulfra rock.

The north-going stream runs until about 2 hours after high water by the shore, and the south-going stream until about 1½ hours after low water.

In Adolphus channel the flood stream sets north-westward and ebb south-eastward, both attaining a velocity of from 2 to 4 knots at springs.

The channel is covered with ripplings and swirls when the streams are at their strength, giving the appearance of shoal water, but Mid and Quetta rocks were the only dangers found.

The flood sets westward past Mount Adolphus islands, and meeting the stream through Adolphus channel causes heavy overfalls off the salient points. The streams attain great velocity at springs among the islands of the group.

Off Albany rock there is a heavy confused sea when the streams run strong.

It is high water, full and change, at Raine island at 8h. 10m., and the flood runs an hour and three-quarters later in the stream; springs rise 10 feet. The strength of the stream sometimes exceeds 2 knots, the flood coming from the eastward.

It is high water, full and change, at Possession island at 1h.; the rise at springs being 9½ feet; the flood sets 7 hours S. 22° W., and the ebb 5 hours N. 22° E.

In Normanby sound and Thursday island harbour the flood stream sets to the westward, and the ebb to the eastward, the flood being strongest during the south-east trade.

In Normanby sound the streams run 3 to 5 knots in the direction of the channel. Between Vivien point and Prince of Wales island, both streams at times run 7 knots, but are less felt when Vivien point bears westward of N. 45° W.

On the north side of Thursday island harbour, the flood to the westward is from one to 3 knots, but with the ebb there is slack water. On the south side of the harbor the flood runs 2 to 4 knots, and the ebb along the edge of Madge reefs will sometimes reach 4 to 5 knots. The tide sets over Hovell rock with considerable strength.

In Flinders passage the tides run 3 to 5 knots, and cause overfalls between Horn island and Tuesday islets.

It is high water, full and change at Murray islands at 9h. 30m.; springs rise 10 feet. Close northward of the islands, the flood sets to the westward, and the ebb to the eastward, about 2 knots at springs. Between Maĕr and the two islets the tidal streams run with great force.

In the neighbourhood of Bramble cay, and in the south part of Bligh entrance, the flood runs in a westerly and the ebb in an easterly direction, 1½ knots at springs; the flood runs 2 hours after high water. The neap tides are comparatively little, both in range and velocity.

The time of high water, full and change, does not appear to differ more than 1½ hours throughout the whole length of the Great Barrier reefs, the average time of high water being at about 9h. 15m., and the rise of tide from 6 to 12 feet.

At Swain reefs the general direction of the flood through the reefs was found to be south-west, and the ebb to the north-eastward, the velocity between springs and neaps being from 1½ to 2 knots; but the stream appeared to run with greater strength through the more confined channels.

Between Swain reefs and Lizard island the flood appeared to run in, and the ebb out, through the openings of the reefs, with a strength depending in great measure upon the breadth of the passage.

From Lizard island to lat. 12° 30′ or 13° S., the strength of the stream being confined to the openings, the velocity is increased or diminished according to the width of the channel.

From lat. 12° 30′ S. to Pandora entrance, in lat. 11° 26′ S., the velocity at springs increases to 2½ and 3 knots, with a regular ebb and flow, except that the flood appeared to continue half an hour longer than the ebb.

At Raine island it is high water at 8h. 10m., the rise being 10 feet at springs; and it is in this vicinity that the strength of the stream increases materially. The flood rushes in through the smaller channels with great velocity; and a well-found merchant vessel, under full sail with a fair wind, has been barely able to effect an entrance against the strength of the ebb near Stead passage (in lat. 11° 55′ S.). The neap tides are comparatively weak; a reference to the phases of the moon therefore becomes a question of importance when navigating near this part of the Great Barrier reefs.

From Pandora entrance (in lat. 11° 26′ S.) to the north-west extremity of the reefs, the sea being more confined between the coasts of Australia and New Guinea, the streams run with still greater velocity than further southward, the flood having been known to run 5 knots through Yule entrance (in lat. 10° 23′ S.). Such a stream alone should deter a sailing-vessel from attempting to effect an entrance through any of the narrow gaps in this part of the barrier; but the strength of the stream diminishes very considerably as the distance from the reef is increased.

Gulf of Carpentaria: It was high water at the entrance of Van Diemen inlet, full and change, at 6h. 45m.; but in the upper part, the tides were 3½ hours later. The duration of both tidal streams was 12 hours, and the direction of the rising stream from the northward, following the trend of the eastern shore of the gulf.

It is high water, full and change, at Norman river, at 7h. 30m. p. m. in January, and at 7h. 30m. a. m. in July, and are two hours earlier each successive month. There is only one tide in 24 hours.

Burketown: The rise and fall at springs is from 9 to 13 feet, and at neaps from 3 to 8 feet—the ebb running to the north-west, the flood to the south-south-east.

It is high water in Investigator road, full and change, at 8h. a. m.; springs rise 9 feet, but the neaps are very irregular.

The stream of rising tide sets to the southward, and the falling tide to the northward, from one to 2 knots at springs. The north-going stream makes from 1½ to 2½ hours before high water.

It is high water at Bountiful isles, full and change, at 7h. 45m.; the stream of rising tide sets south-westward at the rate of 2 knots.

Tidal streams run at times at the rate of 4 knots through Brown strait; that of the rising tide sets to the southward.

It is high water, full and change, at the Goulburn islands, at 6h., springs rise 6 feet; in the channels, the stream of rising tide sets to the eastward.

It is high water, full and change, in port Cockburn, at 5h. 45m.; springs rise about 14 feet. The streams run with a velocity of 2 to 4 knots in Apsley strait; the flood comes from the northward.

Baudin Island: The stream of rising tide sets to the south and west and begins about 20 minutes before low water. The stream of falling tide runs to the north and east, and begins to set 2 hours before high water.

It is high water, full and change, at the Montgomery isles, at noon; springs rise 36 feet; the flood stream sets to the southward, at the rate of 2 to 3½ knots near the shore, and in the approach to Doubtful bay.

The streams run with a velocity of 7 to 8 knots through Sunday strait and the narrow channels in the entrance of King sound, and in the very narrow portions possibly stronger. In the fairway of the sound its rate is about 5 knots; near the western shore from 6 to 7 knots; and abreast Torment point approach to Fitz Roy river from 3 to 4 knots. Two of the boats of H. M. S. *Beagle* were nearly swamped in the entrance of Fitz Roy river, by the flood rushing in as a tidal bore, several feet in height.

King Sound: It is high water, full and change, in port Usborne, at 1h. 45m.; springs rise 34 feet. The tidal stream is scarcely felt.

Ashmore Reef: It is high water, full and change, at West islet between 10h. and 11h.; rise of tide 15 feet. The flood stream sets eastward and the ebb westward.

Browse Islet: At Browse islet, springs rise from 13 to 19 feet; neaps range about 4 feet. The tidal streams run strong. The stream of rising tide sets to the eastward and the falling tide to the westward.

It is high water, full and change, at Sandy islet, Scott reef, at about 11h., rise of tide 13 feet; the stream of rising tide sets to the eastward.

It is high water, full and change, at the Lacepede islands, at about noon; springs rise 20 feet. The stream of rising tide at the anchorage sets south-eastward, and of the falling tide north-westward. Inshore of the Lacepedes the streams set at the rate of from 2 to 3 knots an hour at springs.

Eighty Miles Beach: It is high water, full and change, at the northern Turtle isle, at 11h.; springs rise 28 feet. The stream of rising tide sets south-eastward at the rate of one to 2 knots.

Bedout Island: The stream of rising tide sets to the south-eastward, and of falling tide to the north-westward, rate one to 2 knots. The rise and fall is about 14 feet.

It is high water, full and change, at Depuch isle, at 10h. 40m.; springs rise 14 feet. At the anchorage the flood sets S. E. by E., and the ebb N.W. by W. from one to 2 knots.

It is high water, full and change, at port Robinson at 11h. 15m.; springs rise 19 feet. The tidal streams are not strong.

It is high water, full and change, in Gascoyne road, at about 10h. Springs rise 5 feet, neaps are irregular.

The stream of rising tide sets from East to S.E. and the falling tide N.W.; rate from one to 2 knots.

It is high water, full and change, in Champion bay at 9h.; springs rise $1\frac{3}{4}$ feet, and neaps $1\frac{1}{4}$ feet.

It is high water, full and change, in Warnbro sound at 9h.; springs rise 2 feet and neaps $1\frac{1}{2}$ feet; they are, however, very irregular, being greatly influenced by the prevailing wind.

93. *Eastern Coast of Asia, and the East Indies.*

The tidal currents along the eastern coast of Asia resemble in some respects those found along the coasts of Great Britain, France, Spain, and Portugal, or those along the northeastern coast of Brazil. Their variety is, however, greater owing to the presence of considerable diurnal tide or inequality in the China Sea and neighboring waters. Along this coast of Asia there are arms and belts of shallow water in which the tidal currents are in part rotary; there are several large tidal estuaries; the Bore of the Tsien-tang at Hang Chau is far famed; and in most of the rivers the duration of rise is much less than the duration of fall.

It will be noticed, from the statements quoted below, that the streams enter Formosa Strait from both ends; that there is a great crowding up of the cotidal lines near Wei-hai-wei; that there are strong currents southwest of Kiusiu; and that for the southeastern coast of Japan the flood sets southwesterly, as toward a loop of a stationary wave. Strong currents occur in the passages leading to the Inland Sea.

The following are a few quotations taken from the China Sea Directory, Vol. I (1896), Vol. II (1906), Vol. III (1904), Vol. IV (1894), and Eastern Archipelago, I (1890).

In regard to the tidal currents around the islands of the Pacific Ocean, it may be said that the information is very meager. Such as exists may be gathered from the sailing directions for the Pacific Islands Vols. I–III. A good portion of this matter, taken chiefly from Admiralty charts, is shown on the chart covering this ocean, (Fig. 6).

The same chart shows a portion of the currents around the East Indies. On account of the large diurnal wave, the arrows in this region are not always reliable. More detailed matter of a few localities will be found in Van der Stok's book entitled Wind and Weather, Currents, Tides and Tidal Streams in the East Indian Archipelago (1897).

Tidal currents for the Philippines are shown upon chart No. 1898, of the Hydrographic Office, United States Navy. One portion of the flood enters through the Sulu Archipelago. All along the northeastern and northwestern coasts of Borneo the flood stream probably progresses westward (Cf. Figs. 36, 37, Part IV B). Another branch passes through Balintang Channel and continues southward as far as Panay Island. Another branch enters through San Bernardino Strait.

Through San Juanico Strait the currents are hydraulic and strong.

As some account of the bearing of the tidal streams of the southern coast of Asia upon the tides has been given in sections 80, 81, Part IV A, and section 30, Part IV B, little will be done here except to refer to Bay of Bengal Pilot, Red Sea and Gulf of Aden Pilot, and Islands of the Southern Indian Ocean.

It will be seen from Fig. 5 that the tidal streams in the upper portions of the Arabian Sea and Bay of Bengal are nearly normal to the coast line. The flood arrow at the mouth of the Gulf of Suez pointing southerly on Fig. 5 instead of northerly is in accordance with the explanation of the tides of this gulf given in Parts IV A and IV B. The Bay of Bengal Pilot (1901) says—

Within a few miles of the Nicobars the flood tidal stream generally sets north-eastward and the ebb stream south-westward; the streams attain in the channels between the islands a rate of 3 to 4 knots.

This indicates that here the streams are strong, as if in the vicinity of a nodal line (see Fig. 23, Part IV A).

94. *Eastern Coast of Asia, quotations.*

Malacca Strait: It is high water, full and change, at Arang Arang, at 7h. approx.; springs rise 10 feet. In the harbour, the flood stream sets to the eastward and the ebb to the westward; but seaward of the 5-fathom bank, the streams set across the channel; the flood setting south-eastward from 3½ hours before until 2½ hours after high water by the shore, and the ebb north-westward.

It is high water, full and change, in Malacca road at 7h. 30m.; springs rise 11 feet, neaps 8½ feet.

The tidal streams set S. E. by E. at the rate of 2½ knots from 3 hours before to 3 hours after high water at One fathom bank.

It is high water, full and change, at Raffles lighthouse, at 11h., but the stream does not set to the eastward till two hours later, and it is then about half ebb by the shore.

The tidal streams from Malacca strait and from the China sea meet between Tree island and Tanjong Bulus, but no dependence can be placed upon them.

The tidal streams in Salat Sinki run with considerable strength, the flood to the westward and the ebb to the eastward.

In Sunda strait, it is high water, full and change, during the north-west monsoon, at 6h.; springs rise 3 feet. The flood sets north-eastward and the ebb south-westward with a rate at springs of 3½ knots, but it should be observed that the tidal streams are much influenced by the prevailing winds outside the strait, so that as a consequence the set of the stream is mainly south-westward during the greater part of the year.

The tidal streams in Banka strait are strong but irregular, and are greatly influenced by the monsoons. The flood stream enters the strait at both ends, meeting near the Nangka islands.

Northwest coast of Borneo (lat., 5° 3′ N.; long., 115° 12′ E.). The flood stream on the Outer bar sets in 1½ hours after low water, and the ebb stream runs out about 1½ hours after high water, the rate at springs being from 2 to 3 knots. To seaward of the bar, the direction of the tidal streams has not been determined. Between the bar and Sapo point, the flood generally sets to the south-west; the ebb to the north-east.

Balabac Strait: The flood stream sets to the eastward and the ebb to the westward. The strength of the stream or of the current depends greatly on the prevailing winds. The greatest velocity observed was 2½ knots.

It is high water, full and change, at Bangkok river bar at 7h. 40m., but this is subject to a large correction, the greater part of which varies with the moon's declination.

Outside the bar and near the anchorage the flood sets to the westward, and the ebb to the eastward, altering its direction according to the strength of the river stream. Along the eastern shore of the gulf toward cape Liant the ebb sets to the southward and flood to the northward.

Tong-King Gulf: It is high water, full and change, at Fai Tsi Long archipelago at about 5 hours.

The tidal streams among the islands attain a rate of 2 knots an hour in places where confined; in the offing the streams run from one to 1½ knots an hour; the flood coming from the south-west, and the ebb from the north-east; off Kebao the streams run nearly tide and half tide.

Hainan Strait: In North channel the flood sets S.W. by W. from one to 3 knots an hour, and the ebb N.E. by E. from one to 3½ knots.

In Middle channel, at the position charted (12 miles N.E. by E. ¾ E. of Hainan point), the flood sets N.N.W. from 1½ to 3 knots, and the ebb N.E. by E. one to 3 knots. (This is probably for only a portion of the time of flood and ebb.)

On full and change days in summer the	E.	set commences at	3 p. m.
" " " " " " "	"	W. " "	" 11 p. m.
" " " " " " winter	"	E. " "	" 3 a. m.
" " " " " " "	"	W. " "	" 11 a. m.

and occurs about one hour later every day.

It is high water, full and change, at West or Fort point, Nau chau, at 10h. 20m.; springs rise 12¾ feet, neaps 8 feet.

At Nau chau the stream runs 2½ knots at springs, changing about one hour after high and low water, the flood setting to the southward, and the ebb to the northward.

It is high water, full and change, at Breaker point at 10h. 0m. approximately; springs rise 8 feet.

From January to May, between Hongkong and Breaker point, the ebb tidal stream ran eastward, but generally speaking it was weak. Eastward of Breaker point the flood stream sets eastward.

Port Swatau: The flood stream is said to continue for one to 1½ hours after high water on the bar.

Namoa Island: The flood stream comes in both northward and southward of the island.

The ebb tidal stream off Jokako point has been observed to set south-westward 4½ knots in one tide.

Amoy: In the Inner harbour the duration of the flood tide is about 7¼ hours, and of the ebb 5¼ hours. The rate of the ebb stream during the first three hours is 4 to 5 knots at springs, and during its latter part 2 to 3 knots; the average rate of the flood stream is 2 to 3 knots at springs. The flood stream runs from three-quarters of an hour before low water to a quarter of an hour after high water.

Kwing Bay: In March, off Tau point, the flood stream sets south-westward and the ebb north-eastward, 2 to 2½ knots an hour.

The flood stream enters Hai tan strait by both the northern and southern entrances; these streams meet between Rocky and Middle islands, in which vicinity, and more especially between Hill and Middle islands, there are, with strong winds, heavy overfalls, dangerous for boats.

Pescadores Islands: Off the Rover group, the north-going or flood stream makes at 4 hours after high water, and the south-going or ebb stream at 2 hours before high water. The rate of the north-going stream in Shōgun suidō sometimes exceeds 4 knots during the strength of the south-west monsoon, while the south-going stream rarely reaches 3 knots, but these rates may be reversed during the north-east monsoon.

At about 3 miles off the coast, in the vicinity of Tamsui harbour, the ebb tidal stream sets north-eastward at 2½ to 3 knots an hour. This stream runs round the northern end of Formosa, and causes a turbulent ripple off Syau ki and Foki kaku. The flood stream runs south-westward at 2 knots an hour.

Chusan Archipelago: The tidal streams around and between the islands are very rapid, sometimes attaining a rate of 7 and 8 knots; and the tide ripplings are numerous and dangerous for boats when there is much wind. As a rule, the sea does not run high, but the day before the approach of a typhoon, and during its continuance, a heavy swell rolls in upon the rock-bound coast. The direction of the tidal streams eastward of Chang tau is rotary, turning with the hands of a watch; but in the straits between the islands, in the mouth of Hangchau bay, and close to the land, it follows the conformation of the coast. Clear of local influences, the following is a broad guide:

The first half of the flood runs in directions from South to West; the last half from West to North.

The first half of the ebb runs from North to East, the last half from East to South.

Usually, as the moon crosses the meridian, the bore passes Haining, where it is nearly a straight line across the river, 9 cables wide, 8 to 11 feet high, and traveling 12 to 13 knots an hour; its front being a uniform sloping cascade of bubbling foam, falling forward and pounding on itself and on the river before it at an angle of between 40° and 70°. The highest and steepest part is over the deep channel of the river.

A quarter of an hour after the bore has passed Haining, the water has risen 13 feet; at 2h. 0m. it has risen 18 feet; it is high water at 3h. 0m. when the tide has reached a height of 19 feet, and the stream at once commences to run out swiftly. At 5h. 0m. it is at the mean level; at 8h. 0m. it is nearly low water. The out-going stream, however, continues to run rapidly eastward until the arrival of the next bore. The water is at its lowest for the 2 hours preceding the bore.

It is high water at Hangchau fu about the same time as at Haining, but the rise and fall does not exceed 6 or 7 feet.

At Haining the flood lasts for 3 hours; the ebb for 9 hours. At Hangchau fu the flood continues for 1¼ hours, and is nearly all in the bore.

The tidal streams off the mouth of the Yangtse kiang are rotary and turn in a direction with the hands of a watch; the first half of the flood runs in directions from South to West, the last half from West to North; the first half of the ebb runs in directions from North to East, the last half from East to South.

The rate of the stream varies with the age of the moon between one and 4 knots an hour.

The streams on the south-eastern coast of Shantung, eastward to Staunton island, appear to follow the general direction of the coast, the flood stream setting west-south-westward, and the ebb east-north-eastward, at an average rate of 1½ knots an hour.

The times of the high water at various parts of the promontory, from Tsing hai bay to Wei hai wei, alter considerably at short intervals of distance, whilst the tidal streams change almost simultaneously at short intervals of distance.

Pe Chili Strait: In Charybdis harbour it is high water, full and change, at 10h. 30m.; springs rise 9 feet. The tidal stream sets northward in Hope sound and Charybdis harbour during the flood, and southward during the ebb. For some distance eastward of Miau tau strait the flood stream sets westward, and the ebb eastward; but within the strait, a few miles westward of Teng chau, the flood sets eastward and the ebb westward.

Northward of the Li tsin ho, the flood sets north-westward along the shore, and the ebb south-eastward, turning, but not regularly, at high and low water. At Lan mun sha banks, near the shore, the flood sets southward and the ebb northward.

Liantung Gulf (Sand Point): The flood stream sets northward along the shore, the ebb south-eastward; the streams turn earlier near the shore than in the offing.

On the east coasts of Kamchatka, Yezo, and Nipon the tidal streams are weak, and no exact observations are available; probably the streams set to the southward with a rising tide, and to the northward with a falling tide. Along the south coast of Japan, the flood stream sets to the westward and the ebb to the eastward.

The flood sets northward up the Kii and Bungo channels, the stream from the first channel setting westward in the Seto Uchi, and that from the Bungo channel dividing into two parts, one stream setting westward toward Simonoseki strait, and the other eastward, meeting the Kii channel stream at the east end of Bingo Nada. On the west coast of Kiusiu and in Korea strait the flood stream runs to the northward; to the westward and north-west through the Korean archipelago, and to the northward along the west coast of Korea.

In the Japan sea the tidal streams are weak and irregular. In the gulf of Tartary the flood stream sets to the northward.

Throughout the above coasts the streams overrun the rise and fall of tide by about one hour on the open coast, to 2 to 3 hours and even more in the Seto Uchi, among the inner islands, and in confined straits.

Amongst the islands off the south coast of Korea the flood stream sets to the westward, the ebb to the eastward, turning about 2 hours after high and low water by the shore.

The flood stream sets north-eastward along the western shore of the strait of Tartary at the rate of 2 miles an hour.

Southwest Japan: The tides near Kusakaki sima appear regular, flood flowing to the northward and ebb southward.

The tides near Mikomoto are regular, the flood setting W.S.W., and the ebb E.N.E. from 1½ to 3 miles an hour.

It is high water, full and change, in Yokohama bay at 5h. 45m. Springs rise 5 feet; neaps 3¾ feet. The tidal stream is scarcely perceptible in Yokohama bay.

Near the extreme of Futsu saki the tidal streams sweep round at a rate of more than 3 knots an hour at springs.

The rise in Ofunato harbour is about 5 feet; there is no perceptible tidal stream there.

It is high water, full and change, in Fuk ura, eastward of Naruto passage, at 6h. 14m.; springs rise 6¼ feet, neaps 4¼ feet. At Anaga ura, northward of the passage, the time of high water is variable, and the rise is 2 to 4 feet. The stream sweeps through the passage with great velocity, and the roar of its breakers can be heard for several miles. The south-going stream begins, at springs, 3 hours and 25 minutes after the moon's meridian passage, and 2 hours and 8 minutes after the moon's meridian passage at neaps.

Me sima Group: Strong tidal streams set through the channels between the islands, the flood to the north-west, and the ebb to the south-east; but the general direction of the tidal streams is more to the northward and southward.

West coast of Kiusiu: Between Me saki and Noma no hana the flood stream sets to the northward along the coast, and the ebb tide to the southward, attaining at spring tides a velocity of from 2½ to 3 knots an hour. The stream sweeps round the bays, causing tide-rips off the prominent points.

It is high water, full and change, at Nagasaki at 8h. 11m.; springs rise 10¾ feet, and neaps about 7 feet, but they are variable.

La Pérouse Strait: The tides set east and west through the strait, the east-going stream attaining at spring tides a velocity of from 4 to 5 knots an hour.

Eastern Archipelago.

Arru Islands: The flood stream in Dobbo harbour comes in from the westward, and the ebb stream from the eastward. In the south-east monsoon the flood is weak, but the ebb runs from one to 1½ knots an hour.

In the offing the flood stream sets to the S.S.E. and the ebb to the N.N.W.

Dampier Strait: The flood stream sets to W.S.W. and the ebb to E.N.E., but the streams appear to be greatly affected by the prevailing monsoons.

95. *Table of slack waters and mean maximum velocities.*

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
BAY OF FUNDY.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
From Cape Roseway, S. 51° E., 11 mi.*	....	W. Bell Dawson..	1904........	....	....	Southerly	0.80	....	....	E. by N.	0.85
Cape Sable, S. 22° W., 3½ mi.*	....	.....do...........	1904........	L.W.†−3 15	....	WNW.	2.70	HW.−2 30	....	ESE.	2.30
S. 22° W., 12½ mi.*	....	.....do...........	1904........	L.W.†−1 17	....	NW. by W.	1.90	HW.−1 08	....	E. by S.	2.10
Seal Island Light, S. 8° W., 8 mi.*	....	.....do...........	1904........	L.W.†−1 02	....	NW. by N.	2.34	HW.−1 13	....	SE.	2.37
S. 70° W., 13 mi.*	....	.....do...........	1904........	L.W.†− 13	....	N. by W.	2.95	HW.+ 25	....	SSE.	2.00
Lurcher Shoal, S. 82° E., 6 mi.*	....	.....do...........	1904........	L.W.†+ 10	....	N. by E.	2.20	HW.+ 20	....	S.	2.15
S. 80° W., 10 mi.*	....	.....do...........	1904........	L.W.†+ 35	....	N. by E.	1.82	HW.+ 22	....	S. by E.	1.87
Brier Island Light, S. 84° W., 5¼ mi.*	....	.....do...........	1904........	L.W.†+ 41	....	NNE.	3.25	HW.+ 44	....	SSW.	3.19
Petit Passage, N. 28° W., 9¾ mi.*	....	.....do...........	1904........	L.W.†+ 43	....	NE.	2.30	HW.+1 00	....	SW.	2.40
Brier Island Light, N. 63° W., 15 mi.*	....	.....do...........	1904........	L.W.†− 49	....	ENE.	1.67	HW.+ 04	....	W½S.	1.62
Gannet Rock, S. 48° E., 5 mi.*	....	.....do...........	1904........	L.W.†+ 35	....	NE. by E.	2.85	HW.− 05	....	W. by S.	4.40
Big Duck Island, N. 87° E., 3¾ mi.*	....	.....do...........	1904........	L.W.†+1 40	....	Northerly	0.65	HW.− 55	....	S. by E.	1.70
W. Quoddy Light, S. 17° W., 4½ mi.*	....	.....do...........	1904........	L.W.†+ 10	....	NE. by E.	2.90	HW.+ 30	....	SW. by W.	2.40
Moose Peak Light, S. 48° E., 6 mi.*	....	.....do...........	1904........	L.W.†+1 05	....	NE. by N.	1.00	HW.+ 05	....	W. by S.	1.55

Directions true unless otherwise noted. * Directions and bearings magnetic; variation 18° W. † Tides at St. John, N. B.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
ST. LAWRENCE RIVER.	° ′ ″			h. m.	h. m.	° ′	Knots	h. m.	h. m.	°	Knots
Quebec Harbor		W. F. Maxwell	1885-9	LW.*+1 10	Duration,5 00			HW.+1 05	Duration,7 30		
St. Laurent		do	1885-9	LW.*+ 31	Duration,5 00			HW.+ 54	Duration,7 25		
Berthier		do	1885-9	LW.*+ 10	Duration,5 05			HW.+ 25	Duration,7 20		
Grosse Isle		do	1885-9	LW.*− 19	Duration,5 10			HW.+ 08	Duration,7 10		
L'Islet		R. Pelletier	1900	LW.*−1 19	Duration,5 30			HW.− 57	Duration,6 50		
In Upper Traverse		A. Fournier	1900	LW.†+3 52	Duration,5 25			HW.+3 13	Duration,7 00		
In Lower Traverse		E. Lebel	1900	LW.†+3 57	Duration,5 45			HW.+3 35	Duration,6 45		
Orignaux Point		W. F. Maxwell	1885-9	LW.†+2 18	Duration,5 55			HW.+2 45	Duration,6 30		
In Brandy Pot Channel		do	1885-9	LW.†+2 04	Duration,6 05			HW.+1 46	Duration,6 20		
Tadousac		do	1885-9		Duration,6 08				Duration,6 15		
Green Island		do	1885-9		Duration,6 00				Duration,6 24		
Bic Island		do	1885-9		Duration,5 50				Duration,6 34		
GULF OF MAINE.											
Off Massachusetts coast	41 35 23 69 57 52	J. E. Pillsbury	July 27-28, 1885		HW.‡− 05	S.25 W.	1.55		LW.− 30	N.22 E.	1.27
Do	41 43 00 69 53 30	do	July 28-29, 1885		HW.‡−1 20	S.64 W.	0.50		LW.+ 18	N.20 E.	1.36
CAPE COD BAY.											
Off Scusset	41 48 11 70 31 25	H. Mitchell	July 23-24, 1860		T.§−2 43	N.58 W.	0.18		T.+2 58	N.46 E.	0.10
Off Manomet Point	41 50 46 70 30 24	do	July 22-23, 1860		T.§−5 26	S.8 E.	0.06		T.+1 09	Northerly	0.58
GULF OF MAINE.											
Cape Cod, near Race Point.	42 04 37 70 15 13	Robert Platt	Aug. 20-21, 1877	HW.*+5 53	HW.‡−2 53	S.46 W.	0.96	HW.− 20	HW.+2 58	N.61 E.	0.91
Off Massachusetts coast	42 52 25 69 53 37	J. E. Pillsbury	July 30-31, 1885		HW.‡−3 12	N.46 W.	0.50		LW.−4 14	N.86 E.	0.56

Directions true unless otherwise noted.

* Tides at Quebec. † Tides at Father Point. ‡ Tides at Boston. § Local transits.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
FORE RIVER.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Portland, Me.	43 39 13 70 14 47	J. B. Weir	July 14, 1873	....	HW.* −2 54	S.36 W.	0.57	....	HW.+2 33	N.52 E.	0.93
Do	43 38 59 70 15 06	....do	July 12, 1873	....	HW.* −2 48	S.41 W.	0.58	HW.− 20	HW.+2 33	N.49 E.	0.90
Do	43 38 42 70 15 31	....do	July 5, 1873	....	HW.*−3 04	S.55 W.	0.77	....	LW.−3 18	N.48 E.	0.74
Do	43 38 51 70 15 21	....do	July 11, 15, 1873	LW.*+1 02	HW. −3 00	S.46 W.	0.74	HW.− 30	HW.+1 52	N.46 E.	0.74
Do	43 38 34 70 15 46	....do	July 10, 1873	....	HW.*−2 48	S.58 W.	0.91	....	LW.−3 00	N.66 E.	0.75
Do	43 38 32 70 15 59	....do	July 9, 1873	....	HW.*−2 52	S.86 W.	0.72	....	LW.−2 49	N.83 E.	0.84
Do	43 38 32 70 16 12	....do	July 8, 1873	....	HW.*−3 17	N.89 W.	0.70	....	LW.−3 18	N.66 E.	0.66
Do	43 38 29 70 16 30	....do	July 7, 1873	....	HW.*−3 07	S.80 W.	0.75	....	LW.−3 11	N.56 E.	0.58
Do	43 38 26 70 16 55	....do	July 1, 1873	LW.*+00	HW. −3 03	N.46 W.	0.76	HW.+ 20	LW.−2 48	S.60 E.	0.84
Do	43 38 32 70 17 06	....do	July 2, 1872	LW.*−17	HW. −3 16	N.35 W.	0.76	HW.+ 15	LW.−2 44	....	0.71
NANTUCKET SHOALS.											
Nantucket Shoals	41 00 .. 69 27 ..	Lieut. C. H. McBlair	July 9–11, 1852	LW.†+ 4 08	HW. +0 11	N. 57 E.	1.94	....	LW.−0 04	S. 34 W.	1.81
Do	41 02 .. 69 34 ..	....do	Aug. 14–16, 1852	LW.†+ 2 10	HW. −0 57	N. 36 E.	1.85	HW.+2 35	LW.−1 14	S. 13 W.	1.45
Do	41 05 .. 69 37 ..	....do	Aug. 16–18, 1852	LW.†+ 1 50	HW. −1 31	N. 34 E.	2.42	HW.+2 40	LW.−0 42	S. 31 W.	2.36
Do	41 12 30 69 43 24	....do	July 5–7, 1852	LW.†+ 2 31	HW. −0 38	N. 38 E.	1.61	HW.+2 20	LW.−1 01	S. 16 W.	1.86

Directions true unless otherwise noted.

*Tides at Boston.

†Tides at Governors Island.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NANTUCKET SHOALS—continued.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Nantucket Shoals	41 11 .. 69 51 ..	Lieut. C. H. McBlair	July 7–8, 1852	L.W.*+ 2 30	HW. −0 31	N. 46 E.	1.83	HW.+2 03	L.W.−1 01	S. 16 W.	1.66
Do	41 17 26 69 55 39	do	Aug. 23–25, 1852	HW.*− 2 44	HW. +0 15	N. 35 E.	1.94	HW.+3 59	L.W.+0 32	S. 36 W.	1.66
East coast, Nantucket	41 19 45 69 59 12	H. P. Ritter	Sept. 6, 19, 1890	L.W.†− 0 36	L.W. +1 34	N. 11 W.	0.91	HW.−1 50	HW.+1 40	S. 28 E.	0.99
NANTUCKET SOUND.											
Shovelful Lt. Ship	41 32 42 69 59 17	H. L. Marindin	Sept. 18–27, 1887	L.W.†− 1 52				HW.−1 36			
Nantucket Sound	41 20 27 69 59 39	H. Mitchell	Aug. 27–31, 1857		L.W.† +0 40	N. 6 E.	0.30		HW.−0 11	S. 42 E.	0.22
Do	41 32 13 70 01 06	do	Aug. 9–10, 1857		L.W.† +0 58	S. 34 E.	1.78		HW.+1 00	N. 71 W.	1.75
Do	41 34 20 70 01 39	do	Aug. 9–10, 1857		L.W.† +1 19	S. 6 E.	1.13		HW.+1 18	N. 14 W.	0.63
Do	41 22 32 70 02 30	do	Aug. 24–25, 1857		L.W.† +0 03	S. 38 E.	0.19		HW.+1 50	N. 44 W.	0.94
Do	41 33 34 70 03 51	do	Aug. 7–8, 1857		L.W.† +2 58	N. 81 E.	0.78		HW.+2 45	N. 65½ W.	0.57
Do	41 24 35(?) 70 25 30	do	July 12–14, 1857		L.W.† +1 38	N. 4 E.	1.28		HW.+1 51	S. 21 W.	1.26
Handkerchief Lt. Ship	41 29 14 70 04 00	H. L. Marindin	Sept. 28–29, 1887	L.W.†− 1 18				HW.−1 14			
Nantucket Sound	41 27 21 70 26 49	H. Mitchell	July 18–19, 1857		L.W.† +3 52	N. 86 E.	1.55		HW.+3 38	N. 76 W.	1.41
Edgartown	41 23 23 70 30 20	do	July 15–21, 1871	L.W.†+ 0 44	HW. −2 10	Westerly	0.47	HW. +1 04	L.W.−2 20	N. 85 E.	0.51
Nantucket Sound	41 28 52 70 37 10	do	July 24–25, 1857		L.W.† +2 25	N. 59 E.	2.79		HW.+1 40	S. 68 W.	2.04

Directions true unless otherwise noted. * Tides at Governors Island. † Tides at Boston.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack: Time	Flood: Time	Flood: Direction	Flood: Velocity	Slack: Time	Ebb: Time	Ebb: Direction	Ebb: Velocity
NANTUCKET SOUND—continued.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Nantucket Sound	41 29 41 70 38 43	H. Mitchell	July 29–30, 1857	....	LW.*+3 38	N. 73(?) E.	1.94	....	HW. +3 29	S. 74 W.	2.75
Do	41 30 41 70 34 50	....do	July 30–31, 1871	HW.*+0 03	HW. +2 59	N. 66 W.	2.35	LW. −0 10	LW. +2 47	S. 84 E.	2.67
BUZZARDS BAY.											
Bet. Mashnee Island and Bennets Neck.	41 37 53 70 37 44	....do	July 14–15, 1860	....	T.†+5 52	N. 23 E.	0.38	....	T. −1 28	S. 43 W.	0.38
In Back River Harbor	41 43 23 70 37 15	....do	July 16–17, 1860	....	T.†+7 02	....	0.13	....	T. −1 30	S. 24 W.	0.13
NARRAGANSETT BAY.											
Providence Harbor, R. I.	41 47 53 71 23 09	H. L. Marindin	Oct. 10, 1874	....	....	....	....		HW.*−0 02	S. 51 E.	0.66
Do	41 48 03 71 23 27	....do	Sept. 11–12, 1874	....	LW.*−0 06	N. 31 W.	0.41	....	HW. +0 32	S. 40 E.	0.94
Do	41 48 12 71 23 37	....do	Sept. 10–11, 1874	....	LW.*−1 20	N. 44 W.	0.70	....	HW. +0 04	S. 33 E.	0.91
Do	41 48 25 71 23 40	....do	Sept. 9–10, 1874	....	LW.*−2 10	N. 22 W.	0.65	....	HW. −1 00	S. 30 E.	0.81
Do	41 48 37 71 23 50	....do	Sept. 8–9, 25, 1874	....	LW.*+0 22	N. 14 W.	0.74	....	HW. −0 02	S. 12 E.	0.82
Do	41 48 47 71 23 50	....do	Sept. 19, 21, 1874	....	LW.*−2 20	N. 35 E.	0.39	....	HW. +0 30	S. 13 W.	0.56
Do	41 48 55 71 23 50	....do	Sept. 14–15, 1874	....	LW.*−2 30	N. 35 E.	0.56	....	HW. −0 01	S. 44 W.	0.70
Do	41 48 59 71 23 24	....do	Sept. 17, 1874	....	LW.*−2 51	N. 62 E.	1.02	....	HW. −0 11	S. 83 W.	1.38
Do	41 49 00 71 23 43	....do	Sept. 15–16, 1874	....	LW.*−2 19	N. 45 E.	0.50	....	HW. −0 04	S. 63 W.	0.63
Do	41 49 01 71 23 34	....do	Sept. 17, 1874	HW.*+2 42(?)	LW. −2 46	S. 81 E.	0.27	....	HW. −0 28	N. 74 W.	1.42

Directions true unless otherwise stated. * Tides at Boston. † Local transits.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb.		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NARRAGANSETT BAY—continued.	° ′ ″			h. m.	h. m.	°	Knots	h. m.	h. m.	°	Knots
Providence Harbor, R. I.	41 49 03 71 23 17	H. L. Marindin	Oct. 9, 1874	....	LW.*−2 10	N. 23 E.	0.69	....	HW.−0 03	S. 30 W.	1.79
Do	41 49 11 71 23 16	do	Sept. 23, 1874	....	LW.*−2 11	N. 8 W.	0.36	....	HW.+0 30	S. 10 E.	0.61
Do	41 49 17 71 23 16	do	Sept. 23, 1874	....	LW.*−2 12	N. 17 W.	0.62	....	HW.+0 31	S. 2½ W.	0.75
Do	41 49 23 71 23 16	do	Sept. 23, 1874	....	LW.*−1 46	N. 35 E.	0.43	....	HW.+0 18	S. 58 W.	0.87
Do	41 49 25 71 23 05	do	Sept. 24, 1874	....	LW.*−2 03	N. 85 E.	0.50	....	HW.−0 08	S. 56 W.	0.96
Do	41 49 29 71 22 58	do	Sept. 24, 1874	....	LW.*−2 10	N. 26 E.	0.35	....	HW.+0 13	S. 39 W.	0.95
Do	41 49 35 71 22 53	do	Sept. 24, 1874	....	LW.*−1 58	N. 21½ E.	0.74	....	HW.−0 07	S. 44 W.	1.32
EASTERN LONG ISLAND SOUND.											
Between Latimers Reef and Eel Grass Ground.	41 18 25 71 56 43	Lieutenant Blake	July 5, 6 and 14, 1845	T.†+5 05	T.†+8 10	S. 71 W.	1.38	T.†−1 14	T.†+1 45	N. 77 E.	1.35
Off Groton Point	41 17 56 72 00 12	do	July 15, 16 and 19, 20, 1845	T.†+4 49	T.†−4 31	S. 82 W.	1.05	T.†−1 22	T.†+1 14	S. 75 E.	1.16
Near Race Point	41 14 32 72 02 53	do	Aug. 9, 10, 1845	T.†−6 36	T.†−3 50	N. 68 W.	3.46	T.†− 53	T.†+2 23	S. 9 E.	3.73
	41 06 13 72 45 43	Lieut. F. H. Crosby	May 11, 12, 1887	HW‡.−2 16	HW. 15	S. 61 W.	0.8	LW. −1 52	LW. + 15	N. 58 E.	0.8

Directions true unless otherwise noted. * Tides at Boston. † Local transits. ‡ Tides at Governors Island.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
WESTERN LONG ISLAND SOUND.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
....	41 05 55 72 56 00	Lieut. F. H. Crosby	May 4, 5, 1887	HW.*−2 30	HW. + 21	S. 69 W.	0.9	LW. −1 36	LW. + 32	N. 62 E.	0.7
2.5 mi. N 3° W. from Stamford Shoal Lt. S. E. from Bridgeport.	41 06 09 73 06 18	W. J. Sears, U. S. Navy	Nov. 21, 22, 1886	HW.†−4 [illegible]6	HW. −1 31	S. 60 W.	1.30	HW. +2 02	HW. +4 55	N. 88 E.	1.25
7.4 mi. N. 109 W. from Stamford Shoal Light.	41 01 13 73 15 19	....do....	Nov. 16, 17, 1886	HW.†−4 35	HW. −1 17	S. 87 W.	0.81	HW. +1 45	HW. +4 52	N. 83 E.	0.66
....	41 00 15 73 24 20	Lieut. F. H. Crosby	....do....	HW.*−2 05	HW. + 40	S. 78 W.	1.2	HW. +3 56	HW. −5 46	N. 70 E.	0.8
....	40 54 25 73 41 31	....do....	Nov. 11, 12, 1886	HW.*−1 16	HW. +1 00	S. 52 W.	0.6	HW. +4 34	HW. −5 06	N. 61 E.	0.5
....	40 51 52 73 44 54	....do....	Nov. 10, 11, 1886	HW.*+1 12	HW. +4 12	S. 35 W.	0.4	....	HW. −3 29	S. 50 E.	0.6
Between Sands Point and New Rochelle.	40 52 22 73 44 23	H. Mitchell	July 16–18, 1858	HW.*−1 40	HW. + 44	S. 60 W.	0.69	LW. −3 [illegible]9	LW. + 37	N. 65 E.	1.00
NEW YORK EAST RIVER.											
Between Stepping Stones and City Island.	40 49 32 73 46 57	H. Mitchell	July 21–24, 1858	LW.*−1 08	HW. −2 12	N. 14 E.	0.80	HW. +1 55	LW. −2 29	S. 17 W.	0.41
Off Throgs Neck	40 48 08 73 47 26	....do....	July 18–24, 1858	LW.*−0 12	HW. −1 24	East.	1.10	HW. +1 25	LW. −2 25	S. 85 W.	0.90
Off Old Ferry Point....	40 48 12(?) 73 49 50(?)	....do....	July 24–28, 1858	LW.*−0 06	HW. −1 53	N. 86 E.	1.64	HW. +1 48	HW. −2 39	S. 69 W.	1.16
Between Laurences Point and Sunken Meadow.	40 47 25 73 54 46	....do....	July 11–20, 1858	LW.*+1 20	LW. +4 30	N. 44 E.	3.25	HW. +1 44	HW. +4 10	S. 49 W.	2.29
Off Polhemus Dock....	40 47 08(?) 73 55 10(?)	....do....	June 1–9 1857	LW.*+1 43	HW. −1 18	N. 47 E.	3.37	HW. +2 11	LW. −2 06	S. 35 W.	2.52
Off Graham Avenue, Long Island City, East of Blackwells Island.	40 45 58.9 73 56 38.1	....do....	May 23–June 1, 1857	LW.*+1 24	HW. −1 20	N. 33 E.	4.17	HW. +1 39	LW. −2 09	S. 36 W.	3.84

Directions true unless otherwise noted. *Tides at Governors Island. †Tides at New London.

12770—07——25

Table of slack waters and mean maximum velocities—Continued

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NEW YORK EAST RIVER—cont'd.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Off Eighty-first street	40 46 15 73 56 42	H. Mitchell	May 8–18, 1857	LW.*+1 45	HW. −1 17	N. 38 E.	5.13	HW. +1 47	LW. −1 38	S. 38 W.	5.66
Between Fifty-second street and Blackwells Island.	40 45 12 73 57 43	....do	July 9–12, 1858	LW.*+1 21	HW. −1 08	N. 25 E.	2.35	HW. +1 43	LW. −2 11	S. 30 W.	2.74
Off Twenty-third street	40 43 57 73 57 58	H. L. Marindin	Oct. 4–7, 1886	LW.*−1 38	HW. −1 19	N. 16 W.	2.30	HW. +1 57	LW. −1 56	S. 12 E.	1.72
Northern end Wallabout Bay.	40 42 30 73 58 22	Lieut. M. Woodhull	July 8, 9, 1854	LW.*+1 07	HW. − 40	N. 37 E.	2.80	HW. +2 07	LW. −2 12	S. 38 W.	2.62
Off Atlantic Dock	40 41 07½ 74 00 44	H. Mitchell	July 28–30, 1858	....	HW.*−1 10	N. 58 E.	1.38	....	LW. −1 43	S. 57 W.	1.75
NEW YORK LOWER BAY.											
Main Channel	40 28 49 74 00 28	H. L. Marindin	Aug. 4–5, July 8–9, 1887	LW.†+1 06	LW. +3 03	Not observed	1.69	HW. −0 09	HW. +2 53	Not observed	2.29
Do	40 28 57 74 00 49	H. Mitchell	Aug. 8–10, 1858	....	HW.†−2 13	S. 86 W.	2.04	....	LW. −2 15	N. 85 E.	2.28
Junction Main and Swash channels.	40 29 15 73 58 53	....do	Aug. 22–23, 1858	....	HW.†−2 01	N. 80 W.	0.90	....	LW. −2 35	S. 74 E.	1.47
Gedney Channel	40 29 18 73 57 51	H. L. Marindin	July 28–30, Aug. 5 and 9–10, 1887	LW.†+1 26	LW. +4 24	Not observed	2.09	HW. + 41	HW. +3 38	Not observed	2.53
North of Flynn's Knoll	40 29 40 74 01 06	H. Mitchell	Sept. 7, 1858	....	HW.†−2 13	N. 80 W.	1.53	....	LW. −2 56	S. 69 E.	1.41
Blind Channel between Eastern and Gedney channels.	40 29 59 73 58 27	....do	Aug. 24–26, 1858	....	HW.†−1 42	N. 32 W.	0.78	....	LW. −2 22	S. 63 E.	0.94
Swash Channel	40 30 26 74 00 48	H. L. Marindin	July 1, 7, 29, 30, 1887	LW.†+ 46	LW. +3 58	Not observed	1.95	HW. + 48	HW. +4 06	Not observed	2.13
Do	40 30 33 74 01 12	H. Mitchell	Aug. 12–13, 1858	....	HW.†−2 08	N. 75 W.	1.11	....	LW. −1 57	S. 67 E.	1.18

Directions true unless otherwise noted. * Tides at Governors Island. † Tides at Sandy Hook.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NEW YORK LOWER BAY—cont'd.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
East Channel	40 30 51 73 57 55	H. L. Marindin	July 18-19, Aug. 9-10, 27-28, 1887	LW.*+1 07	LW. +4 31	Not observed	1.70	HW. +1 01	HW. +4 22	Not observed	2.27
Do	40 31 26 74 00 25	....do	June 29-30, July 18 and 28, 1887	LW.*+1 09	LW. +4 00	Not observed	2.13	HW. + 47	HW. +4 54	Not observed	2.18
West entrance Swash Channel.	40 31 33 74 02 19	H. Mitchell	Aug. 20-22, 1858	....	HW.*−2 54	S. 69 W.	0.79	....	LW. − 36	S. 45 E.	0.67
East Channel	40 31 44 74 00 56	....do	Aug. 15-16 1858	....	HW.*−1 39	N. 51 W.	0.82	....	LW. − 13	S. 58 E.	0.87
Fourteen Foot Channel.	40 31 49 73 59 39	H. L. Marindin	June 20-24 July 13-15, 1887	LW.*+1 00	LW. +3 58	Not observed	1.39	HW. +1 21	HW. +4 15	Not observed	1.94
Do	40 31 58 74 00 09	H. Mitchell	Aug. 16-18 1858	....	HW.*−2 00	N. 49 W.	0.96	....	LW. −1 31	S. 66 E.	1.27
Off Elm Tree Beacon	40 33 11 70 05 00	....do	June 30, July 1, 1859	LW.†+1 12	HW. − 41	N 30 E	0.35	HW. +3 11	LW. + 28	S. 72 W.	0.28
....	40 33 42 74 01 48	....do	Aug. 4-13, 1858	....	HW.*− 23	N. 8 W.	1.17	....	LW. − 03	S. 9 E.	2.27
....	40 33 46 74 01 52	....do	Aug. 15-18, 1858	....	HW.*+ 06	N. 12 E.	0.94	....	LW. + 22	S. 10 E.	1.43
....	40 33 56 74 01 53	....do	Aug. 18-20, 1858	....	HW.*+ 41	N. 20 E.	0.81	....	LW. + 39	S. 9 E.	1.38
Gravesend Bay	40 34 53(?) 74 01 09(?)	....do	Aug. 28-29, 1858	....	HW.*−2 34	N. 34 E.	0.37	....	LW. −1 56	S. 69 E.	0.54
The Narrows	40 36 10 74 02 35	....do H. L. Marindin G. C. Hanus	July 30, Aug. 3, 1858 Sept. 15-16, 1885 Oct. 4-6, 1886	LW.*+3 23	....	N. 39 W.	1.0	HW. + 1 40	....	S. 31 E.	1.9

Directions true unless otherwise noted.   * Tides at Sandy Hook.   † Tides at Governors Island.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NEW YORK LOWER BAY—continued.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
The Narrows	40 36 15 74 02 19	H. Mitchell	July 30–Aug. 3, 1858	....	HW.*–0 57	N. 37 W.	1.19	....	LW. – 44	S. 32 E.	1.73
NEW YORK UPPER BAY.											
The Narrows	40 36 56 74 03 13	H. Mitchell H. L. Marindin G. C. Hanus	July 30–Aug. 3, 1858 Sept. 15-16, 1885 Oct. 4-6, 1886	LW.†+3 36	....	N. 28 W.	1.2	HW.+2 31	....	S. 16 E.	1.5
Off Erie Basin	40 40 00 74 01 28	H. L. Marindin	Aug. 1 and 2, 1872	LW.*+1 33	HW.–2 07	N. 18 E.	1.24	HW.+1 55	LW.–1 40	N. 29 E.	1.09
Between Governors Island and Bedloe Island.	40 41 16 74 02 05	H. Mitchell	Aug. 31.–Sept. 4, 1858	....	HW.*+ 03	N. 29 E.	1.05	....	LW.–0 33	S. 28 W.	1.71
Off Castle Garden	40 42 10 74 01 12	Lieut. R. Wainwright.	Oct. 3-4, 1855	HW.*– 50	HW.+1 23(?)	S. 73 E. (?)	0.63(?)	....	LW.+1 56(?)	S. 14 E. (?)	2.10(?)
HUDSON RIVER.											
Off Canal Basin	40 42 35 74 01 53	H. L. Marindin	Aug. 22, 1873	HW.*–2 11	HW.– 03	N. 17 E.	0.67	HW.+2 36	HW.–5 27	S. 15 W.	1.22
Off Barclay street	40 42 55 74 01 17	Schooner Madison.	June 27-28, 1854	LW.*+3 45	HW.– 01	N. 24 E.	1.87	HW.+2 53	LW.– 51	S. 14 W.	2.52
....	40 43 11 74 01 44	H. L. Marindin	Aug. 21, 22, 23, 1873	HW.*–3 03	HW.– 04	N. 13 E.	0.87	HW.+2 10	HW.–6 20	S. 11 W.	1.38
Off Pier 45	40 43 43 74 01 04	do	Aug. 29 and Sept. 1, 1873	HW.*–2 31	HW.+ 04	N. 10 E.	2.07	HW.+3 37	HW.–5 52	S. 7 W.	1.44
Off Charlton street	40 43 43 74 01 07	Schooner Madison.	June 29-30, 1854	HW.*–2 22	HW.+ 10	N. 18 E.	1.74	LW.–2 45	LW.+ 02	S. 8 W.	2.31

Directions true unless otherwise noted. * Tides at Governors Island. † Tides at Sandy Hook.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
HUDSON RIVER—cont'd.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Off Pier 9, Jersey City...	40 43 44 74 01 38	H. L. Marindin ..	Aug. 23 and 25, 1873	HW.*−2 54	HW.+ 00	N.4 E.	0.80	HW.+2 02	HW.−5 40	S.12 W.	1.42
....	40 44 16 74 01 26	....do...........	Aug. 25–27, 1873	HW.*−2 27	HW.+ 17	N.20 E.	0.93	HW.+2 02	HW.−6 01	S.18 W.	1.78
Off Seventeenth street ..	40 44 48 74 01 01	Schooner Madison.	July 1–2, 1854	HW.*−2 24	HW.+ 04	N.21 E.	1.78	LW.−3 14	LW.− 31	S.20 W.	2.32
Off Thirty-second street.	40 45 29 74 00 42	....do...........	July 5–6, 1854	HW.*−1 12	HW.+1 08	N.18 E.	1.94	LW.−3 21	LW.+ 42	S.48 W.	2.74
Off Forty-first street.....	40 45 50 74 00 24	H. Mitchell	Sept. 4–5, 1858	....	HW.*+ 00	N.27 E.	1.75	....	LW.+ 07	S.32 W.	2.32
....	40 45 51(?) 74 00 23	H. L. Marindin ..	Sept. 13–14, 1872	HW.*−2 17	HW.+ 03	N.34 E.	1.04	HW.+2 42	LW. 18	S. 26 W.	2.49
Off Forty-second street..	40 45 52 74 00 32	F. F. Nes...... ...	Sept. 13–14, 1872	HW.*−2 26	HW.+ 22	N.38 E.	1.36	LW.−3 24	LW.+ 01	S.34 W.	2.34
Jersey shore, opposite Forty-first street.	40 45 58 74 00 53	H. Mitchell	Sept. 13, 1872	....	HW.*+ 02	N.30 E.	1.13	....	LW.− 32	S. 29 W.	1.50
Off One hundred thirty-first street.	40 49 11 73 57 48	Lieut. R. Wainwright.	Aug. 17–18, 1855	HW.*−0 51	HW.+2 10	N.38 E.	0.57	HW.+3 11	LW.+1 15	S.18 W.	2.19
DELAWARE BAY.											
Off Cape Henlopen......	38 49 47 75 02 43	H. L. Marindin ...	Aug. 24–28, 1886	LW.†+1 53	LW.+4 25	N.59 W.	1.42	HW.+1 23	HW.+5 12	S.34 E.	2.24
New Castle.............	39 39 20 75 33 16	....do...........	Aug. 2–9, 1886	LW.‡−1 17	LW.+1 24	....	3.07	HW.− 03	HW.+2 42	....	2.20
Philadelphia	39 56 52 75 08 10	F. A. Kümmell ...	Jan. 25 to July 1, 1902	LW.‡+ 38	LW.+3 00	N.27 E.	1.3	HW.+1 04	HW.+3 40	S.5 W.	1.3
Petty Island............	39 57 31 75 07 54	H. L. Marindin ...	July 20–31, 1886	LW.‡+ 39	LW.+2 59	....	1.86	HW.+1 15	HW.+4 54	....	1.86

Directions true unless otherwise noted. * Tides at Governors Island. † Tides at Sandy Hook. ‡ Tides at Philadelphia.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
CHESAPEAKE BAY.	° ′ ″			h. m.	h. m.	°	Knots	h. m.	h. m.	°	Knots
Off Wolf Trap Light Boat.	37 23 39 76 09 59	Lieut. J. I. Almy..	Nov. 17–19, 1851	HW.*+0 35	HW.+2 50	N. 1 E.	0.5	LW.−0 50	LW.+3 00	S.	1.1
Baltimore Harbor	39 15 55 76 34 29	F. A. Kümmell...	Jan.-June, 1903	LW.†+0 05	LW.+3 30	N. 24 W.	0.10	HW.+0 30	HW.+3 05	S. 24 E.	0.08
CAPE FEAR RIVER.											
Off mouth of Elizabeth River.	33 54 14 78 00 57	W. I. Vinal.......	Feb. 16, 1872	HW.‡− 2 41	HW.− 54	N. 40 W.	0.36	HW.+0 35	LW.−1 30	N. 89 E.	1.50
SAVANNAH RIVER.											
Near Fort Pulaski.......	32 02 19 80 52 14	H. L. Marindin...	May 25–29, June 1, 1874	....	HW.§−1 53	N. 77 W.	1.40	....	HW.+2 50	S. 85 E.	1.52
Do	32 02 11 80 54 17	.....do	May 6–7, 1874	....	HW.§−2 04	S. 86 W.	1.06	....	HW.+2 37	S. 89 E.	2.01
Off northeast corner of Hutchinson Island.	32 07 33 81 06 48	J. N. Maffitt......	Mar 23–24, 1852	....	HW.‖−1 10	N. 30 W.	0.74	....	LW.−1 17	S. 58 E.	0.76
Northwest of Kings Island.	32 07 30 81 07 58	.....do	Mar. 23, 1852	....	HW.‖−1 14	S. 67 W.	0.42	....	LW.−1 38	N. 76 E.	1.25
FLORIDA.											
Fernandina Bar	30 42 33 81 24 39	F. D. Granger....	Apr. 21–22, 1874	LW.**+1 18	LW.+3 38	S. 88 W.	0.53	HW.+0 27	LW.−2 27	N. 54 E.	1.34
Do	30 42 13 81 23 20	.....do	May 5, 7, 1874	LW.**+0 19	HW.−2 36	N. 16 W.	0.56	HW.+0 32	LW.−1 56	S. 52 E.	0.61
Do	30 41 48 81 25 02	.....do	Apr. 23–24, 1874	LW.**+0 25	LW.+3 25	N. 28 W.	1.02	HW.+0 32	HW.+3 55	S. 44 E.	1.19
Do	30 41 30 81 24 22	.....do	Apr. 18, May 1–2, 1874	LW.**+0 09	LW.+3 00	N. 66 W.	0.60	HW.+0 12	LW.−2 33	S. 80 E.	0.76

Directions true unless otherwise noted.
* Tides at Old Point Comfort.
† Tides at Baltimore.
‡ Tides at Smithville (Southport), N. C.
§ Tides at Fort Pulaski, Savannah River, Ga.
‖ Tides at Savannah, Ga.
** Tides at Old Fernandina, Fla.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
SAN FRANCISCO BAY.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Off Presidio	37 48 28	G. Bradford	Jan. 6–8,	T.*+6 39	T.+ 8 07	S. 78 E.	1.25	T.− 1 22	T.+2 47	N. 84 W.	2.12
	122 27 37		1875								
Raccoon Straits	37 52 23	do	Nov. 21–23,	L.W.†+1 17				H.W.+ 0 30			
	122 26 06		1871	L.W.†+1 22	H.W.− 2 34	N. 69 E.	3.30	H.W.+ 0 49	L.W.−1 51	S. 48 W.	3.40
Between Black Point and	37 48 25	do	Jan. 4–6,	T.*+7 10	T.+ 9 13	N. 86 E.	1.15	T.+12 22	T.+3 23	N. 81 W.	1.90
Anita Rock Spindle.	122 27 04		1875								
Off Black Point	37 48 33	do	Nov. 12–14,	T.*+5 58	T.+ 8 41	N. 86 E.	1.30	T.− 1 03	T.+2 11	S. 81 W.	1.32
	122 26 02		1874								
North end of Southampton Shoal.	37 54 35	do	Feb. 26–28,	L.W.‡+1 53				H.W.+ 1 26			
	122 25 13		1873	T.*+6 59	T.+10 30	N. 7 W.	2.52	T.+ 45	T.+3 46	S. 14 E.	2.48
Between north entrance	37 52 53	do	Nov. 16–18,	L.W.†+2 40				H.W.+ 1 59			
of Raccoon Strait and Southampton Shoal.	122 25 13		1871	L.W.†+2 22	H.W.− 1 08	N. 12 W.	0.90	H.W.+ 2 11	L.W.− 38	S. 16 E.	1.21
Off Southampton Shoal	37 53 49	do	May 29–31,	L.W.‡+2 45				H.W.+ 1 44			
	122 25 08		1873	T.*+7 37	T.+10 34	N. 4 E.	1.52	T.+ 1 00	T.+3 54	S. 16 E.	1.88
Off southeast point of	37 50 57	do	Nov. 7–9,	L.W.†+1 39				H.W.+ 33			
Angel Island.	122 25 06		1871	L.W.†+1 30		S 82 E.	1.60	H.W.+ 48		S. 40 W.	2.1
Between North Point and	37 50 20	do	Nov. 7–9,	L.W.†+1 26				H.W.+ 48			
Angel Island.	122 24 54		1871	L.W.†+2 20		N 77 E.	1.10	H.W.+ 48		N. 60 W.	1.50
				L.W.§+1 58	L.W.+ 4 42	N. 69 E.	1.20	H.W.+ 27	H.W.+3 55	N. 79 W.	1.30
Off Southampton Shoal	37 52 54	do	Apr. 17–19,	L.W.‡+2 47				H.W.+ 1 41			
	122 24 37		1873	T.*+7 54	T.+11 05	N. 7 W.	1.35	T.+ 1 15	T.+4 33	S. 3 W.	1.68
Off Shore between Black	37 48 41	do	Nov. 10–12,	T.*+6 06	T.+ 9 03	N. 89 E.	1.85	T.+12 11	T.+2 49	West.	1.72
Point and Alcatraz.	122 25 34		1874								
Off Southampton Shoal	37 53 09	do	Feb. 20–22,	L.W.§+3 05	H.W.− 38	N. 22 W.	0.81	H.W.+ 1 52	L.W.− 22	S. 9 E.	1.06
	122 23 34		1873	L.W.‡+3 05				H.W.+ 1 25			
Off North Point	37 48 30	do	Mar. 20–22,	T.*+6 05	T.+ 8 38	S. 70 E.	1.45	T.+11 22	T.+2 02	N. 40 W.	2.12
	122 24 28		1873								

Directions true unless otherwise noted.

* Local transits.
† Tides at North Point, San Francisco Bay.
‡ Tides at Angel Island, San Francisco Bay.
§ Tides at Fort Point, San Francisco Bay.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack: Time	Flood: Time	Flood: Direction	Flood: Velocity	Slack: Time	Ebb: Time	Ebb: Direction	Ebb: Velocity
SAN FRANCISCO BAY—continued.	° ′ ″			h. m.	h. m.	°	Knots	h. m.	h. m.	°	Knots
South of middle of Southampton.	37 53 27 122 24 28	G. Bradford	Feb. 12-14, 1873	LW.*+ 51	HW.− 1 38	N. 19 E.	0.96	HW.+ 1 20	LW.−1 46	S. 9 W.	1.21
One-eighth mile north of North Point.	37 48 23 122 24 24	....do	Nov. 2-7, 1871	LW.†+ 24 LW.†+ 22		S 60 E	1.35	HW.− 15 HW.− 12		N. 60 W.	1.55
East of Angel Island	37 51 50 122 24 18	....do	Jan. 20-22, 1875	LW.*+3 42 T.‡+8 54	T.+11 16	N. 12 W.	2.20	HW.+ 2 21 T.+ 1 47	T.+5 15	S. 6 E.	2.40
Southampton Shoal, south end.	37 53 04 122 24 12	....do	Feb. 10-12, 1873	LW.*+1 25 LW.§+ 55	HW.− 1 08	N. 13 E.	1.14	HW.+ 1 50 HW.+ 1 30	LW.−1 35	S. 10 W.	1.14
Between Point Richmond and Southampton Shoal.	37 54 10 122 24 10	....do	Feb. 24, 26, 1873	LW.‖+2 49 T.‡+8 13	T.+11 12	N. 32 W.	1.95	HW.+ 2 10 T.+ 1 40	T.+3 57	S. 28 E.	2.05
Between North Point and Alcatraz.	37 48 40 122 25 03	....do	Oct. 29-31, 1874	T.‡+5 55	T.+ 9 05	S. 78 E.	1.78	T.+11 58	T.+1 52	N. 76 W.	2.02
Off Telegraph Hill	37 48 08 122 23 53	....do	Oct. 27-29, 1874	T.‡+5 43	T.+ 8 01	S. 38 E.	2.32	T.+10 51	T.+2 02	N. 43 W.	2.40
....	37 47 46 122 23 29	....do	Oct. 15-17, 1874	T.‡+5 21	T.+ 7 59	S. 37 E.	1.50	T.+10 28	T.+1 31	N. 28 W.	1.45
Between City and Shoals north of Goat Island.	37 48 34 122 23 17	....do	July 30-Aug. 1, 1874	LW.*+2 03 LW.*+2 01 T.‡+6 23	LW.+ 4 36 T.+ 8 58	S. 44 E. S. 44 E.	1.4 1.4	HW.+ 45 HW.+ 40 T.+11 56	HW.+4 12 T.+3 02	N. 31 W. N. 31 W.	1.8 1.8
Between Mission Rock and Rincon Point.	37 47 01 122 23 09	....do	Sept. 9-11, 1874	LW.*+1 12 T.‡+6 07	T.+ 8 50	S. 5 E.	1.88	HW.− 06 T.− 06	T.+2 20	N. 1 W.	2.20
Northwest of Mission Rock.	37 46 32 122 23 06	....do	Aug. 24-27, 1874	LW.*+1 05 T.‡+6 08	T.+ 8 51	S. 11 E.	1.42	HW.− 40 T.+11 38	T.+2 57	N. 11 E.	1.58
Between Mission Rock and Merrimac Street Wharf.	37 46 11 122 23 03	....do	Sept. 22-24, 1874	LW.*+ 50 T.‡+6 11	T.+ 8 39	S. 30 E.	1.88	HW.− 39 T.+11 24	T.+2 32	N. 8 W.	1.85

Directions true unless otherwise noted.

*Tides at Fort Point, San Francisco Bay.
†Tides at North Point, San Francisco Bay.
‡Local transits.
§Tides at current station.
‖Tides at Angel Island, San Francisco Bay.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
SAN FRANCISCO BAY—continued.	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Southeast from Rincon	37 47 03	G. Bradford	Sept. 7-9,	LW.*+1 15				HW.+ 05			
Point.	122 23 02		1874	T.†+6 33	T.+ 9 29	S. 8 E.	2.00	T.+12 23	T.+2 57	N. 1 W.	2.18
South of Mission Rock	37 45 57	....do	Aug. 12-15,	LW.*+1 15				HW.− 07			
	122 22 56		1874	T.†+5 56	T.+ 8 37	S. 24 E.	1.40	T.+11 21	T.+2 49	N. 7 W.	1.80
Northeastward of Mis-	37 46 21	.... do	Aug. 10-12,	LW.*+1 23				HW.+ 02			
sion Rock.	122 22 46		1874	T.†+5 35	T.+ 8 39	S. 27 E.	2.38	T.+11 03	T.+1 57	N. 2 W.	2.15
Northwest of Goat Is-	37 49 07	....do	July 28-30,	LW.*+1 56				HW.+ 53			
land.	122 22 45		1874	T.†+6 15	T.+ 9 04	S. 45 E.	1.98	T.+12 28	T.+2 26	N. 8 W.	2.08
Northwest from Point	37 44 58	....do	Sept. 24-26,	LW.*+0 59				HW.+ 38			
Avisadero.	122 22 17		1874	T.†+5 57	T.+ 8 51	S. 25 E.	2.10	T.+12 06	T.+2 35	N. 25 W.	2.18
Northward from Point	37 44 30	.... do	Dec. 7-9,	T.†+6 31	T.+ 9 45	S. 21 E.	1.58	T.+12 46	T.+2 58	N. 42 W.	1.40
Avisadero.	122 21 53		1874								
North of Goat (Yerba	37 49 53	....do	July 24-28,	HW.*+1 11	T.+ 9 13	S. 53 E.	1.58	HW.+ 38	T.+3 55	N. 25 W.	1.68
Buena) Island.	122 21 49		1874	T.†+6 31				T.+ 0 39			
Near Potrero	37 45 26	....do	Aug. 27-29,	LW.*+1 01				HW.− 10			
	122 22 43		1874	T.†+5 41	T.+ 8 15	S. 25 E.	1.80	T.+11 18	T.+2 15	N. 8 W.	2.12
CALIFORNIA COAST											
Off San Pedro	33 41 54	A. P. Osborn	Jan. 7-8,	LW.‡− 41	HW.−3 32	S. 87 W.	0.34	HW.+ 23	LW.−2 30	N. 43 E.	0.29
	118 15 58		1897								
Do	33 42 36	....do	Jan. 6-7,	LW.‡+1 20	HW.−2 19	S. 12 W.	0.42	HW.+ 28	LW.−2 18	N. 64 E.	0.32
	118 16 31		1897								
ALASKA COAST											
Frederick Sound	57 03 15	C. M. Thomas	July 24, Aug.	LW.§+1 12	HW.−2 22	N. 70 E.	0.89	HW.− 13	LW.− 49	West.	0.79
	133 19 30		5-7, 1887.								
Unimak Island	53 57 25	J. J. Gilbert	July 23-24,	....	....	N. 64 W.	2	....	....	S. 60 E.	2
	166 13 40		1901								
Unalga Pass	54 23 01	....do	July 14-17,	....	....	N. 34 W.	1 to 6	....	....	S. 26 E.	1 to 6
	164 50 06		1901								

Directions true unless otherwise noted. * Tides at Fort Point. † Local Transits. ‡ Tides at Sausalito, California. § Tides at Astoria, Oregon.

Table of slack waters and mean maximum velocities—Continued.

Station	Latitude and longitude	Observing party	Date	Slack	Flood			Slack	Ebb		
				Time	Time	Direction	Velocity	Time	Time	Direction	Velocity
NEW ZEALAND	° ′ ″			*h. m.*	*h. m.*	°	*Knots*	*h. m.*	*h. m.*	°	*Knots*
Tory Channel	41 13 .. 174 20 ..	Light keeper	May 15, 29, June 14, 28, July 13, 27, 1900	T.*+2 13	......	......	......	T.+8 34	......	......	......
French Pass	40 55 30 173 56 30	....do	....do	T.*+1 19	......	......	......	T.+7 13	......	......	......
Stephens Island	40 40 .. 174 01 ..	....do	....do	T.*+2 33	......	......	......	T.+8 07	......	......	......

Directions true unless otherwise noted.

*Local transits.

96. *Table showing hourly values of duration (azimuth) and velocity of the current.*

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before— 3	2	1	Solar hours after— 0	1	2	3
GULF OF MAINE.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
Nantucket Shoals Light Ship.	40 37 00	R. L. Faris	Sept. 9–10,	HW.*	198	204	205	220	242	308	38
	69 37 15		1903		0.4	0.4	0.4	0.4	0.3	0.1	0.2
				LW.*	59	85	98	126	152	175	194
					0.3	0.4	0.4	0.4	0.4	0.4	0.4
Georges Bank	41 10 04	Robert Platt, U. S.	June 6–10,	HW.*	181	181	185	206	284	340	353
	68 55 35	Navy	1877		1.1	1.1	0.9	0.6	0.4	0.6	0.9
				LW.*	350	348	355	45	141	173	181
					0.9	0.9	0.6	0.3	0.4	0.7	1.1
Do	41 20 46	do	June 21–24,	HW.*	171	188	205	250	290	322	341
	68 23 07		1877		1.6	1.3	0.9	0.6	0.9	1.5	1.7
				LW.*	337	343	0	47	123	148	168
					1.7	1.5	1.0	0.4	0.7	1.2	1.6
Do	41 31 00	do	June 25–27,	HW.*	179	196	226	266	309	334	3
	67 52 30		1877		1.7	1.2	0.9	0.8	1.4	1.6	1.4
				LW.*	6	30	61	102	145	166	179
					1.4	1.6	1.3	1.3	1.7	1.9	1.8
Do	41 36 38	do	Aug. 28–29,	HW.*	164	178	215	262	308	332	342
	67 24 12		1877		1.2	0.9	0.7	0.8	1.2	1.6	1.6
				LW.*	342	1	29	75	113	144	163
					1.6	1.1	0.6	0.6	1.0	1.5	1.3
Off Chatham Lights.	41 37 30	H. Mitchell	Aug. 19–20,	HW.*	187	16	11	5	9	16	.....
	69 51 50		1857		0.1	0.3	0.9	1.2	1.0	0.4	0.0
				LW.*	.....	192	191	190	189	188	187
					0.0	0.2	0.7	1.0	0.9	0.5	0.2
Georges Bank, Georges Shoals.	41 37 57	J. A. Howell	Aug. 22–23,	HW.*	182	208	235	260	290	330	0
	67 43 30		1872		1.8	1.8	2.0	1.4	1.4	1.3	1.9
				LW.*	5	35	60	85	115	148	178
					2.1	2.0	1.7	1.2	1.4	1.6	1.7
Off Chatham Lights.	41 40 40	H. Mitchell	Aug. 20,	HW.*	150	40	35	30	20	6	.....
	69 52 12		1857.		0.2	0.6	0.9	0.7	0.4	0.1	0.0
				LW.*	213	204	190	180	165	158	151
					0.1	0.4	0.7	0.9	1.0	0.7	0.3
Do	41 40 45	Robert Platt, U. S.	Sept. 14–15,	HW.*	176	30	17	10	9	13	15
	69 45 40	Navy.	1857		0.2	0.2	0.6	0.8	0.9	0.8	0.6
				LW.*	18	22	208	204	194	165	176
					0.5	0.2	0.1	0.3	0.4	0.3	0.2
About 7 mi. E. of Nansett Lights.	41 52 40	do	Sept. 12–13,	HW.*	270	315	315	325	330	330	340
	69 48 00		1877		0.2	0.2	0.3	0.6	0.8	1.0	1.0
				LW.*	345	0	0	20	335	310	280
					0.9	0.8	0.5	0.2	0.1	0.2	0.2
Georges Bank	41 56 39	do	July 15–17,	HW.*	154	181	204	238	272	307	336
	66 38 15		1877		1.8	1.5	1.0	1.0	1.3	1.6	1.8
				LW.*	341	351	359	42	86	122	148
					1.8	1.8	1.5	1.2	1.1	1.6	1.8
Do	41 58 00	do	Aug. 30–31,	HW.*	142	146	148	318	339	346	349
	69 26 00		1878		0.8	0.5	0.2	0.1	0.3	0.5	0.6
				LW.*	348	351	355	72	135	146	144
					0.6	0.4	0.3	0.2	0.5	0.8	0.8

*Tides at Boston. Directions true.

Table showing hourly values of duration (azimuth) and velocity of the current.—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
GULF OF MAINE—con.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
5½ mi. E.½N. of Cape	42 04 00	Robert Platt, U.S.	Aug. 23–24,	H.W.*	70	0	320	325	315	305	295
Cod Light	69 57 20	Navy	1877		0.3	0.2	0.4	0.5	0.6	0.7	0.8
				L.W.*	295	300	315	325	0	60	70
					0.8	0.7	0.6	0.4	0.2	0.3	0.3
3½ mi. N.½W. of	42 07 04	....do..........	Aug. 24–25,	H.W.*	70	80	.....	.....	250	240	245
Race Point	70 15 00		1877		0.7	0.5	.....	.....	0.7	0.8	0.8
				L.W.*	245	245	230	.....	50	50	65
					0.8	0.7	0.4	.....	0.3	0.4	0.6
Stellwagen Bank.....	42 17 15	....do..........	Aug. 30–31,	H.W.*	80	100	160	200(?)	235	240	260
	70 16 10		1877		0.5	0.4	0.5	0.2(?)	0.3	0.6	0.6
				L.W.*	260	270	280	40	60	70	80
					0.6	0.5	0.3	0.2	0.5	0.6	0.5
BOSTON HARBOR†											
Nantasket Roads.....	42 19 09	C. H. Davis......	Oct. 6, 12,	H.W.*	78	78	76	76	268	262	260
	70 52 28		1848		1.8	1.7	1.2	0.1	0.6	1.4	2.0
				L.W.*	260	262	269	315	75	77	78
					2.0	1.8	1.9	0.1	0.9	1.6	1.8
Hypocrite Channel...	42 41 09	....	....	H.W.*	39	42	45	240	239	239	240
	70 52 32				1.1	0.8	0.4	0.1	0.6	1.0	1.1
				L.W.*	240	242	245	60	55	43	39
					1.1	0.8	0.3	0.1	0.6	1.0	1.1
South Channel........	42 20 35	H. Mitchell.......	Aug. 30–31,	H.W.*	75	76	76	77	239	241	243
	70 55 43		1860		1.5	1.3	0.9	0.1	0.8	1.5	1.8
				L.W.*	243	244	244	245	70	75	75
					1.8	1.8	1.4	0.1	0.9	1.0	1.5
Broad Sound	42 22 57	C. H. Davis.......	Oct. 11,	H.W.*	13	10	357	.....	290	274	260
	70 56 14		1848		0.4	0.4	0.3	0.0	0.2	0.3	0.4
				L.W.*	258	252	278	344	356	6	13
					0.4	0.2	0.1	0.1	0.2	0.3	0.4
President Roads......	42 19 54	....do..........	Oct. 16,	H.W.*	71	75	82	86	254	256	255
	71 00 00		1848		1.3	1.3	0.9	0.2	0.5	0.9	1.0
				L.W.*	254	246	230	75	71	70	71
					1.0	0.7	0.2	0.3	0.7	0.9	1.2
Off East Boston.......	42 21 33	....do..........	June 16,	H.W.*	165	152	139	130	295	301	307
	71 02 30		1848		1.0	1.0	0.7	0.1	0.4	0.7	0.9
				L.W.*	309	313	320	325	160	169	168
					1.0	1.0	0.8	0.2	0.5	0.8	1.0
GULF OF MAINE											
Georges Bank	42 24 46	Robert Platt, U.S.	July 19,	H.W.*	130	110	60	358	333	327	343
	66 08 11	Navy.	1877		0.7	0.6	0.3	0.2	0.4	0.9	1.0
				L.W.*	347	37	85	117	137	140	130
					0.9	0.6	0.3	0.7	0.7	0.7	0.8
Do	42 27 09	....do..........	Aug. 15–16,	H.W.*	161	182	227	266	317	330	349
	67 37 45		1878		0.8	0.5	0.4	0.4	1.0	1.4	1.5
				L.W.*	351	16	45	74	114	144	160
					1.5	1.0	0.7	0.4	0.4	0.7	0.8

Directions true unless otherwise noted.
*Tides at Boston.
† For 47 additional stations in Boston Harbor, see Coast and Geodetic Survey Tide Tables for 1903.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
GULF OF MAINE—con.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
Georges Bank	42 28 39	Robert Platt, U.S. Navy.	Aug. 13–14, 1877.	HW.*	125	125	131	149	178	215	278
	66 03 30				1.2	1.0	0.7	0.6	0.5	0.6	0.7
				LW.*	305	3	49	102	121	124	125
					0.9	0.7	0.4	0.6	1.1	1.2	1.2
Off Thatcher Island	42 33 11	....do	Sept. 24–25, 1877.	HW.*	60	50	30	310	290	280	280
	70 31 17				0.2	0.2	0.2	0.2	0.3	0.5	0.5
				LW.*	290	300	330	10	40	50	60
					0.4	0.3	0.2	0.2	0.2	0.2	0.2
Georges Bank	42 50 00	....do	Aug. 8–9, 1877.	HW.*	132	156	214	277	298	304	308
	65 56 30				1.0	0.6	0.4	0.8	1.2	1.4	1.5
				LW.*	309	313	327	8	72	106	130
					1.5	1.2	0.8	0.5	0.7	1.2	1.3
Do	43 04 00	....do	Aug. 6–7, 1877.	HW.*	97	118	173	242	276	292	316
	65 40 40				1.2	0.8	0.4	0.6	0.9	1.0	0.9
				LW.*	326	354	33	68	83	90	93
					0.8	0.4	0.3	0.5	0.9	1.3	1.3
Do	43 47 23	....do	Aug. 23, 1878.	HW.*	228	214	205	242	285	312	340
	67 37 30				0.3	0.2	0.1	0.2	0.1	0.2	0.3
				LW.*	343	310	292	267	238	240	220
					0.3	0.2	0.2	0.3	0.3	0.3	0.4
Portsmouth Harbor (S. 77° W. of Whaleback light).	43 03 30	P. A. Welker	Oct. 25, 1898	HW.†	175	176	177	178	179	180	12
	70 42 10				0.2	0.8	1.0	0.8	0.5	0.1	0.4
				LW.†	12	14	15	16	17	18	175
					0.7	1.4	1.4	1.1	0.8	0.4	0.1
Portsmouth Harbor (S. 78° E. of Portsmouth light).	43 04 15	....do	Oct. 6, 24, 1898.	HW.†	152	160	168	174	178	173	0
	70 42 19				0.3	0.8	1.1	1.1	0.8	0.1	0.5
				LW.†	358	349	342	343	7	3	148
					0.7	1.3	1.4	1.1	0.7	0.1	0.2
Portsmouth Harbor (N. 5° W. of Portsmouth light).	43 04 35	....do	Sept. 26–28, Oct. 4, 1898.	HW.†	90	101	117	127	135	.....	288
	70 42 37				0.6	1.5	1.9	1.7	1.0	0.0	1.1
				LW.†	290	295	294	286	275	263	87
					1.3	2.2	2.7	2.4	1.4	0.6	0.3
Portsmouth Harbor (N. 25° W. of Portsmouth light).	43 04 40	....do	Sept. 26, 29–30, Oct. 10, 1898.	HW.†	71	77	83	89	94	100	235
	70 42 50				0.6	1.4	1.6	1.4	1.0	0.4	0.2
				LW.†	237	244	249	249	245	238	70
					0.3	0.6	0.9	1.1	1.1	0.6	0.2
Portsmouth Harbor (S. of Clark Island).	43 04 31	....do	Oct. 11, 18, 1898.	HW.†	88	86	84	83	81	79	261
	70 43 31				1.0	1.7	1.7	1.4	1.0	0.4	0.7
				LW.†	262	264	264	263	259	253	89
					1.1	2.4	2.3	1.7	1.0	0.4	0.6
Portsmouth Harbor (off Goat Island Ledge buoy).	43 04 27	....do	Oct. 7, 1898	HW.†	88	87	86	85	84	83	268
	70 43 59				1.3	2.0	2.0	1.5	1.0	0.4	0.7
				LW.†	268	267	266	265	264	263	88
					1.1	2.2	2.4	1.9	1.1	0.3	1.0
Portsmouth Harbor (S. of Portsmouth Navy-Yard).	43 04 35	....do	Oct. 13, 17, 1898.	HW.†	137	135	132	125	128	125	305
	70 44 28				1.8	2.9	3.1	2.9	2.0	0.9	0.5
				LW.†	306	311	315	317	316	315	138
					0.9	1.9	2.8	2.6	1.8	0.6	1.5

Directions true unless otherwise noted. *Tides at Boston. †Tides at Portland.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
NANTUCKET SHOALS.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
NW. side Fishing Rip.	41 02 (?)	Lieut. C. H. Mc-	July 8–9,	HW.*	188	204	221	222	227	259	300
	69 28 (?)	Blair.	1852.		0.7	1.2	1.4	1.0	0.8	0.8	1.0
				LW.*	308	341	6	22	66	.....	187
					1.0	1.4	1.6	1.5	1.0	0.5	0.6
Nantucket Shoals	41 00 (?)	.....do...........	July 9–11,	HW.*	78	197	210	229	240	256	265
	69 27 (?)		1852.		1.0	0.2	1.3	1.9	1.7	1.5	1.3
				LW.*	279	313	5	38	43	40	56
					1.3	0.9	1.5	1.8	1.6	1.3	0.8
Do	41 01 (?)	.....do...........	July 10–11	HW.*	186	209	222	236	244	254	256
	69 27 (?)		1852.		0.3	0.7	1.3	2.2	2.2	1.2	0.8
				LW.*	281	326	13	25	23	42	146
					0.7	0.5	0.8	1.2	1.2	0.4	0.3
Do	41 08 08	.....do...........	Aug. 24–25,	HW.*	126	166	176	196	216	222	234
	69 31 48		1852.		0.4	1.7	2.4	2.8	2.5	2.1	1.2
				LW.*	247	299	356	20	35	36	108
					1.2	1.0	1.6	2.4	2.2	1.3	0.4
Do	41 02 (?)	.....do...........	Aug. 14–16,	HW.*	213	204	217	220	238	292	320
	69 34 (?)		1852.		1.1	1.6	1.8	1.7	1.3	0.9	0.9
				LW.*	326	358	18	32	66	105	159
					1.0	1.3	1.4	1.3	0.9	0.7	1.0
Do	41 05 ..	.....do...........	Aug. 16–18,	HW.*	193	206	227	252	238	245	257
	69 37 ..		1852.		1.3	2.0	2.0	1.9	1.6	1.0	0.9
				LW.*	326	10	34	45	68	95	189
					0.9	1.5	2.2	2.0	1.1	0.6	1.2
Do	41 08 38	Lieut. Vreeland ..	Sept. 21–22,	HW.†	202	210	255	5	20	20	30
	69 39 51		1891.		2.6	1.9	0.8	0.4	2.0	2.2	2.0
				LW.†	30	40	.....	180	195	200	202
					2.0	1.3	0.0	1.0	1.7	2.1	2.6
Do	41 12 00	.....do...........	Sept. 10–12	HW.†	205	215	250	300	340	10	30
	69 40 00		and 15–16,		1.1	0.8	0.4	0.4	0.8	1.3	1.6
			1891.	LW.†	35	45	......	180	190	200	205
					1.6	1.1	......	0.6	1.2	1.3	1.1
Do	41 12 18	.....do.........	Sept. 16–17,	HW.†	220	230	270(?)	......	10	25	25
	69 40 31		1891.		1.4	1.1	0.4	......	1.1	1.8	1.6
				LW.†	25	25	100(?)	200	200	210	220
					1.6	0.9	0.2	1.0	1.7	1.7	1.4
Off Sankaty Head	41 22 10	.....do...........	Sept. 5–7,	HW.†	187	205	350	15	15	15	25
	69 42 34		1891.		1.6	0.6	0.4	1.1	1.5	1.3	0.9
				LW.†	25	20	150	160	180	185	187
					0.8	0.4	0.2	0.9	1.7	1.8	1.6
Nantucket Shoals	41 12 30	Lieut. C. H. Mc-	July 5–7,	HW.*	198	212	218	222	235	251	308
	69 43 24	Blair.	1852.		0.5	1.2	1.6	1.5	1.2	0.7	0.7
				LW.*	324	7	16	19	25	24	196
					0.9	1.6	1.8	1.5	1.0	0.3	0.4
SW. end Great Rip...	41 12 (?)	Lieut. C. H. Davis.	Aug. 30–31,	HW.†	232	245	251	26	58	64	55
	69 45 (?)		1848.		2.1	1.5	0.4	0.6	1.4	1.8	1.2
				LW.†	55	72	171	200	215	224	230
					1.2	0.8	0.4	0.7	1.6	2.1	2.2

Directions true unless otherwise noted. * Tides at Governors Island. † Tides at Boston.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
NANTUCKET SHOALS—continued.	° ′ ″				° *kn*	° *kn*	° *kn*	° *kn*	° *kn*	° *kn*	° *kn*
NE. of Davis South Shoal.	41 00 (?)	Lieut. J. N. Maffitt	Aug. 15-17, 1849.	HW.*	293	303	308	325	10	52	64
	69 50 (?)				2.7	2.3	2.0	1.7	1.3	1.8	2.3
				LW.*	65	69	82	127	212	259	293
					2.3	2.1	1.7	1.2	1.2	2.1	2.7
Nantucket Shoals	41 04 41	Lieut. C. H. Davis	Aug. 6-8, 1846.	HW.*	274	282	318	46	94	92	94
	69 50 25				2.0	1.3	0.8	0.8	1.7	2.3	2.4
				LW.*	95	100	136	214	252	250	274
					2.2	1.5	0.8	0.7	2.1	2.4	2.0
Do	41 11 (?)	Lieut. C. H. McBlair	July 7-8, 1852.	HW.†	146	192	213	226	229	270	330
	69 51 (?)				0.7	1.2	1.8	1.7	1.4	1.1	1.2
				LW.†	344	12	14	38	57	125	143
					1.3	1.5	1.6	1.1	0.6	0.8	0.4
Do	41 21 25	do	Aug. 25-26, 1852	HW.†	175	200	215	228	233	253	288
	69 51 22				0.4	1.4	2.2	2.2	1.7	1.4	0.5
				LW.†	310	16	40	44	42	76	144
					0.5	1.2	1.8	1.6	1.7	0.9	0.3
Do	41 01 18	Lieut. C. H. Davis	Aug. 12-14, 1846.	HW.*	277	288	287	305	35	89	96
	69 51 26				1.9	1.7	1.3	1.0	1.1	1.3	1.5
				LW.*	98	104	136	201	243	261	277
					1.5	1.3	0.9	0.5	0.9	1.6	1.9
Do	41 05 16	do	Aug. 14-15, 1846.	HW.*	242	257	257	300	15	66	79
	69 56 00				1.5	1.6	1.4	1.0	0.7	0.8	1.2
				LW.*	84	103	121	148	200	226	242
					1.2	1.1	0.9	0.6	0.7	1.1	1.5
Do	41 17 26	Lieut. C. H. McBlair	Aug. 23-25, 1852.	HW.†	130	160	191	219	225	230	254
	69 55 39				1.0	1.0	1.2	1.5	1.5	1.3	0.9
				LW.†	278	312	356	37	54	64	125
					0.8	0.7	0.9	1.5	1.6	1.2	1.0
Do	41 03 57	Lieut. C. H. Davis	Aug. 6-7, 1846.	HW.*	272	284	306	5	40	67	80
	69 54 07				1.7	1.4	1.2	1.5	1.7	1.9	1.7
				LW.*	85	109	154	203	230	249	270
					1.5	1.0	0.8	1.2	1.6	1.8	1.7
Do	41 11 18(?)	Lieut. J. N. Maffitt	Aug. 5-7, 1849.	HW.*	256	258	265	274	0	41	70
	69 58 16(?)				1.4	1.5	1.1	0.8	0.6	0.9	1.3
				LW.*	73	91	121	147	209	233	256
					1.4	1.4	1.2	0.9	0.8	1.2	1.4
Near Nantucket	41 11 21	Lieut. C. H. Davis	Aug. 23, 1847	HW.*	242	247	270	28	38	41	47
	69 58 16				1.7	1.2	0.3	0.4	1.0	1.6	1.5
				LW.*	46	50	....	205	232	238	242
					1.3	0.8	0.0	0.7	1.3	1.8	1.7
Do	41 25 27	H. Mitchell	Aug. 4-5, 7-8, 1857.	HW.*	242	254	261	50	66	72	85
	70 01 57				1.4	0.8	0.3	0.3	0.8	1.4	1.4
				LW.*	85	85	123	225	225	225	242
					1.3	0.8	0.4	0.8	1.5	1.5	1.4

Directions true unless otherwise noted. * Tides at Boston. † Tides at Governors Island.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before— 3	2	1	0	Solar hours after— 1	2	3
NANTUCKET SOUND.	° ′ ″				° *kn*	° *kn*	° *kn*	° *kn*	° *kn*	° *kn*	° *kn*
Off Shovelful, S. of Powder Hole.	41 32 00	Lieut. M. Woodhull.	Aug. 28–29, 1852.	HW.*	330	30	100	100	90	85	85
	70 01 02				0.9	0.6	1.2	2.3	2.6	2.2	1.3
				LW.*	85	0	294	310	310	320	330
					1.2	0.1	1.2	1.7	1.7	1.0	0.9
Off Great Point......	41 24 15	.....do...........	Aug. 7–8, 1852.	HW.*	240	240	......	65	65	70	75
	70 03 40				0.9	0.5	0.0	0.2	0.6	1.2	0.9
				LW.*	75	......	215	230	240	240	240
					0.9	0.0	0.3	0.6	0.7	0.8	0.9
N. of Handkerchief Shoal.	41 33 52	.....do..........	Sept. 1–2, 1852.	HW.*	285	260	160	140	150	150	165
	70 03 43				0.5	0.1	0.3	0.4	0.4	0.3	0.1
				LW.*	......	260	290	285	285	285	285
					0.0	0.1	0.3	0.5	0.6	0.6	0.5
Nantucket Sound....	41 27 00	H. Mitchell.......	July 5–6, 1857.	HW.*	273	284	......	67	70	72	81
	70 05 27				1.4	0.9	0.0	0.6	1.0	1.2	1.0
				LW.*	81	87	......	235	262	273	273
					0.9	0.6	0.0	0.5	1.0	1.3	1.4
Do..............	41 21 31	Lieut. M. Woodhull.	Aug. 17–18, 1852.	HW.*	237	240	80	70	70	70	75
	70 19 55				0.9	0.6	0.3	1.1	1.3	1.1	0.9
				LW.*	75	75	......	237	240	238	238
					0.9	0.5	0.0	0.5	1.0	1.2	0.9
Between Horseshoe Shoal and Bishop and Clerks Lightship.	41 32 20	H. Mitchell	July 13–14, 1857.	HW.*	295	255	300	100	81	81	81
	70 15 10				1.0	0.8	0.3	0.4	0.8	0.9	0.8
				LW.*	81	50	20	......	210	200	295
					0.8	0.7	0.4	0.0	0.6	0.8	1.1
Between Cross Rip Light and Horseshoe Shoal.	41 27 13(?)	.....do...........	July 8–9, 1857.	HW.*	261	261	261	......	81	81	81
	70 17 28(?)				1.4	0.9	0.5	0.0	1.0	1.1	0.9
				LW.*	81	81	81	......	250	255	261
					0.9	0.8	0.4	0.0	0.3	0.9	1.4
Between Longs and Nortons Shoal.	41 25 49	.....do........	July 17–18, 1857.	HW.*	239	245	290	36	50	60	70
	70 21 46				1.1	0.6	0.2	0.5	0.9	1.3	1.4
				LW.*	70	70	90	150	216	216	230
					1.4	1.1	0.7	0.4	0.8	1.0	1.1
Nantucket Sound....	41 20 08(?)	.....do..........	July 19–20, 1857.	HW.*	194	210	216	36	36	36	36
	70 25 40(?)				2.8	2.2	0.6	0.6	3.1	3.1	2.8
				LW.*	36	36	36	194	194	194	194
					2.7	2.0	1.1	0.1	2.3	3.4	3.0
Do..............	41 24 20	Lieut. M. Woodhull.	Aug. 14–15, 1852.	HW.*	190	200	345	350	345	345	350
	70 26 26				0.6	0.2	0.2	0.4	0.7	0.7	0.5
				LW.*	350	345	190	190	193	193	[illegible]
					0.5	0.3	0.3	0.9	0.9	0.7	0.5
Off Cape Poge.......	41 25 47	.....do..........	Aug. 13–14, 1852.	HW.*	260	265	265	270	......	120	125
	70 26 50				0.9	0.7	0.5	0.1	0.0	0.4	0.6
				LW.*	125	140	170	170	235	250	260
					0.6	0.5	0.4	0.2	0.4	0.7	0.9

Directions true unless otherwise noted.

*Tides at Boston.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
VINEYARD SOUND.	° ′ ″				°/kn	°kn	°/kn	°/kn	°/kn	°/kn	°/kn
Off Edgartown Light	41 23 14	H. L. Marindin..	Sept. 11–25,	HW.*	278	277	280	85	90	90	90
	70 30 00		1891.		0.7	0.5	0.1	0.8	0.9	0.6	0.4
				LW.*	90	......	292	286	278	280	274
					0.4	......	0.3	0.7	0.6	0.4	0.7
Swimming Place, near Edgartown.	41 22 33	....do............	Sept. 14–25,	HW.*	169	173	......	0	0	0	0
	70 30 24		1891.		1.3	1.0	0.3	1.6	1.8	1.4	0.8
				LW.*	0	0(?)	180(?)	180	180	180	174
					0.8	0.4	0.5	1.2	1.3	1.2	1.2
Off West Chop.......	41 29 17	Lieut. M. Woodhull.	July 31, Aug.	HW.*	262	262	245	100	100	108	105
	70 35 52		1, 1852.		2.9	2.3	0.4	1.0	2.5	3.4	3.6
				LW.*	105	105	115	......	260	262	262
					3.6	2.8	1.5	0.0	2.6	3.1	3.0
S. entrance to Woods Hole.	41 30 47	....do............	Sept. 21–22,	HW.*	284	280	280	112	105	105	105
	70 39 42		1850.		1.1	0.7	0.2	0.6	1.3	1.3	1.2
				LW.*	105	100	300(?)	245	280	284	285
					1.1	0.5	0.3	0.7	1.0	1.1	1.1
Do..............	41 30 49	....do............	July 31–Aug.	HW.*	295	310	......	75	80	95	85
	70 39 43		1, 1851.		0.4	0.2	0.0	0.4	0.5	0.4	0.2
				LW.*	85	......	300	290	300	295	295
					0.2	0.0	0.2	0.4	0.6	0.5	0.4
Do..............	41 30 45	....do............	Oct. 10–11,	HW.*	310	315	......	......	160	150	140
	70 40 02		1850.		0.8	0.5	0.0	......	1.3	1.5	1.4
				LW.*	140	135	135	0	320	310	310
					1.3	0.9	0.4	0.2	0.5	0.9	0.8
Do..............	41 30 37	Lieut. J. R. Goldsborough.	Nov. 5–6,	HW.*	295	285	260	170	100	90	90
	70 40 11		1849.		1.0	1.0	0.3	0.7	1.0	1.1	1.0
				LW.*	90	90	100	......	280	295	295
					1.0	0.8	0.3	......	0.9	1.0	1.0
Do..............	41 30 42	Lieut. M. Woodhull.	July 5–6,	HW.*	295	295	......	160	145	140	145
	70 40 15		1851.		0.4	0.2	0.1	0.3	0.7	0.7	0.6
				LW.*	150	170	190	295	290	290	295
					0.6	0.4	0.1	0.3	0.4	0.4	0.4
Robinsons Hole, S. end.	41 26 34	....do............	Sept. 29–30,	HW.*	310	305	310	330	150	115	140
	70 48 16		1850.		2.4	2.6	2.3	1.2	0.5	1.0	1.0
				LW.*	145	170	170	180	240	315	310
					1.0	0.7	0.6	0.4	0.5	1.0	2.3
Do..............	41 26 34	....do............	July 18–19,	HW.*	284	290	300	150	120	115	145
	70 48 16		Aug. 16–17,		0.3	0.2	0.1	0.1	0.6	0.7	0.7
			1851.	LW.*	150	200	250	260	250	250	280
					0.6	0.4	0.3	0.4	0.4	0.4	0.3
S. entrance to Quicks Hole.	41 26 06	Lieut. J. R. Goldsborough.	Nov. 12–13,	HW.*	312	320	325	0	118	122	120
	70 50 37		1849.		2.3	2.2	1.4	0.3	1.1	1.4	1.2
				LW.*	118	136	140	200(?)	255	305	310
					1.1	0.7	0.4	0.2	0.5	1.8	2.2

Directions true unless otherwise stated.

*Tides at Boston.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
VINEYARD SOUND—con.	° ′ ″				° kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
S. entrance to Quicks	41 25 59	Lieut. M. Wood-	Sept. 30 and	HW.*	300	300	310	130	110	115	120
Hole.	70 50 38	hull.	Oct. 1,		2.1	1.5	0.8	0.2	1.5	1.7	1.8
			1850.	LW.*	120	120	125	125(?)	240	270	300
					1.8	1.2	0.7	0.1(?)	0.5	1.6	2.1
Between Gay Head	41 23 16(?)	H. Mitchell	July 6–7,	HW.*	230	235	250	......	60	85	90
and Nawashena	70 51 08(?)		1857.		1.4	1.1	0.7	0.0	0.2	1.4	1.4
Island.				LW.*	90	80	70	200(?)	230	230	230
					1.4	1.1	0.4	0.3	1.0	1.3	1.4
BUZZARDS BAY.											
N. entrance to Woods	41 31 32	Lieut. M. Wood-	July 1–2 and	HW.*	330	340	......	175	165	165	165
Hole.	70 41 35	hull.	Aug. 6–7,		0.5	0.4	0.0	0.4	0.8	0.8	0.7
			1851.	LW.*	170	165	165(?)	330	335	335	335
					0.6	0.4	0.1	0.2	0.4	0.6	0.6
Do	41 31 29	.....do...........	Sept. 22–23,	HW.*	328	332	......	182	180	180	180
	70 41 39		Oct. 31,		0.8	0.5	0.0	0.6	1.1	1.2	1.0
			and Nov.	LW.*	180	190	260	295	305	320	325
			1, 1850.		1.0	0.4	0.2	0.5	0.7	1.0	0.9
Do	41 31 39	Lieut. J. R. Golds-	Nov. 10–11,	HW.*	340	350	350	165	168	170	175
	70 41 53	borough.	1849.		0.7	0.4	0.1	0.2	0.7	0.9	0.7
				LW.*	178	180	200	320	325	335	340
					0.7	0.7	0.2	0.3	0.7	0.7	0.7
Between Sconticut	41 36 30	Lieut. G. C.	Apr. 23–24,	HW.†	218	218	220	......	275	?	20
Neck and West	70 42 48	Hanus.	1896.		0.1	0.2	0.1	0.0	0.1	0.2	0.3
Falmouth.				LW.†	30	30	30	30	......	195	210
					0.2	0.2	0.2	0.1	0.0	0.1	0.1
Between Clark Point	41 31 00	.....do...........	Apr. 21–23,	HW.†	220	200	210	210	......	90	30
and Naushon Island.	70 49 30		1896.		0.2	0.2	0.3	0.2	0.0	0.1	0.2
				LW.†	40	70	70	90(?)	......	165	210
					0.3	0.2	0.2	0.2	0.0	0.1	0.1
N. entrance to Quicks	41 27 13	Lieut. M. Wood-	Aug. 9–10,	HW.*	340	355	15	......	185	195	195
Hole.	70 50 58	hull.	1851.		1.3	1.2	0.7	0.0	0.9	1.7	1.6
				LW.*	195	195	205	250	320	325	335
					1.6	1.3	0.7	0.4	1.1	1.2	1.3
Do	41 27 20	.....do...........	July 21–22,	HW.*	325	335	350	0	186	190	205
	70 50 59		1851.		1.0	0.9	0.6	0.2	0.8	1.8	1.5
				LW.*	205	210	230	255	300	320	320
					1.5	1.0	0.4	0.2	0.8	1.0	1.0
Do	41 27 21	.....do...........	Sept. 24, 26,	HW.*	350	10	25	65	170	180	180
	70 51 02		1850.		1.5	1.4	0.8	0.5	1.7	1.9	1.5
				LW.*	185	195	220	320	330	340	350
					1.4	0.9	0.3	0.3	1.1	1.5	1.5
Do	41 27 16	Lieut. J. R. Golds-	Nov. 13–14,	HW.*	347	350	0	90(?)	187	204	215
	70 51 03	borough.	1849.		1.4	0.9	0.5	0.2	1.2	2.1	1.8
				LW.*	215	214	215	270(?)	301	312	345
					1.7	1.3	0.7	0.2	1.1	1.4	1.4

Directions true unless otherwise noted.

* Tides at Boston. † Tides at Clark Point, near New Bedford.

12770—07——26

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
EASTERN LONG ISLAND SOUND.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
South of New London.	41 13 32	Lieut. C. P. Perkins	June 17, 18, 1887	HW.*	130	120	130	100	80?	265	280
	72 04 45				1.7	2.4	2.2	1.1	0.5	0.9	2.4
				LW.*	250	280	280	285	285	285	100 (?)
					1.3	2.5	2.8	2.2	1.5	0.6	0.4
Between Plum Island and Saybrook.	41 12 35	....do...........	June 16, 17, 1887	HW.†	96	98	110	160	253	260	268
	72 15 52				1.5	1.6	1.2	0.4	1.2	1.9	2.1
				LW.†	275	278	273	278	276	0	86
					2.2	2.5	1.9	1.6	0.6	0.1	1.1
Off Terrys Point (Orient), Long Island.	41 10 11	E. E. Haskell...	July 19 and 21–22, 1890	HW.‡	350	70	80	88	110	(?)	220
	72 18 53				0.3	2.0	2.5	2.2	1.6	0.3	1.4
				LW.‡	240	240	240	240	245	290 (?)	350 (?)
					2.5	3.2	3.3	2.9	1.8	0.6 (?)	0.3 (?)
Between Terrys Point, Long Island, and Saybrook.	41 12 14	....do...........	July 8, 11–12, 1890	HW.‡	350 (?)	75	73	80	115	175	215
	72 19 31				0.7 (?)	1.3	1.5	1.4	0.7	0.6	1.3
				LW.‡	230	227	225	230	237	240	320 (?)
					1.4	2.1	2.4	2.4	2.0	1.1	0.7 (?)
Do...............	41 13 53	....do...........	July 7–8, 1890	HW.‡	105	105	105	105	105	125	228
	72 20 08				2.2	2.5	2.5	2.2	1.7	0.4	0.9
				LW.‡	240	250	255	275	330	85	105
					1.7	2.0	1.7	0.9	0.5	1.5	2.2
Off Saybrook (Lynde Point) Light-house.	41 15 14	....do...........	July 5, 10–11, 1890	HW.‡	120	125	130	130	(?)	250	245
	72 20 23				1.4	1.2	0.9	0.3	(?)	1.2	1.7
				LW.‡	265	270	275	275	305	104	120
					1.8	1.7	1.2	0.7	0.3	1.1	1.3
SW. from Saybrook..	41 09 47	Lieut. C. P. Perkins	June 14–15, 1887	HW.†	65	75	75	85	150	195	220
	72 25 43				2.1	2.3	1.7	1.2	0.4	1.2	2.1
				LW.†	220	230	260	275	300	30	65
					2.1	2.3	1.9	1.2	0.4	0.7	2.1
SW. from Saybrook..	41 07 15	....do...........	June 9–10, 1887	HW.§	73	73	73	110	232	260	250
	72 35 16				1.8	1.5	1.0	0.3	0.5	1.1	1.5
				LW.§	260	285	270	280	50	67	71
					1.6	1.3	0.9	0.4	0.3	1.0	1.8
Mid-Sound S. of The Thimbles.	41 07 00	E. E. Haskell....	July 28, 29, 1890	HW.‡	345	90	90	30	45	90	170
	72 44 58				0.2	0.6	0.8	0.8	0.7	0.5	0.2
				LW.‡	250	240	240	240	235	195	(?)
					0.6	1.1	1.2	1.1	0.5	0.3	(?)
SE. from New Haven.	41 06 30	Lieut. C. P. Perkins	May 25, 26, 1887	HW.§	80	75	70	70	250	240	240
	72 46 02				0.8	0.7	0.5	0.3	0.3	0.7	1.0
				LW.§	235	245	270	290	70	80	80
					1.0	0.9	0.6	0.3	0.2	0.5	0.8

Directions true unless otherwise noted.

* Tides at Little Gull Island.
† Tides at Saybrook.
‡ Tides at New London.
§ Tides at Falkner Island.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
WESTERN LONG ISLAND SOUND.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
NW. of Eatons Point, Long Island.	40 58 00 73 27 36	Lieut. C. P. Perkins	May 18, 19, 1887	HW.*	27	33	50	0	285	265	260
					0.5	0.6	0.3	0.1	0.4	0.5	0.8
				LW.*	270	270	270	280	295	350	30
					0.8	0.9	0.9	0.5	0.3	0.3	0.5
Off Stamford Light	40 59 16 73 31 03	....do	Apr. 26, 27, 1887	HW.*	67	55	50	80	300	265	240
					0.5	0.6	0.4	0.1	0.1	0.3	0.4
				LW.*	235	240	235	225	200	90	70
					0.5	0.5	0.4	0.2	0.1	0.2	0.4
Between Great Captain Light and Oyster Bay.	40 57 47 73 35 44	Lieut. Goldsborough	July 8, 9, 1847	HW.†	271	302	40	60	80	90	120
					0.8	0.4	0.3	0.8	1.1	1.0	0.6
				LW.†	130	167	210	233	247	257	268
					0.5	0.3	0.5	0.9	1.1	1.0	0.8
Off Matinicock Point	40 55 02 73 38 38	E. E. Haskell	Aug. 7, 8, 13, 14, 1890	HW.‡	100	100	90	90?	210?	230?	230?
					0.6	0.7	0.6	0.1?	0.1?	0.3?	0.6?
				LW.‡	230 (?)	215	208	208	180?	150?	100?
					0.6 (?)	0.6	0.4	0.2	0.2?	0.4?	0.6?
NEW YORK, LOWER BAY.											
Scotland Wreck Light Ship (old position).	40 26 24 73 55 56	Ensign J. M. Ellicott	Aug. 11–13, 1885	HW.†	125	135	135	145	170	300?	315
					0.4	0.6	0.5	0.4	0.1	0.2	0.4
				LW.†	315	330	320	330	340	103	125
					0.4	0.6	0.6	0.4	0.1	0.2	0.4
Inside Sandy Hook	40 27 28 74 00 52	H. Mitchell	July 13 and 28, 1856	HW.†	338	212	174	172	176	181	181
					0.12	0.17	0.39	0.49	0.56	0.44	0.34
				LW.†	181	200	184	204	358	20	350
					0.18	0.27	0.22	0.05	0.14	0.26	0.25
Sandy Hook Bay	40 27 33 74 02 20	....do	July 13, 28, 29, 1856	HW.†	66	38	229	230	249	255	275
					0.39	0.16	0.13	0.43	0.65	0.62	0.57
				LW.†	271	285	292	290	353	25	61
					0.57	0.42	0.42	0.31	0.26	0.27	0.38
Do	40 27 39 73 55 25	Lieut. G. C. Hanus, U. S. Navy	Aug. 11–13, 1885	HW.†	125	133	140	143	200	280	291
					0.6	0.7	0.6	0.4	0.1	0.2	0.6
				LW.†	300	300	300	287	275	140	130
					0.6	0.8	0.7	0.4	0.1	0.2	0.6
Inside Sandy Hook	40 27 50 74 00 56	H. Mitchell	July 10, 15, 26, 1856	HW.†	246	172	182	177	165	176	180
					0.07	0.36	0.50	0.53	0.61	0.57	0.48
				LW.†	175	179	178	139	346	341	280
					0.40	0.25	0.21	0.07	0.09	0.20	0.13
S. of SW. Spit, in Ship Channel.	40 28 27 74 01 54	....do	July 15–16, 1856	HW.†	52	69	277	358	208	247	223
					0.31	0.24	0.24	0.28	0.15	0.27	0.68
				LW.†	226	260	314	4	48	37	40
					0.69	0.81	0.40	0.51	0.62	0.43	0.32

Directions true unless otherwise noted.

* Tides at Stamford. † Tides at Sandy Hook. ‡ Tides at Willets Point.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after			
					3	2	1	0	1	2	3
NEW YORK, LOWER BAY—continued.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
N. of Sandy Hook....	40 28 30	H. Mitchell	Aug. 2, July	HW.*	86	89	126	128	209	251	256
	74 00 56		10, 15, 16,		1.48	1.19	0.75	0.71	0.81	1.24	1.38
			23, 1856	LW.*	260	290	270	193	12	92	91
					1.32	1.21	0.73	0.73	0.78	1.39	1.48
Do	40 28 52	.....do...........	July 23, Aug.	HW.*	111	108	126	184	244	272	267
	73 59 53		1, 1856		1.68	1.45	1.02	0.94	1.16	1.64	1.53
				LW.*	275	283	264	212	185	126	111
					1.41	0.94	0.48	0.52	0.69	1.20	1.66
....	40 29 17	Ensign E. F. Leiper, U. S. Navy.	Aug. 11-13,	HW.*	133	138	130	130	215	270	280
	73 54 54		1885		0.5	0.6	0.6	0.4	0.1	0.3	0.6
				LW.*	290	290	290	270	255	170	135
					0.6	0.7	0.7	0.6	0.4	0.2	0.5
....	40 30 12	Lieut. J. M. Hawley, U. S. Navy.	Aug. 28-30,	HW.*	82	110	106	130	217	254	268
	74 02 50		1885		0.7	0.5	0.3	0.1	0.1	0.4	0.6
				LW.*	268	268	287	313	6	41	75
					0.6	0.6	0.5	0.4	0.5	0.7	0.8
HUDSON RIVER.											
Bull's Ferry, off Ninety-sixth street.	40 47 50	H. Mitchell	Sept. 26-27,	HW.†	25	206	206	194	200	200	.....
	73 58 50		1871		0.1	0.5	0.9	1.2	1.4	0.8	0.0
				LW.†	26	32	37	37	26	26	.....
					0.5	1.2	1.5	1.6	1.2	0.9	0.0
Off Verplanck's Point.	41 14[42]	.....do...........	Sept. 9, 11,	HW.†	326	326	......	184	184	184	184
	73 58[16]		and 23, 1871		1.0	0.3	0.0	0.7	1.0	1.0	0.6
				LW.†	184	......	342	342	342	342	342
					0.4	0.0	0.4	0.9	0.9	1.0	1.0
Off Cold Spring	41 24[56]	.....do....	Sept. 13-15,	HW.†	353	340	330	150	150	160	160
	73 57[51]		1871		1.1	0.9	0.4	0.1	0.6	0.9	0.9
				LW.†	160	150	......	353	353	353	353
					0.9	0.5	0.0	0.5	0.9	1.1	1.1
Off New Windsor.....	41 28[22]	.....do	Sept. 14 and	HW.†	40	40	20	165	160	173	165
	70 00[20]		20, 1871		1.2	0.9	0.4	0.2	0.6	0.8	1.0
				LW.†	170	170	170	15	44	41	40
					1.0	0.6	0.1	0.3	0.8	1.3	1.3
Off Carthage	41 33[23]	.....do...........	Sept. 19-20,	HW.†	45	45	37	200	230	230	217
	73 58[32]		1871		0.9	0.7	0.2	0.2	0.7	0.9	1.0
				LW.†	205	205	205	......	40	45	45
					0.9	0.8	0.2	0.0	0.8	0.9	0.9
ARTHUR KILL.											
Off Tottenville.	40 31 05	H. Mitchell	Aug. 15, 20,	HW.*	225	225	225	225	45	45	45
	74 15 05		1856		0.9	1.0	1.1	0.9	0 4	0.7	1.2
				LW.*	45	45	45	45	225	225	225
					1.2	1.1	0.9	0.5	0.3	0.5	0.7
Off Rossville..........	40 33 28	.....do...........	Aug. 16,	HW.*	225	225	225	225	.....	45	45
	74 13 15		1856		0	0.5	0.4	0.2	0.0	0.2	0.5
				LW.*	45	45	43	45	225	225	225
					0.5	0.5	0.4	0.1	0.2	0.4	0.5

Directions true unless otherwise noted.

* Tides at Sandy Hook. † Tides at Governors Island.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
HUDSON RIVER—con.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
Off Island View......	40 34 56	H. Mitchell......	Aug. 23,	HW.*	200	200	200	200	200	20	20
	74 12 28		1856		0.8	0.8	0.8	0.6	0.2	0.1	0.6
				LW.*	20	20	20	20	......	200	200
					0.7	0.9	0.9	0.5	0.0	0.3	0.7
About 0.4 mi. N. 5° W.	40 37 12	.....do...........	Aug. 23,	HW.*	170	170	170	170	170	170	350
from Pralls Island.	74 12 08		1856		1.0	1.6	1.5	1.3	0.9	0.2	0.5
				LW.*	350	350	350	350	350	350	170
					0.5	0.8	1.0	1.1	0.9	0.5	1.0
NEWARK BAY.											
Off the mouth of	40 38 37	.....do...........	Sept. 9, 1856.	HW.†	216	216	216	216	216	36	36
Elizabethport	74 11 15				1.1	1.5	1.7	1.5	0.7	0.2	1.0
Creek.				LW.†	36	36	36	36	36	.....	216
					1.0	1.3	1.3	1.1	0.7	0.0	0.7
About 0.2 mi. W. from	40 38 50	.....do...........	Aug. 16,	HW.†	265	265	265	265	265	85	85
Corner Stake Light.	74 10 34		Sept. 10,		1.1	1.2	1.2	0.8	0.4	0.2	0.8
			1856	LW.†	85	85	85	85	85	265	265
					0.8	1.0	0.9	0.7	0.3	0.4	1.0
Off Newark, N. J., on	40 44 16	.....do...........	Aug. 28, 1856.	HW.†	135	135	135	135	135	315	315
Passaic River, at	74 09 42				0.6	0.8	0.8	0.6	0.1	0.2	0.6
outlet of Morris				LW.†	315	315	315	315	315	315	135
Canal.					0.6	0.8	0.8	0.7	0.5	0.1	0.5
KILL VAN KULL.											
About 0.1 mi. S. from	40 38 27	.....do...........	Aug. 21,	HW.†	105	105	105	105	......	285	285
Bergen Point Light.	74 09 03		Sept. 9,		1.8	1.7	1.1	0.6	0.0	0.7	1.5
			1856	LW.†	285	285	285	285	285	105	105
					1.5	2.0	1.7	1.0	0.2	0.8	1.7
Off Port Richmond. .	40 38 39	.....do...........	Aug. 15-16,	HW.†	80	80	80	80	260	260	260
	74 07 49		1856		1.8	1.8	1.5	0.8	0.3	1.6	2.1
				LW.†	260	260	260	260	......	80	80
					2.1	2.2	1.6	0.9	0.0	1.2	1.7
Off New Brighton....	40 38 49	.....do...........	Aug. 15, 1856.	HW.†	90	90	90	270	270	270	270
	74 05 55				0.6	0.4	0.2	0.2	0.6	0.9	1.0
				LW.†	270	270	270	270	90	90	90
					1.0	[illegible]	0.6	0.2	0.2	0.5	0.6
CHESAPEAKE BAY.											
Elizabeth River, Norfolk Harbor.	36 49 41	J. B. Weir........	May 20, 21,	HW.‡	350	350	350	350	170	170	170
	76 17 36		1876		0.7	0.8	0.7	0.4	0.4	0.8	0.8
				LW.‡	170	170	170	170	170	170	350
					0.8	0.7	0.8	......	0.6	0.5	0.2
Do................	36 50 26	.....do..........	May 15, 29,	HW.‡	285	285	285	285	......	105	105
	76 16 41		1876		0.5	0.6	0.4	0.3	0.0	0.2	0.4
				LW.‡	105	105	105	105	285	285	285
					0.4	0.4	0.4	0.1	0.1	0.4	0.3

Directions true unless otherwise noted.

* Tides at Sandy Hook. † Tides at Governors Island. ‡ Tides at Old Point Comfort.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
CHESAPEAKE BAY—continued.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
Elizabeth River, Norfolk Harbor.	36 50 31	J. B. Weir........	May 20, 21,	HW.*	280	280	280	280	100	100	100
	76 17 14		1876		0.4	0.6	0.5	0.2	0.2	0.5	0.6
				LW.*	100	100	100	100	.....	280	280
					0.6	0.6	0.4	0.2	0.0	0.3	0.5
Do..............	36 50 37	.....do...........	May 15, 16,	HW.*	330	330	330	330	.....	150	150
	76 17 45		29, 1876		0.5	0.5	0.4	0.3	0.0	0.4	0.6
				LW.*	150	150	150	150	330	330	330
					0.6	0.7	0.6	0.4	0.1	0.2	0.5
Do..............	36 51 41	.....do...........	May 24, 27,	HW.*	310	310	310	310	130	130	130
	76 19 05		1876		0.6	0.8	0.6	0.2	0.3	0.8	1.0
				LW.*	130	130	130	130	310	310	310
					0.9	0.9	0.8	0.4	0.1	0.5	0.7
Do..............	36 51 54	.....do...........	May 25, 26,	HW.*	310	310	310	310	130	130	130
	76 19 32		1876		0.7	0.8	0.6	0.4	0.1	0.4	0.8
				LW.*	130	130	130	310	.....	310	310
					0.8	0.9	0.7	0.1	0.0	0.3	0.6
Approaches to Chesapeake Bay.	37 01 15	Lieut. B. F. Sands.	Sept. 11–12,	HW.*	.....	95	105	125	130	160	260
	75 56 00		1851		0.0	0.7	0.9	0.9	0.6	0.2	0.4
				LW.*	260	280	280	285	285	300	.....
					0.4	0.9	1.5	1.7	1.1	0.4	0.0
Do..............	37 03 37	.....do...........	Sept. 9, 10,	HW.*	70	70	70	75	80	.....	260
	75 54 50		1851		0.4	0.6	0.9	0.7	0.4	0.0	0.4
				LW.*	260	280	285	285	285	.....	70
					0.4	0.6	0.7	0.7	0.4	0.0	0.3
Grove Wharf, James River.	37 11 ..	Lieut. J. N. Maffitt.	July 31–Aug.	HW.*	.....	.....	.....	.....	.....	.....	.....
	76 39 ..		2, 1855		0.6	0.3	0.1	0.2	0.4	0.5	0.4
				LW.*	.....	.....	.....	.....	.....	.....	.....
					0.4	0.1	0.1	0.4	0.6	0.7	0.6
Off Wolf Trap Light Boat.	37 23 39	Lieut. J. I. Almy..	Nov. 16–19,	HW.*	21	29	37	160	168	176	184
	76 09 59		1851		1.0	0.8	0.3	0.5	0.8	1.0	1.0
				LW.*	184	192	200	355	3	11	19
					1.0	0.7	0.1	0.6	0.9	1.1	1.1
....	37 36 49	Lieut. S. P. Lee ...	Nov. 5–6,	HW.*	335	335	0	170?	170	165	170
	76 10 29		1850		0.7	0.6	0.4	0.3	0.4	0.5	0.5
				LW.*	170	170	170	.....	340	340	335
					0.5	0.4	0.4	.....	0.2	0.4	0.6
Near Watts Island Light.	37 42 25	G. Bradford	May 27–31,	HW.*	26	32	240	250	242	228	217
	75 55 57		1881		0.6	0.2	0.3	0.4	0.5	0.5	0.3
				LW.*	216	194	42	47	49	48	44
					0.3	0.3	0.5	1.1	1.3	1.2	0.9
Near Watts Island Light.	37 44 15	.....do...........	Mar. 3–Apr.	HW.*	36	272	275	266	245	258	.....
	75 52 01		23, May		0.3	0.2	0.3	0.5	0.5	0.3	0.0
			19–20, 1881	LW.*	.....	50	51	46	51	54	43
					0.0	0.4	0.4	0.5	0.5	0.4	0.3

Directions true unless otherwise noted.

* Tides at Old Point Comfort.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
CHESAPEAKE BAY—continued.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
West of Smiths Island	37 59 25 76 09 00	Lieut. S. P. Lee	Aug. 30, 31, 1849	HW.*	....	308	311	238	234	196	192
						0.4	0.2	0.2	0.4	0.4	0.5
				LW.*	......	182	176	176	94	94	277
						0.4	0.3	0.2	0.1	0.3	0.4
Near Point Lookout, Md.	38 00 30 76 17 37	....do	June 25, 26, 1849	HW.*	314	324	337	347	252	234	219
					0.8	0.7	0.5	0.2	0.4	0.6	0.6
				LW.*	219	201	263	276	285	298	310
					0.6	0.2	0.2	0.5	0.7	0.8	0.8
Near Point No Point	38 09 54 76 16 16	....do	Aug. 26, 27, 1849	HW.*	28	0	330	297	268	240	211
					0.4	0.5	0.4	0.2	0.3	0.7	0.8
				LW.*	211	184	153	125	......	70	38
					0.8	0.7	0.5	0.3	0.0	0.1	0.3
In Hooper Straits	38 13 14 76 05 50	....do	Sept. 30, Oct. 1, 1849	HW.*	36	29	21	200	209	218	226
					0.5	0.4	0.2	0.1	0.4	0.5	0.5
				LW.*	226	235	72	64	55	47	39
					0.5	0.2	0.2	0.4	0.5	0.6	0.6
Off Cedar Point, Md.	38 16 41 76 18 13	....do	Oct. 9, 10, 1849	HW.*	168	357	347	336	324	171	171
					0.1	0.1	0.3	0.3	0.2	0.1	0.4
				LW.*	171	170	170	169	169	168	168
					0.5	0.6	0.7	0.7	0.6	0.4	0.2
Mouth of Patuxent River.	38 19 19 76 23 28	....do	Oct. 4, 5, 1849	HW.*	247	252	256	261	265	50	68
					0.5	0.6	0.6	0.4	0.1	0.2	0.4
				LW.*	68	87	108	......	239	242	246
					0.4	0.4	0.3	0.0	0.2	0.4	0.5
Off Cove Point, Md.	38 25 47 76 22 50	....do	Oct. 12, 13, 1849	HW.*	......	6	4	2	359	357	355
					0.0	0.3	0.7	0.9	0.8	0.6	0.2
				LW.*	355	164	167	173	178	183	188
					0.2	0.1	0.4	0.5	0.5	0.4	0.2
Mouth of Great Choptank River.	38 36 15 76 19 49	Lieut. McArthur	July 25, 1848	HW.*	45	42	42	42	......	200	211
					1.0	0.9	0.6	0.4	0.0	0.3	0.7
				LW.*	211	211	200	200	......	53	48
					0.7	0.8	0.5	0.3	0.0	0.4	0.8
Great Choptank River.	38 39 40 76 15 00	....do	July 18, 19, 1848	HW.*	90	93	90	90	83	80	......
					0.2	0.5	0.6	0.6	0.4	0.2	0.0
				LW.*	......	230	255	265	267	270	270
					0.0	0.2	0.4	0.6	0.6	0.3	0.1
Off Holland Point	38 42 28 76 27 29	Lieut. S. P. Lee	Oct. 20, 21, 1849	HW.*	182	198	15	15	14	14	13
					0.3	0.1	0.1	0.3	0.4	0.5	0.5
				LW.*	13	13	12	124	140	156	175
					0.5	0.4	0.2	0.1	0.3	0.4	0.4
Off Herring Bay, Md.	38 47 44 76 26 39	....do	Oct. 18, 19, 1849	HW.*	247	241	......	33	27	22	16
					0.4	0.3	0.0	0.2	0.4	0.5	0.4
				LW.*	16	11	6	274	265	258	249
					0.4	0.3	0.1	0.1	0.3	0.4	0.4

Directions true unless otherwise noted.

*Tides at Old Point Comfort.

Table showing hourly values of duration (azimuth) and velocity of the current—Con.

Station	Latitude and longitude	Observing party	Date	Tides	Solar hours before—			Solar hours after—			
					3	2	1	0	1	2	3
CHESAPEAKE BAY—continued.	° ′ ″				°/kn	°/kn	°/kn	°/kn	°/kn	°/kn	°/kn
Between Tilghmans	38 50 47	Lieut. McArthur.	June 17, 18,	HW.*	157	166	180	177	180	.....	3
Point and Mouth	76 13 41		1847		0.2	0.3	0.4	0.3	0.1	0.0	0.1
of Wye River.				LW *	3	5	10	5	5	0	.....
					0.1	0.2	0.3	0.4	0.3	0.2	0.0
In Eastern Bay, Md..	38 52 24	Lieut. S. P. Lee ..	Oct. 15, 16,	HW.*	18	27	36	46	55	65	201
	76 17 36		1849		0.1	0.2	0.3	0.3	0.2	0.1	0.2
				LW.*	201	202	204	205	206	207	.....
					0.2	0.4	0.5	0.5	0.4	0.1	0.0
Off Thomas Point	38 53 04	.....do...........	Oct. 17, 18,	HW.*	.....	223	3	10	11	19	33
Light.	76 24 53		1849			0.1	0.2	0.5	0.6	0.8	0.9
				LW.*	.....	18	14	8	197	212	206
						0.7	0.5	0.2	0.2	0.3	0.4
Baltimore Harbor....	39 10 08	F. P. Webber	June 7–25,	HW.†	170	170	170	170	170	170	345
	76 23 46		1867		0.4	0.5	0.6	0.5	0.3	0.1	0.2
				LW.†	345	345	345	345	345	170	170
					0.2	0.4	0.4	0.3	0.1	0.2	0.4
Do..............	39 10 43	.....do	May 31–	HW.†	150	150	150	285	285	285	285
	76 28 14		June 4,		0.3	0.2	0.1	0.2	0.3	0.4	0.4
			1867	LW.†	285	285	285	150	150	150	150
					0.4	0.3	0.2	0.1	0.3	0.3	0.3
Do..............	39 10 49	.....do...........	June 5, 1867	HW.†	210	210	210	210	210	10	10
	76 26 30				0.5	0.8	0.8	0.5	0.2	0.3	0.8
				LW.†	10	10	10	10	10	.....	210
					0.8	1.0	0.9	0.7	0.4	0.0	0.4
Do..............	39 11 06	.....do...........	May 30, 1867	HW.†	110	110	110	290	290	290	290
	76 27 47				0.6	0.5	0.1	0.2	0.3	0.4	0.4
				LW.†	290	290	290	.....	110	110	110
					0.4	0.3	0.2	0.0	0.3	0.5	0.6
Do..............	39 11 19	.....do...........	June 4, 1867	HW.†	190	190	190	190	190	.....	25
	76 24 00				0.5	0.6	0.5	0.4	0.2	0.0	0.6
				LW.†	25	25	25	25	25	190	190
					0.6	1.0	0.9	0.5	0.2	0.2	0.5
Do..............	39 11 30	.....do...........	May 28, 29,	HW.†	140	140	140	.....	280	280	280
	76 27 08		1867		0.2	0.2	0.1	0.0	0.1	0.2	0.3
				LW.†	280	280	280	280	.....	140	140
					0.3	0.3	0.2	0.1	0.0	0.2	0.2
Do..............	39 11 32	.....do...........	May 27, 1867	HW.†	70	70	.....	205	205	205	205
	76 25 15				0.2	0.1	0.0	0.1	0.2	0.3	0.3
				LW.†	205	205	205	....	70	70	70
					0.3	0.3	0.2	0.0	0.2	0.3	0.5

Directions true unless otherwise noted. * Tides at Old Point Comfort. † Tides at Baltimore.

97. *Table of harmonic constants.*

Station	Latitude and longitude	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
GULF OF MAINE.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Cashes Ledge*	42 52 55	Capt. C. D. Sigsbee	Sept. 1-4, 1875	M_2	0.365	236.4	0.288	319.1	0.369	246.1	179.9	0.282	269.9
	68 54 29			C	− 0.140		−0.078		0.156		15.1		
NANTUCKET SHOALS.													
South end of Great Rip	41 12 09	Lieut. C. H. Davis	Aug. 2-3, 1848	M_2	1.805	207.0	0.656	245.8	1.880	210.6	196.6	0.395	286.6
	69 41 02			C	−0.238		0.113		0.263		334.6		
Sankaty Head*	41 11 50	....do	July 20-21, 1848	M_2	1.454	202.3	1.054	228.9	1.752	211.2	215.5	0.391	295.5
	69 48 25			C	−0.248		0.098		0.267		328.9		
NANTUCKET SOUND.													
Cross Rip light vessel*	41 26 46	Lightkeeper	July 23-Aug. 12,	M_2	0.049	139.1	0.920	245.5	0.920	246.0	259.8	0.047	349.8
	70 17 26		1857	M_4			0.045	116.7					
				M_6			0.070	29.9					
				S_2	0.035	101.9	0.154	260.2	0.157	261.1	271.0	0.013	1.0
				C	0.179		0.131		0.222		205.2		
ATLANTIC COAST.													
Off Marthas Vineyard*	40 43 ..	Lieut. Ackley	Aug. 6-7, 1879	M_2	0.402	193.5	0.368	259.8	0.458	221.0	207.8	0.296	297.8
	70 28 ..			C	−0.110		−0.076		0.134		24.6		
Off Gay Head*	40 38 30	Lieut. J. E. Pillsbury	Sept. 28-29, 1877	M_2	0.243	236.0	0.364	281.2	0.410	89.1	49.2	0.153	139.2
	70 38 00			C	−0.221		−0.362		0.423		47.5		
Do.*	40 53 50	...do	Sept. 27-28, 1887	M_2	0.104	239.2	0.259	283.7	0.270	99.2	61.8	0.070	151.8
	70 44 30			C	−0.206		−0.048		0.212		2.1		
Do.*	41 07 40	....do	Aug. 30-Sept. 3,	M_2	0.157	213.7	0.277	312.4	0.279	136.4	86.1	0.155	176.1
	70 52 10		1887	C	0.070		−0.169		0.183		101.5		
Off Block Island	40 37 00	....do	Sept. 14, 18-20,	M_2	0.349	202.4	0.255	313.1	0.369	187.2	146.0	0.226	236.0
	71 09 30		1887	C	0.079		−0.104		0.131		117.2		
SE. of Block Island*	41 04 30	....do	Sept. 6, 20-22,	M_2	0.165	189.2	0.073	310.7	0.170	183.9	155.2	0.060	245.2
	71 18 30		1887	C	−0.054		0.051		0.074		306.6		
Off Block Island*	40 17 56	Lieut. Ackley	Aug. 21, 22, 1879	M_2	0.368	177.6	0.356	255.3	0.399	212.1	211.5	0.321	301.5
	71 41 30			C	0.049		0.081		0.095		229.8		

*For stations marked thus (*) results to the left of the double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

Station	Latitude and longitude	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth.	Amplitude	True azimuth
ATLANTIC COAST—continued.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Off Montauk Point*	40 49 45	Lieut. Pillsbury	Sept. 5-6, 15-16,	M_2	0.246	235.9	0.193	310.7	0.256	252.8	193.5	0.178	283.5
	71 44 00		1887	C	−0.016		−0.058		0.060		64.6		
Do.*	40 59 40	....do	Sept. 8-9, 1887	M_2	0.378	264.8	0.546	311.8	0.617	118.6	49.5	0.244	139.5
	71 45 00			C	−0.007		−0.249		0.249		78.4		
Off New Jersey coast*	39 33 41	Lieut. Ackley	Sept. 1-2, 1879	M_2	0.145	267.6	0.120	357.3	0.145	268.3	172.8	0.120	262.8
	72 12 20			C	−0.228		−0.238		0.330		38.2		
Do.*	39 56 16	....do	Aug. 31-Sept. 2,	M_2	0.112	183.6	0.080	289.3	0.116	170.9	152.7	0.075	242.7
	72 50 00		Sept. 10-11, 1879	C	−0.169		−0.128		0.212		29.1		
Off Fire Island*	40 32 30	Lieut. Pillsbury	Oct. 8-12, 1887	M_2	0.095	220.0	0.251	309.9	0.251	130.0	82.0	0.95	172.0
	73 09 40			C	−0.024		0.077		0.081		279.3		
Approaches to New York*	40 09 00	....do	Oct. 25-26, 29-30,	M_2	0.236	123.7	0.166	322.9	0.285	130.0	136.9	0.045	46.9
	73 20 45		1887	C	0.031		−0.043		0.053		117.3		
Off New Jersey coast*	38 57 36	Lieut. Ackley	Sept. 10-11, 1879	M_2	0.161	172.9	0.208	329.3	0.258	158.0	120.1	0.052	210.1
	73 33 00			C	−0.224		−0.210		0.307		36.2		
Off Barnegat Light*	39 53 00	Lieut. Pillsbury	Oct. 12-14, 1887	M_2	0.051	88.3	0.094	324.0	0.100	135.6	103.3	0.040	13.3
	73 55 45			C	0.096		0.049		0.108		200.0		
Off Ocean City, Md.*	38 18 11	Lieut. Lee	Aug. 11-13, 1849	M_2	0.274	223.8	0.040	323.9	0.274	223.6	174.0	0.039	264.0
	74 56 01			C	−0.094		0.034		0.100		339.1		
Coast of Virginia	37 54 39	Lieut. Almy	Aug. 9-11, 1851	M_2	0.070	265.0	0.099	291.1	0.119	102.7	55.9	0.026	145.9
	75 15 36			C	−0.024		0.054		0.059		294.0		
Do.	37 51 06	....do	Aug. 12-14, 1851	M_2	0.092	194.9	0.050	257.0	0.095	203.4	198.2	0.043	288.2
	75 14 02			C	0.051		−0.012		0.052		166.8		
Off coast of North Carolina*	33 43 24	Lieut. Bankhead	Aug. 17-18, 1859	M_2	0.364	125.6	0.336	282.9	0.485	115.3	138.6	0.097	228.6
	78 14 ..			C	0.023		0.055		0.060		24.8		
Do.*	33 23 15	....do	July 16-17, 1859	M_2	0.398	154.2	0.331	272.8	0.449	42.7	146.4	0.258	236.4
	77 57 30			C	0.163		0.434		0.464		250.3		

* For stations marked thus (*) the results to the left of the double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

Station	Latitude and longitude	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
CHESAPEAKE BAY.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Off Rappahannock Light-boat*	37 34 40	Lieut. Almy	Nov. 20–23, 1851	M_2	0.503	327.4	0.094	110.6	0.508	326.4	169.9	0.056	259.9
	76 11 16			C	−0.246		0.209		0.320		318.8		
Off Drum Point, Patuxent River	38 19 08	R. L. Faris	Oct. 28–Nov. 11,	M_2	0.383	565	0.078	192.6	0.387	55.3	171.5	0.054	261.5
	76 20 23		1897.	S_2	0.059	117.2	0.021	241.0	0.060	113.7	167.8	0.017	257.8
				C	0.027		0.057		0.063		244.7		
Sharps Island Light-house	38 31 04	....do	Oct. 4–19, 1897	M_2	0.290	72.3	0.092	273.3	0.303	74.1	163.3	0.032	73.3
	76 25 50			S_2	0.046	90.3	0.017	328.6	0.046	94.0	167.9	0.014	77.9
				C	−0.065		0.018		0.067		34.5		
Bloody Point Bar Light	38 44 47	E. H. Tillman	Aug. 16–28, 1897	M_2	0.315	120.9	0.033	154.7	0.316	121.2	185.0	0.018	275.0
	76 28 02			C	−0.017		0.012		0.021		35.2		
Near Thomas Point	38 52 29	....do	Sept. 3–Oct. 1,	M_2	0.555	131.0	0.211	136.6	0.593	131.7	200.8	0.019	290.8
	76 25 10		1897.	C	−0.217		−0.040		0.221		10.4		
Greenbury Point	38 56 26	....do	July 29–Aug. 12,	M_2	0.539	132.4	0.181	125.0	0.568	131.7	198.4	0.022	108.4
	76 25 48		1897.	S_2	0.093	155.8	0.043	129.3	0.101	151.5	203.2	0.018	113.2
				C	−0.153		−0.070		0.168		24.6		
Off Sandy Point Light-house	39 00 49	....do	June 23–July 21,	K_1	0.220	211.4	0.041	213.2	0.224	211.5	190.6	0.001	100.6
	76 22 02		1897.	M_2	0.644	146.8	0.140	134.3	0.658	146.3	192.0	0.030	282.0
				O_1	0.166	231.3	0.019	255.3	0.117	231.9	188.6	0.008	98.6
				S_2	0.069	181.2	0.049	99.7	0.070	171.9	192.7	0.048	282.7
				C	−0.002		0.012		0.013		281.3		
3⅝ mi. E. of Seven Foot Knoll	39 09 17	....do	May 18–June 16,	M_2	0.513	160.7	0.222	206.3	0.538	166.0	198.4	0.151	288.4
	76 19 49		1897.	M_4	0.008	111.3	0.005	190.6	0.008	116.0	188.6	0.005	278.6
				M_6	0.008	75.0	0.012	269.6	0.015	265.3	122.8	0.002	32.8
				S_2	0.060	188.3	0.015	314.1	0.060	186.6	171.4	0.012	261.4
				C	−0.099		−0.076		0.125		37.5		
Baltimore Entrance	39 12 29	....do	Apr. 28–May 7,	M_2	0.149	142.2	0.128	163.5	0.193	151.2	220.3	0.037	310.3
	76 24 23		1897.	C	−0.018		−0.040		0.044		56.0		
FLORIDA STRAITS.													
Off Fowey Rocks	25 34 15	Lt. J. E. Pillsbury	May 7–June 1,	K_1	....	....	....	....	0.130 (?)	14.0 (?)	....	....	....
	79 56 43		1885.	M_2					0.216	91.5			
			Feb. 28–May 29,	O_1					0.096 (?)	290.1 (?)			
			1886.	C					2.573				

* For stations marked thus (*) the results to the left of the double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

Station	Latitude and longitude	Observing party	Date	Component	North and south: Amplitude	North and south: Epoch	East and west: Amplitude	East and west: Epoch	Resultant flood: Amplitude	Resultant flood: Epoch	Resultant flood: True azimuth	Minimum after flood: Amplitude	Minimum after flood: True azimuth
FLORIDA STRAITS—continued.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Off Fowey Rocks*	25 33 33	Lt. J. E. Pillsbury.	May 7-14, 1885	M_2	0.165	87.8	0.078	233.1	0.178	82.3	160.5	0.041	250.5
	79 55 25			C	2.130		−0.032		2.133		182.1		
Between Rebecca Shoals and Cuba	23 37 48	....do	Feb. 16-17, 1887	K_1	....	....	....	....	0.132	349.8	285.2	....	....
	82 33 56		May 7-8, 1887	M_2					0.078	106.2	285.2		
				O_1					0.132	347.8	285.2		
				C(3½ fth.)					1.818		285.2		
				C(15 fth.)					2.095		285.2		
				C(30 fth.)					1.919		285.2		
				C(65 fth.)					1.756		285.2		
GULF OF MEXICO.													
Yucatan Channel	21 36 00*	Lt. J. E. Pillsbury.	Apr. 13-17, 1887.	K_1	....	....	....	....	0.251	248.6	[185]	....	....
	86 16 10			M_2					0.331	95.9			
				O_1					0.213	243.6			
				C					3.125				
Do*	21 36 20	....do	Mar. 25-26, 1887.	M_2	0.158	277.4	0.200	161.0	0.230	318.0	129.6	0.119	39.6
	86 31 55			C	0.490		−0.080						
WEST INDIES.													
Windward Passage*	20 02 ..	Lt. J. E. Pillsbury.	Apr. 1888	M_2	0.106	136.9	0.061	128.4	0.122	314.8	30.4	0.008	300.4
	73 43 ..		Mar. 1889	C	−0.109		0.045		0.118		338.1		
Mona Passage	18 01 15	....do	Apr. 8, 1888	M_2	0.159	208.4	0.045	165.0	0.163	206.2	192.0	0.030	102.0
	67 39 00		Feb. 28-Mar. 1, 1889.	C	−0.037		−0.058		0.069		57.5		
East of Désirade Island*	16 19 09	....do	Mar. 12-14, 1888.	M_2	0.161	121.2	0.075	0.1	0.166	127.3	162.6	0.062	72.6
	60 50 26			C	0.244		0.014		0.244		181.8		
East of St. Lucia*	13 33 45	....do	Mar. 19-20, 1888.	M_2	0.126	123.8	0.307	74.4	0.319	259.2	72.7	0.092	342.7
	60 46 45			C(0 fth.)	0.396		−0.947		1.026		111.7		
				C(15 fth.)	−0.308		−0.733		0.795		66.2		
				C(30 fth.)	−0.391		−1.095		1.163		69.3		
				C(65 fth.)	−0.094		−0.438		0.455		76.6		
				C(130 fth.)	0.026		0.152		0.154		259.3		

* For stations marked thus (*) the results to the left of the double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

Station	Latitude and longitude	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
WEST INDIES—continued.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Between St. Vincent and St. Lucia *	13 28 57	Lt. J. E. Pillsbury.	Feb. 22–25, 28–29, 1888.	M_2	0.158	207.6	0.192	353.8	0.238	187.4	127.4	0.072	217.4
	61 03 45		Jan. 25, 26, 1889 ..	C(0 fth.)	0.329		−0.858		0.919		110.0		
				C(3½ fth.)	0.352		−1.082		1.138		107.0		
				C(15 fth.)	0.313		−1.040		1.086		105.8		
				C(30 fth.)	0.037		−1.080		1.081		90.9		
				C(65 fth.)	0.139		−0.705		0.719		100.2		
				C(130 fth.)	−0.160		+0.094		0.186		328.6		
Between Barbados and Tobago ...	12 13 00	....do	Jan. 26–28, 1888 ..	M_2	0.055	298.4	0.120	48.3	0.121	232.8	100.7	0.051	190.7
	60 02 13			C	0.214		−0.769		0.798		105.6		
Off Tobago Island	11 31 49	....do	Jan. 31–Feb. 12, 1888.	M_2	0.140	148.0	0.177	308.6	0.222	136.0	128.1	0.037	218.1
	60 23 40			C(0 fth.)	1.514		−0.940		1.782		148.2		
				C(15 fth.)	1.062		−0.322		1.110		163.1		
				C(30 fth.)	0.856		−0.295		0.905		161.0		
				C(65 fth.)	0.704		−0.283		0.759		158.1		
				C(130 fth.)	1.030		−0.271		1.065		165.3		

* For stations marked thus (*) the results to left of double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

GULF STREAM PERMANENT CURRENT

[Observations by Lieut. J. E. Pillsbury and Lieut. C. E. Vreeland.]

Station	Latitude North	Longitude West	Date	Number of observations	Velocity	True azimuth
	° ′ ″	° ′ ″			*Knots.*	°
North of Bahama Islands	30 56 15	76 16 10	Apr. 21–22, 1889	56	0.67	205
Florida Strait	26 55 00	79 11 40	Nov. 24–26, 1889	39	0.54	160
Do	25 37 28	79 47 24	May 7–16, 1886	68	2.92	188
Do	25 34 43	79 25 24	Apr. 6–7, May 3–29, 1885; Mar. 19, 29, Apr. 19, 1886.	107	1.76	171
Do	25 34 27	79 53 34	May 19–20, 1885; Apr. 7–8, May 16–30, 1886.	164	3.28	176
Do	25 34 15	79 56 43	May 7–June 1, 1885; Feb. 28–May 29, 1886; Apr. 29, 1887.	568	2.57	179
Do	25 34 00	79 33 39	May 5–6, 1885; Apr. 22, 1886.	22	1.88	171
Do	25 32 41	79 41 13	Apr. 18, May 1–2, 1885; May 4–10, 1886.	70	2.64	179
Old Bahama Channel	22 35 00	78 06 30	Apr. 24–25, 1888; Mar. 27–29, 1889.	161	0.28	77
Santaren Channel	23 45 00	79 25 45	Apr. 8–9, 1889	53	0.08	225
Nicholas Channel	23 24 40	80 22 10	Mar. 30–31, Apr. 10–11, 1889	65	0.52	292
Florida Strait	24 01 00	82 28 45	May 9–10, 1887	34	1.63	309
Do	23 10 35	82 29 00	May 6–7, 1887	65	1.40	246
Do	24 16 00	82 29 27	Mar. 2–3, 1887	29	1.11	267
Do	23 44 20	82 30 00	Feb. 12–13, 1887	19	3.37	264
Do	23 18 15	82 31 54	Feb. 26–27, 1887	37	0.95	247
Do	23 27 10	82 32 10	Feb. 17, 1887	16	1.96	259
Do	24 02 00	82 35 55	May 4–5, 1887	43	0.27	327
Do	23 44 30	82 36 00	May 10, 1887	16	1.73	297
Do	24 16 00	82 39 27	Feb. 15–16, 1887	22	0.30	119
Do	24 17 00	82 41 25	Feb. 9–10, 1887	7	0.13	229
Do	23 27 50	82 41 37	Apr. 27–28, 1887	48	2.52	265
SW. of Tortugas	24 38 10	84 00 00	Dec. 30–31, 1889	44	0.35	1
Do	24 11 50	84 05 05	Dec. 5–6, 19–21, 1889	111	1.79	341
North of Cuba	22 47 00	84 11 50	Dec. 13–14, 1889	52	0.99	51
Do	23 12 30	84 24 20	Dec. 15–16, 1889	50	0.27	355
Between Tortugas and Cuba	23 32 00	84 31 00	Dec. 16–17, 1889	57	0.82	326
Do	23 56 40	84 32 15	Dec. 18–19, 1889	51	1.41	329

Table of harmonic constants—Continued.

MISSISSIPPI RIVER PERMANENT CURRENT

[Observations by H. L. Marindin.]

Station	Latitude North	Longitude West	Date	Number of observations	Velocity	True azimuth
	° ′ ″	° ′ ″			*Knots.*	°
South West Pass	29 02 08	89 19 43	Feb. 23-24, Mar. 4, Apr. 4, 1876.	90	2.72	42
Do	29 04 02	89 18 18	Apr. 4, 1876	12	2.92	45
Do	29 06 32	89 16 19	Feb. 23-24, Mar. 4, Apr. 4, 17-18, 1876.	167	2.91	26
Above Cubits Gap	29 12 14	89 16 36	Feb. 14, 1876	33	2.94	335

YUCATAN CHANNEL PERMANENT CURRENTS

[Observations by Lieut. J. E. Pillsbury in 1887.]

Latitude	Longitude	Surface			3½ fathoms			15 fathoms		
North	West	Number of observations	Velocity	True azimuth	Number of observations	Velocity	True azimuth	Number of observations	Velocity	True azimuth
° ′ ″	° ′ ″		*Knots.*	°		*Knots.*	°		*Knots.*	°
21 54 00	85 11 37	47	0.48	238	25	0.63	....	6	0.85(?)	....
21 47 40	85 11 22	65	0.38	309	32	0.47	....	8	0.80(?)	....
21 44 40	86 21 10	38	3.01	177	17	3.12	....	5	2.80	182
21 43 00	85 29 40	109	1.16	173	52	1.19	....	12	1.16	185
21 42 15	85 46 25	33	1.64	179	15	1.63	....	2	1.50	163
21 42 00	86 01 50	91	2.77	185	45	2.78	....	11	2.36	185

Latitude	Longitude	30 fathoms			65 fathoms			130 fathoms		
North	West	Number of observations	Velocity	True azimuth	Number of observations	Velocity	True azimuth	Number of observations	Velocity	True azimuth
° ′ ″	° ′ ″		*Knots.*	°		*Knots.*	°		*Knots.*	°
21 54 00	85 11 37	5	0.70(?)	....	6	0.60(?)	....	5	0.40(?)	....
21 47 40	85 11 22	7	0.71	292	7	0.64	309	7	0.40(?)	....
21 44 40	86 21 10	4	2.80	182	4	2.35	182	4	2.12	193
21 43 00	85 29 40	12	1.22	191	11	1.30	179	11	1.02	179
21 42 15	85 46 25	3	1.55	151	4	1.56	179	3	1.13	174
21 42 00	86 01 50	8	2.40	193	10	2.20(?)	....	10	1.55	185

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
SAN FRANCISCO BAY.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Between Lime Point and Presidio*	37 49 21	Edw. Cordell	Dec. 5, 6, 1866	K_1	0.396	43.2	0.325−	41.1	0.512	42.4	235.9	0.009	145.9
	122 27 37			M_2	1.179	284.0	1.561	287.7	1.955+	286.4	249.5	0.061	339.5
	16°.5 E			C	−0.033	......	0.246	......	0.248	......	294.1	......	......
Off Presidio	37 48 28	G. Bradford	Jan. 6–8, 1875	K_1	......	......	......	......	0.563	45.8	......	......	......
	122 27 37			M_2	......	......	......	......	0.803	252.3	......	......	......
				M_4	......	......	......	......	0.312	260.9	......	......	......
				O_1†	......	......	......	......	0.354	28.0	......	......	......
				S_2†	......	......	......	......	0.181	256.9	......	......	......
Off Yellow Point*	37 50 05	Edw. Cordell	Dec. 14–15, 1866	K_1	0.484	37.7	0.193	133.8	0.484	36.6	193.6	0.192	283.6
	122 27 00			M_2	1.825	266.9	0.812	309.6	1.928	272.1	216.0	0.525	306.0
	16°.5 E			C	−0.075	......	−0.425	......	0.432	......	96.5	......	......
Off shore W. of Black Point*	37 48 25	G. Bradford	Dec. 21–23, 1874	K_1	0.052	14.2	0.336	34.3	0.340	33.9	261.8	0.018	351.8
	122 26 37			M_2	0.101	305.9	1.046	263.1	1.048	263.4	265.9	0.068	175.9
				C	−0.072	......	−0.266	......	0.276	......	74.9	......	......
Between Black Point and Anita Rock Spindle.	37 48 25	....do	Jan. 4–6, 1875	K_1	......	......	......	......	0.377	46.6	......	......	......
	122 27 04			M_2	......	......	......	......	1.079	260.1	......	......	......
				M_4	......	......	......	......	0.095	55.4	......	......	......
				O_1†	......	......	......	......	0.237	28.8	......	......	......
				S_2†	......	......	......	......	0.243	264.7	......	......	......
Off Black Point	37 48 33	....do	Nov. 12–14, 1874	K_1	......	......	......	......	0.332	29.5	......	......	......
	122 26 02			M_2	......	......	......	......	1.451	269.4	......	......	......
				M_4	......	......	......	......	0.189	275.0	......	......	......
				O_1†	......	......	......	......	0.209	11.7	......	......	......
				S_2†	......	......	......	......	0.326	274.0	......	......	......
Off Black Point*	37 48 58	Edw. Cordell	Dec. 6–7, 1866	K_1	0.304	74.7	0.603	51.9	0.667	56.3	260.9	0.106	170.9
	122 26 02			M_2	0.733	298.5	2.143	280.1	2.254	281.9	268.3	0.220	178.3
	16°.5 E			C	0.079	......	−0.212	......	0.226	......	126.9	......	......
Between Blossom Rock and Alcatraz*.	37 48 50	....do	Dec. 8–11, 1866	K_1	0.031	61.4	0.791	32.3	0.792	32.3	284.5	0.015+	294.5
	122 24 42			M_2	0.172	40.4	2.255+	276.7	2.257	276.5	288.9	0.143	298.9
	16°.5 E			M_4	0.036	246.2	0.069	300.7	0.073	292.6	266.2	0.028	356.2

* For stations marked thus (*) the results to the left of the double line refer to magnetic directions; all other results refer to true direction.

† By inference from Fort Point, Cal., tides.

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
SAN FRANCISCO BAY—continued.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Between Blossom Rock and Alcatraz*—Continued.		Edw. Cordell	Dec. 8–11, 1866	O_1†	0.190	43.6	0.498	14.5	0.498	14.5	284.5	0.009	249.5
				C	0.218	...	−0.040	...	0.222	...	186.1	...	...
Off Meigg's Wharf*	37 48 41	...do	Mar. 22–26, 1866	K_1	0.173	233.1	0.690	23.5	0.706	25.0	299.0	0.084	29.0
	122 24 36			M_2	0.605	49.0	1.327	265.9	1.418	260.6	307.8	0.340	217.8
	16°.5 E			M_4	0.442	260.6	0.291	165.6	0.443	84.4	10.8	0.290	280.8
				O_1†	0.109	215.8	0.434	5.7	0.440	7.2	299.0	0.053	29.0
				C	0.490	...	−0.473	...	0.681	...	152.5	...	...
Off shore Between Black Point and Alcatraz.	37 48 41	G. Bradford	Nov. 10–12, 1874	K_1	...	...	...	...	0.485	42.1	...	...	...
	122 25 34			M_2	...	...	...	...	1.671	266.7	...	...	...
				M_4	...	...	...	...	0.210	144.0	...	...	...
				O_1†	...	...	...	...	0.305	24.3	...	...	...
				S_2†	...	...	...	...	0.376	271.3	...	...	...
Off Blossom Rock*	37 49 00	Edw. Cordell	Jan. 18, Feb. 1, 1867	K_1	...	...	...	...	0.478	13.2	301.2	0.138	211.2
	122 24 24			M_2	0.933	52.2	1.804	269.7	1.962	262.9	310.6	0.523	220.6
	16°.5 E			M_4	0.221	266.8	0.063	310.2	0.225	269.1	208.6	0.042	298.7
				M_6	0.040	151.4	0.042	206.6	0.051	181.4	244.5	0.027	334.5
				O_1	...	...	...	...	0.309	14.8	301.0	0.095−	211.0
				S_2	0.053	79.6	0.366	306.0	0.368	305.4	292.3	0.038	202.3
				C	0.192	...	−0.641	...	0.669	...	123.2	...	...
Between North Point and Alcatraz.	37 48 40	G. Bradford	Oct. 29–31, 1874	K_1	...	...	...	...	0.384	26.7	...	...	...
	122 25 03			M_2	...	...	...	...	1.882	268.5	...	...	...
				M_4	...	...	...	...	0.058	310.9	...	...	...
				O_1†	...	...	...	...	0.423	8.9	...	...	...
				S_2†	...	...	...	...	0.242	273.1	...	...	...

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† By inference from Fort Point, Cal., tides.

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south: Amplitude	North and south: Epoch	East and west: Amplitude	East and west: Epoch	Resultant flood: Amplitude	Resultant flood: Epoch	Resultant flood: True azimuth	Minimum after flood: Amplitude	Minimum after flood: True azimuth
	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
SAN FRANCISCO BAY—continued.													
Off Telegraph Hill	37 48 08	G. Bradford	Oct. 27-29, 1874	K_1	....	....	....	....	0.429	40.6	....	....	....
	122 23 53			M_2					1.610	249.4			
				M_4					0.101	66.6			
				O_1†					0.270	22.8			
				S_2†					0.362	254.0			
....	37 47 46	....do	Oct. 15-17, 1874	K_1	....	....	....	....	0.266	11.1	....	....	....
	122 23 29			M_2					1.536	250.9			
				M_4					0.259	230.1			
				O_1†					0.167	353.3			
				S_2†					0.346	255.5			
Between Pacific Mail Steamship Co. wharf and Yerba Buena.*	37 48 03	Edw. Cordell	Mar. 26-31, 1866	K_1	0.400	200.6	0.477	311.9	0.520	334.2	318.7	0.341	80.7
	122 23 14			M_2	1.505	83.9	0.987	266.2	1.800	264.6	343.3	0.033	253.3
	16°.5 E.			M_4	0.054	323.7	0.077	96.9	0.087	110.2	317.5	0.035−	47.5
				O_1†	0.252	182.8	0.300	294.1	0.327	316.4	318.7	0.214	80.7
				C	0.908		−0.271		0.948		180.2		
Off Rincon Rock*	37 47 14	....do	Nov. 3-6, 1865	K_1	0.242	209.9	0.039	48.0	0.245−	30.3	7.7	0.012	277.7
	122 23 07			M_2	1.429	79.4	0.402	262.2	1.485−	259.6	0.8	0.019	270.8
	16°.5 E.			M_4	0.081	272.9	0.145+	150.8	0.153	141.9	306.7	0.065−	216.7
				O_1†	0.152	192.1	0.025−	30.2	0.154	12.5	7.7	0.008	277.7
				C	0.418		0.057		0.422		204.3		
Off Long Bridge wharf, Mission B.*	37 46 07	....do	Nov. 22-24, 1866	K_1	0.152	205.6	0.126	42.3	0.195−	32.3	337.1	0.028	247.1
	122 23 06			M_2	1.136	77.2	0.387	260.5	1.200	257.5	357.7	0.021	267.7
	16°.5 E.			M_4	0.101	257.1	0.098	91.1	0.140	83.9	332.5	0.017	242.5
				O_1†	0.096	187.8	0.079	24.5	0.123	14.5	337.1	0.018	247.1
				C	0.229		−0.027		0.231		189.8		
Between Pacific Mail Steamship Co. wharf and Oakland.*	37 47 16	....do	Apr. 1-6, 1866	K_1	0.218	210.7	0.280	45.9	0.352	40.2	324.1	0.045+	234.1
	122 22 27			M_2	1.795−	85.5	1.281	272.0	2.202	267.7	341.0	0.118	251.0
	16°.5 E.			M_4	0.107	327.0	0.054	190.4	0.115	154.1	354.1	0.035−	264.1
				O_1†	0.137	292.9	0.176	28.1	0.221	22.4	324.1	0.028	234.1
				C	0.059		0.131		0.181		261.3		

* For stations marked thus (*) results to the left of the double line refer to magnetic direction; all other results refer to true direction.

†By inference from Fort Point, Cal., tides.

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south: Amplitude	North and south: Epoch	East and west: Amplitude	East and west: Epoch	Resultant flood: Amplitude	Resultant flood: Epoch	Resultant flood: True azimuth	Minimum after flood: Amplitude	Minimum after flood: True azimuth
SAN FRANCISCO BAY—continued.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Northward of Point Avisadero*	37 44 30	G. Bradford	Dec. 7–9, 1874	K_1	....	....	....	....	0.342	15.4	....	....	....
	122 21 53			M_2					1.526	273.7			
				M_4					1.217 (?)	147.4 (?)			
				O_1†					0.215	357.6			
				S_2†					0.343	278.3			
Northward from Point Avisadero*	37 44 04	....do	Dec. 10–12, 1874	K_1	0.289	185.1	0.154	4.8	0.327	5.0	332.0	0.001	62.0
	122 21 39			M_2	1.450	89.6	0.759	263.4	1.635	268.3	332.4	0.073	62.4
				C	−0.134		−0.042		0.140		17.4	....	
Southeast of Yerba Buena*	37 48 06	A. F. Rodgers	Oct. 16–18, 1862	K_1	0.730	173.9	0.289	319.7	0.769	350.0	357.6	0.154	87.6
	122 20 57			M_2	1.125	93.5	1.160	268.1	1.614	270.7	330.6	0.076	60.6
	16°.5 E.			C	0.125		0.104		0.163		236.3		
ALASKA, BERING SEA.													
Off Nunivak Island	60 02 58	Capt. J. F. Pratt	Aug. 6–8, 1902	M_2	0.287	95.5	0.325	271.6	0.434	93.4	131.5	0.015	221.5
	167 15 00			C	0.268		−0.054		0.273		168.6		
Off Cape Romanzof*	61 48 48	....do	Aug. 30–Sept. 2, 1899.	K_1	0.367	48.7	0.390	55.9	0.535	52.5	246.2	0.034	336.2
	166 06 38			M_2	0.608	273.6	0.698	264.9	0.923	268.7	248.5	0.070	158.5
				O_1	0.200	23.7	0.218	30.9	0.300	27.5	246.2	0.019	336.2
				C	0.135		−0.003		0.135		208.2		
Off Northeast Cape	63 16 04	....do	Aug. 9–13, 1902	M_2	1.545	101.9	0.397	104.5	1.595	102.1	194.4	0.018	284.4
	168 41 03			C	0.182		0.043		0.187		193.0		
West of Cape Nome*	64 26 ..	....do	Aug. 11–15, 1900	M_2	0.040	208.9	0.133	246.0	0.137	244.3	277.7	0.023	367.7
	165 02 ..			C	0.063		0.243		0.251		276.5		
Golofnin Bay*	64 28 14	....do	Sept. 11–24, 1899	K_1	0.174	252.6	0.029	186.4	0.174	252.0	205.9	0.026	115.9
	162 52 59			M_2	0.100	315.6	0.020	74.4	0.100	314.6	196.3	0.017	286.3
				M_4	0.011	192.1	0.008	148.0					
				M_6	0.010	271.6	0.019	82.7					
				M_8	0.007	115.4	0.004	8.6					
				O_1	0.154	216.6	0.046	106.0	0.155	218.4	195.5	0.043	105.5
				S_2	0.028	27.6	0.011	176.4	0.030	24.0	182.8	0.005	272.8
				C	−0.215		+0.018		0.216		17.2		

* For stations marked thus (*) results to the left of the double line refer to magnetic direction; all other results refer to true direction.

† By inference from Fort Point, Cal., tides.

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
ALASKA, BERING SEA—cont'd.	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Off Port Safety*	64 28 30	Capt. J. F. Pratt	July–Aug., 1900	M_2	0.056	177.1	0.096	181.9	0.111	180.7	260.4	0.004	350.4
	164 40 ..			C	−0.064		−0.282		0.289		98.0		
Off Nome Army Post*	64 28 35	....do	July 28–Oct. 8, 1900.	M_2	0.057	111.8	0.129	250.3	0.136	255.6	310.1	0.035	40.1
	165 18 30			C	0.048		−0.063		0.079		163.2		
Off Nome City*	64 29 30	....do	Aug. 3, 4, 15, 16, 21–23, 1900.	M_2	0.074	109.9	0.115	236.9	0.125	248.9	316.9	0.054	46.9
	165 25 00			C	0.033		−0.153		0.157		122.7		
Off Penny River*	64 31 30	....do	Aug. 8–24, 1900.	M_2	0.062	262.8	0.191	352.8	0.191	352.8	290.2	0.062	20.2
	165 44 ..			C	0.051		0.058		0.077		248.9		
East of Tapkok Bay*	64 32 ..	....do	July 21–Aug. 1, 1900.	M_2	0.090	309.8	0.126	93.4	0.148	104.8	324.8	0.045	54.8
	163 51 ..				−0.002		0.011		0.014		300.0		
Off Solomon City*	64 32 20	....do	July 26–28, 1900	M_2	0.075	189.8	0.150	179.8					
	164 24 30			C	−0.209		−0.182		0.277		262.2		
Port Clarence*	65 15 00	....do	Aug. 30–Sept. 20, 1900.	K_1	0.066	44.6	0.089	118.2	0.093	103.7	269.5	0.061	359.5
	166 22 10			M_2	0.060	137.7	0.044	203.5	0.064	153.7	227.2	0.037	317.2
				M_4	0.016	174.6	0.008	108.9					
				M_6	0.021	336.8	0.011	259.1					
				M_8	0.006	125.9	0.006	327.2					
				O_1	0.016	200.6	0.048	284.9	0.048	284.2	288.9	0.016	18.9
				S_2	0.026	227.5	0.021	27.4	0.033	219.7	252.5	0.006	342.5
				C	−0.110		−0.099		0.148		63.0		
Inside Cape Spencer*	65 16 28	....do	Sept. 22–Oct. 5, 1900.	K_1	0.047	75.6	0.021	342.2	0.047	256.4	18.1	0.021	288.1
	166 45 10			M_2	0.081	285.0	0.087	107.2	0.112	106.1	333.0	0.002	243.0
				O_1	0.054	246.1	0.118	1.1	0.121	6.4	303.0	0.048	33.0
				S_2	0 034	61.3	0.069	291.0	0.073	284.0	310.0	0.025	220.0
				C	0.140		0.074		0.158		172.1		

*For stations marked thus (*) the results to the left of the double line refer to magnetic direction; all other results refer to true direction.

Table of harmonic constants—Continued.

Station	Latitude and longitude, magnetic variation	Observing party	Date	Component	North and south		East and west		Resultant flood			Minimum after flood	
					Amplitude	Epoch	Amplitude	Epoch	Amplitude	Epoch	True azimuth	Amplitude	True azimuth
NORTH SEA	° ′ ″				*Knots*	°	*Knots*	°	*Knots*	°	°	*Knots*	°
Terschellingerbank	53 27 00	Discussion by J. P.	1898–1899	M_2	0.839	169.5	1.145	189.0	1.,00	182.3	235	0.229	325
	4 51 36	Van der Stok		M_4	0.035	294.6	0.034	343.9	0.046	315.6	221	0.018	311
		Études des Phénomènes de Marée,		S_2	0.186	230.6	0.256	251.0	0.311	244.2	235	0.053	325
		etc.		C					0.119		233		
Haaks	52 57 48	do	1898–1899	M_2	1.309	123.7	0.319	155.7	1.337	125.2	192	0.166	282
	4 18 18			M_4	0.083	261.6	0.016	69.0	0.084	261.6	189	0.008	279
				S_2	0.256	183.5	0.062	213.8	0.263	184.9	192	0.031	282
				C					0.138		178		
Maas	52 01 18	do	1898–1899	M_2	0.893	75.8	0.648	86.4	1.199	79.4	216	0.097	306
	3 53 54			M_4	0.054	115.2	0.052	66.9	0.069	91.9	224	0.031	134
				S_2	0.208	137.1	0.163	146.8	0.261	140.7	219	0.021	309
				C					0.119		190		
Schomvenbank	51 47 18	do	1898–1899	M_2	0.936	75.0	0.762	55.2	1.190	64.7	219	0.202	129
	3 27 18			M_4	0.075	71.8	0.095	60.8	0.121	65.9	232	0.011	142
				S_2	0.259	134.6	0.233	115.4	0.344	126.1	222	0.058	132
				C					0.092		212		
Noord Hinder	51 35 24	do	1890–1894	M_2	1.164	56.5	0.455	22.8	1.226	52.5	199	0.237	109
	2 36 36			M_4	0.107	6.9	0.050	1.4	0.118	5.8	205	0.005	115
				S_2	0.293	107.4	0.209	81.7	0.352	99.0	200	0.075	110
				C					0.042		201		

Results refer to true direction.

CHAPTER VII.

TIDAL CURRENTS IN RELATION TO MARINE ENGINEERING.

98. Upon comparing rivers which discharge into inland seas with those discharging into tidal waters, it will at once be noticed that all estuaries belong to the latter class. Bars resulting from the deposit of alluvial matter are frequently found at the mouths of rivers of both classes, but deltas are more characteristic of rivers discharging into bodies of water having small tides.

It will be noticed that narrow straits connecting the ocean with bays, harbors, ports, or so-called lakes are frequently much deeper than the near-by waters off either end. Where the water is shallow and the current strong, as at the mouth of an estuary, the material easily moved will arrange itself in ridges extending in the direction of the flood and ebb. For, an obstacle upon the bottom will cause a deposition on either side of it—on the one side during the flood and upon the other during the ebb. In a somewhat similar manner a cape, around which the current flows, may be extended into a hook, the hook extending toward the inward side protected from the action of the waves; or it may protect, as it were, a narrow shoal. Again, if rocks are scattered over a bottom easily eroded, the eddying effect of the impinging streams will produce an excavation upon either side of the rocks.

99. *Tidal rivers.**

The scouring action of the tide goes on more or less at all parts of a river; the eroded matter is, upon the whole, driven seaward because the ebb stream is somewhat stronger than the flood stream owing to its smaller cross section and to the natural discharge of the river. The portion of the river meeting the ocean is often more favorably situated for scour than the other portions owing to the facility with which the eroded matter, much of which is held in suspension, can be dispersed through the action of the waves and currents; hence, the greater depth between the capes. Where the ebb stream loses a large portion of its velocity, matter driven or carried by the water will be deposited. As a rule, a bar will thus be formed off the mouth of the river. The action of the waves will take away the soluble matter, leaving the bar composed mainly of sand and shingle.

Tidal currents whose direction some distance offshore is that of the general shore line, are of great importance in preventing the formation of a bar. For example, the rivers discharging into Chesapeake Bay have no bars, because the tidal streams of the bay, although not strong are yet sufficient to drive away any accumulation off the river mouths. Again, the tidal streams of the North Sea prevent the formation of bars off the estuary of the Humber and the Wash. On the other hand, stationary tidal waves in which the particles move to and from the shore permit the formation of bars

*For the law governing the forms of tidal rivers under certain conditions, see section 33.

and deltas. For example, the Atlantic coast of the Southern States, northwestern coast of Brazil, the coasts of India. (See Figs. 14, 22, 16, Part IV B.)

As a rule, bars do not occur as frequently off broad estuaries and bays as off rivers and estuaries of moderate width. The broader the estuary the greater is the dispersive effect of wind waves and littoral currents. On the other hand, an island or shoal lying a short distance offshore and to the right or left of the estuary might cause a bar to be formed, even where the currents along the shore are considerable, because the effect of these currents is much reduced by the intervention of the island or shoal. Similarly for a cape or headland extending outward from the shore.

Sand will be driven along the bottom if the velocity there be 0.4 knot; fine gravel, if about 1 knot; shingle, about 1 inch in diameter, if 2.5 knots; angular stones, about $1\frac{1}{2}$ inches in diameter, if 3.5 knots.

The wind waves play an important part by disintegrating the rocks along the shore and driving about beds of sand and gravel lying beneath the shallow waters. Such effects may even close up the mouths of small streams and divert the lower part of their courses.

100. *On the training of tidal rivers.*

In training a tidal river so as to aid in the production and maintenance of a good depth, two things are of prime importance: 1° The elimination of irregularities of shore line and of depth; 2° the conserving of the tidal volume.

(1) Irregularities of shore line may be gradually effaced by means of groins extending outward from the banks toward the channel. These may be extended from time to time as the material deposited through their agency accumulates. Finally, when the channel becomes sufficiently regular a permanent wall along either bank, and connecting the extremities of groins, should be constructed. This greatly reduces all minor irregularities which the groins alone would occasion.

The river thus brought to a channel having regular banks will exert a scouring effect upon irregularities of depth. However, on account of the hardness or compactness of the river bed some dredging is generally required. With the river properly trained laterally, the work of dredging is greatly facilitated by the increased scour of the stream.

It is evident that a training wall or pier should extend seaward to deep water, otherwise it will act as a groin in impeding the littoral currents and causing a deposit to be formed in the channel near its mouth.

Unless the piers are to form a harbor of refuge and a protection for the entrance to the river, they should not converge but rather should diverge in a manner somewhat analogous to the banks of an estuary; for, besides causing swift currents at the outer ends, a too narrow opening greatly impedes the entrance of the tidal wave. This remark does not apply to a basin-like harbor, which is in no sense a tidal estuary. In this case the motion through the entrance to the harbor will be chiefly hydraulic in character. Converging piers are then advantageous, because the area between them constitutes an addition to the impounded water, and because the narrowness of the entrance enables the tide to there exert a scouring effect in the channel.

In some instances one sea wall may be a sufficient protection for the channel. This should be situated upon the side exposed to drift whether resulting from wind or tide or other current, and should generally be concave toward the protected channel. The outer end of the wall, which should reach deep water, therefore trends in approximately the direction of the movement of the littoral current. Some engineers do not follow this rule of making the jetty concave toward the channel. See a paper by T. W. Symons and discussions thereon, in the Transactions of the American Society of Civil Engineers, Vol. 36 (1896), pp. 109–138.

Where the tide is of little consequence in comparison with the current proper of the stream, parallel walls or jetties are commonly used for deepening the channel by scour and with good results. Such are the jetties constructed by James B. Eads at the outer end of South Pass of the Mississippi Delta. The channel thus narrowed quickly increased in depth. The jetties cause the deposits of the river to be made so far out from the Delta that littoral currents are highly effective in transporting the material elsewhere.

In some cases no sea wall need be constructed if advantage is taken of the most natural course of the streams through the shallow bay or estuary. The main channel of the stream having been selected, all shallow portions of its bed are deepened by means of dredging, and the material taken out used as advantageously as possible in building up shoals or closing up undesirable passages. The improvement of the entrance to New York Harbor on a plan proposed by Major (now General) Gillespie is a conspicuous example of this method.

(2) The deepening of the channel permits the tide to flow with less resistance, and so the range may be increased in the upper portion of the river. An increased range means an increased tidal volume available for scouring. This often means greater velocity for the water particles. In fact, by (142),

$$v=\zeta\sqrt{\frac{g}{h}},$$

where ζ is the height of the tide above the undisturbed surface—that is, the velocity of the current is directly proportional to the amplitude of the tide and inversely proportional to the square root of the depth. Hence, whether or not the velocity at any section will be increased, depends upon how the amplitude of the tide is affected by the increase in depth.

If the river and estuary are so short and so formed that the tide wave is largely stationary, the velocities in some portions may become greatly reduced. The training, deepening, and extension of the tidal river will cause the tidal movement to be propagated with less irregularity and the current to become generally stronger.

If, however, it is not possible to extend the tidal river, as would be the case where rocky formations occur near the head of tide water, it becomes especially important to preserve broad flats as tidal reservoirs. Being usually covered with vegetable growth they offer no serious menace to the near-by channels.

In some instances artificial tidal reservoirs are used for flushing out channels or harbors.* By means of gates a large volume of water from the reservoir can be made to flow out in a comparatively short time, thereby making the scouring effect considerable.

*Thomas Stevenson: The Design and Construction of Harbors, 3d ed., pp. 301–305.

A lake-like broadening of a tidal river is generally serviceable in maintaining the depths at the portions of the river below it. However, the broadening and subsequent contraction should, if possible, be gradual, in order that no great amount of energy be lost by the change of cross section.

The following tidal rivers or estuaries along the coasts of the United States have bars off their mouths: Connecticut River; Hudson River; Winyah Bay; Charleston Harbor; Stone Inlet; North Edisto River; St. Helena Sound; Port Royal Sound; Tybee Roads; Savannah River; Ossabaw Sound; St. Catherine Sound; Sapelo Sound; Doboy Sound; Altamaha Sound; St. Simon Sound; St. Andrews Sound; Cumberland Sound; Nassau Sound; St. Johns River; Mississippi River; Brazos River; Coos Bay; Columbia River; Willapa Bay; Grays Harbor. Nearly all of these bars have been improved by dredging and jetties.

The following are a few references to papers and books relating to the improvement of tidal rivers and harbors:

D. Stevenson: Canal and River Engineering.

E. L. Corthell: A History of the Jetties at the Mouth of the Mississippi River, New York, 1881.

Thos. Stevenson: The Design and Construction of Harbors, Edinburgh, 1886.

L. F. Vernon-Harcourt: The principles of training rivers through tidal estuaries, as illustrated by investigation into the methods of improving the navigation channels of the Estuaries of the Seine, Proc. Roy. Soc. of London, Vol. 45 (1888–89), pp. 504–524.

W. H. Wheeler: Tidal Rivers, London, 1893.

Maj. C. E. Gillette: Seacoast Harbors in the United States, Trans. Am. Soc. of Civil Engineers, Vol. 54 (1904), Part A, pp. 297–324, also papers and discussions by others, Ibid., pp. 325–451.

J. N. Schoolbred: The tidal régime of the River Mersey, as affected by recent dredging at the Bar in Liverpool Bay, Proc. Roy. Soc., Vol. 78 (1906), pp. 161–166.

The reports of harbor commissioners of various cities and states contain many details bearing upon this subject.

101. *Harbors, bays, or lakes connected with the sea by means of a narrow strait.*

Knowing the rise and fall of tide off the outer end of the strait, also the dimensions and depths of the strait and inner body, it is not difficult to ascertain the velocity in the strait at any time, provided that the inner body is sufficiently deep in comparison with its horizontal dimensions for remaining sensibly level and the strait is but a small part of a wave-length long. For then the motion will be nearly steady and Bernoulli's theorem with resistance will apply. See sections 104–106, Part IV A, and sections 9, 15–17, Part V.

If $\zeta_{,}$, $\zeta_{,,}$ denote the heights of the surfaces of the outer and inner bodies, then

$$v=\sqrt{2g}\times\sqrt{\zeta_{,}-\zeta_{,,}}\times\frac{1}{\sqrt{1+\zeta'\frac{lP}{\Omega}}}\cdot$$

The average value of $\sqrt{2g}$ is 8.0215. The empirical coefficient ζ' is, according to Eytelwein, 0.007565; other values are given in section 8. $\frac{\Omega}{P}$, the hydraulic mean depth, is, for most straits, nearly the average depth, or $\frac{\Omega}{b}$, b denoting the breadth at the surface. If the value of $\zeta' \frac{lP}{\Omega}$ is many times unity, as might be the case in a strait of considerable length, the above reduces to Chézy's formula

$$v=c\sqrt{\text{mean depth} \times \text{slope of surface}},$$

wherein $c=92\frac{1}{4}$ if ζ' has Eytelwein's value.

When the dimensions and depths are such that at any given time the flow through the strait is not practically steady, the problem becomes one of great difficulty, and will not be considered here.

In soil which is easily eroded, the swift currents produce and maintain a deep tideway between the outer and inner bodies. Off the outer end of the strait a bar is generally formed, and in some instances off the inner end also. Dredging is usually required at the bar, and the channel thus constructed should be protected by jetties against detritus from the neighboring banks and shoals. The jetties should be parallel or slightly convergent and should extend outward into as deep water as may be practicable, in order that the subsequent dredging may be reduced to a minimum.

The action of the waves upon the beach may cause fine matter to become suspended in the outside water. The flood stream thus discolored will, upon passing the strait, deposit this fine material upon the bottom and shores of the quiet inner body. The ebb stream will be comparatively clear. Thus it is seen that lagoons along the coast may receive sedimentary deposits from the waters outside as well as from the fresh-water streams which may discharge into them.

Examples of erosion in straits.—Lake Pontchartrain and the Rigolets passes. The larger pass at one point reaches the extraordinary depth of 95 feet, and the smaller one (Chef Menteur Pass) the depth of 90 feet. A bar covered by from 1 to 6 feet of water lies off the inner ends of the passes. Rockaway Inlet, leading to Jamaica Bay, New York, is at one point 57 feet deep, while the depth across the bar ranges from nothing to 16 feet. The average depth of San Francisco Bay is less than 10 fathoms. At its narrowest portion the depth of the Golden Gate reaches 60 fathoms. A nearly continuous bar, covered by from 4 to 6 fathoms of water and having a semicircular form, lies to the west of the Golden Gate. The center of the circle is 4.8 miles from Fort Point, and the radius is 2.7 miles.

Other examples along the eastern coast of the United States are Robinsons Hole, Massachusetts; Hatteras Inlet; Ocracoke Inlet; inlet opposite Beaufort, N. C.; New River Entrance; Cape Fear River Entrance; Boca Grande; Charlotte Harbor; West Pass, Apalachicola Bay; entrance to Pensacola Bay; entrance to Mobile Bay; Grand Pass, Barataria Bay; South West Pass, Vermilion Bay; entrance to Galveston Harbor; Pass Cavallo; Aransas Pass; Corpus Christi Pass. All of these inlets have bars outside the capes; in numerous instances they have been improved by dredging and the construction of jetties.

102. *Destructive effects due chiefly to wind waves.*

The destructive effects of the waves during severe storms upon an exposed coast line are frequently so great as to cause much alarm in the locality affected, and to justify the expenditure of large sums of money in preventing them. The power of waves to tear down land is made far more effective where a littoral current, tidal or otherwise, is sufficiently strong for carrying away much of the matter thus brought into the reach of the sea. Where no such current exists, the tendency to form a protecting shoal along the exposed coast is greatly increased.

According to an estimate of Prof. W. M. Davis, all of the mainland of Cape Cod Peninsula north of the bend will be consumed by the waves in eight or ten thousand years.

According to Edward A. Martin, F. G. S., the coast denudation for England has amounted to 41378 acres in thirty-three years (1867–1900).

103. *The formation or arrangement of shoals.*

Through the encroachment of the sea upon the land, particularly noticeable after heavy storms, the near-by waters become discolored by the soluble ingredients of the soil, while the heavier matter remains on the bottom, comparatively near to the scene of the erosion. In this manner beds of sand and shingle are formed.

Immense quantities of alluvial matter are brought to the shallow waters of the sea through the agency of rivers. Besides forming shoals and bars off the mouths of these streams, as was mentioned in section 98, this material, through the action of the waves and currents, is scattered and transported to near-by localities favorable to the formation of shoals, islands, and shore extensions. It is, however, difficult to say how much of the material composing the shallow bed of the ocean adjacent to the shore is transported from river mouths and how much is due to the degradation of the coast line. Maps of soundings constitute almost the only guide in this matter. It will be noticed that the alluvium in the littoral waters, which is continually forming shoals and lowlands, is especially abundant in the vicinity of river mouths.

The effect of currents becomes conspicuous only where their velocity at the bottom is in excess of 0.3 knot. Shoals thus formed, or at least modified, often appear as ridges whose direction coincides with the lines of flow of the maximum current. Any sunken object may serve as the nucleus of a detached shoal. The sand driven along the even bottom will be arrested if it come in contact with an object constituting an irregularity in the bottom. Both flood and ebb currents may bring up sand, and from both directions. Such shoals occur in the following localities: In the North Sea, especially off Lincoln, Norfolk; in the Thames Estuary; off Belgium and between Holland and Norfolk; southeast of Nantucket Island, Massachusetts; south of Cornfield Point, Connecticut; eastern end of Vineyard Sound; Lower New York Bay; Delaware Bay; off Chincoteague Island; Chesapeake Bay Entrance; Essequibo River; and the Gulf of Cambay.

As time goes on, shoals of this kind may rise to the surface and become low, flat islands. But even before they reach the surface the ordinary action of the wind waves may be to drive the sand higher and higher upon the shoals, and so to facilitate their growth, just as heavy matter is being continually washed ashore.

A cape or point sometimes serves to check the motion of the water, and thus aid in the formation of a shoal,—e. g., shoal northeasterly from Great Point, Nantucket Island; Hen and Chickens Shoal, Cape Henlopen; and Hampton Bar, Old Point Comfort.

104. *Littoral drift, deposition, and beach formation.*

In driving material along the foreshore, the influence of the flood stream is much greater than that of the ebb, and so, as a rule, determines the prevailing direction of the drift; for, the material available for transportation results from the disintegration of rocks and soil, which process goes on above high-water mark, and is by the action of the destroying waves brought more within reach of the flood stream than within that of the ebb. Littoral drift is frequently due chiefly to the repeated impacts of wind waves. In fact, stones more than an inch or two in diameter could seldom be moved by tidal currents alone. Moreover there is abundant evidence of such drift in tideless lakes and seas. Wind waves deposit sand and stones upon the shore because the material driven along the bottom beneath the crest of the wave continues to advance as long as the water immediately surrounding it moves shoreward.

In this way sand and stones are driven high upon a shelving beach, the kinetic energy possessed by the moving material and surrounding water being consumed or converted into potential energy in the process. The receding wave can not move all of the stony material thus brought in, because energy must be consumed in moving and imparting velocity to it; the returning current is too feeble at and near the highest point reached by the wave to produce the necessary impact.

Whether matter is held in suspension or driven along the bottom, deposition will take place whenever the velocity of the water becomes sufficiently reduced. Therefore, if any current follows the shoreline and if groins or piers be extended outward, comparatively still water will be found between the groins; and in the course of time solid matter will there be deposited. In this way the lines of high and low water may be carried seaward.

If a straight sandy coast turns suddenly away from the sea, a sharp point or narrow arm may spring from the angle and take the original direction of the coast, although its extreme tip, forming a hook, may be continually directed inland, receiving its direction from the flood tide or incoming waves.

The streams along the coast following the general direction of a growing arm can not turn aside immediately upon arriving at its extremity. There comparatively slow streams and even eddies favor the growth of the arm. A hook results when the end of the arm is so rounded off that the flood stream can follow it well and so drive matter inward before losing too much of its velocity. The effect of the ebb is to turn the hook in the opposite direction or outward. Hence, when the rise and fall of tide is great, the effect of the flood (where the tide is progressive) upon the foreshore will exceed that of the ebb and there will result a hook turning inward. But where the rise and fall of the tide is not great (or where the tide is stationary), a slender arm may be extended through shallow water and form a nearly straight beach, although the advancing end will often be turned slightly inward; e. g., Rockaway Beach and Coney Island. When a hook of considerable extent is formed at the end of the arm, the effect will be that of a receding shoreline, and under some suitable circumstances another and much smaller arm will be formed following the direction of the outer shore of the main arm. This will grow, and finally become hooked. Another slender arm may form an extension of the outer shoreline; and so on. The result will be an arm whose outer shore is nearly straight while the inner shore is indented with bays. Sandy Hook is an example of this mode of growth. The deep water east of this peninsula indicates that the tidal streams in conjunction with the winds are responsible for its origin and growth. But Mitchell says (p. 108, Coast Survey Report, 1873):

> The material forming Sandy Hook is swept up from Long Branch coast by the diagonal wash of the sea. This was placed beyond dispute by my observations of 1857. Materials of the same specific weight as the sand were placed in the sea at many different points down the outside shore, and at different distances off shore. Those within the action of the waves breaking near the shore were swept along to the northward, and finally collected at the point of the Hook. Those placed far off shore never came to land, so that I concluded that the tidal currents took very little part in the transaction.

In these cases of shore extension it is almost certain that the wind waves play an important part both by facilitating littoral drift and by building slender strips or beaches in shallow waters, as will be presently described. That the extremities of beaches hook or turn inland does not prove that their extensions are due to the flood tide; for, similar forms occur around the Great Lakes and the Black Sea. Moreover, large waves, which chiefly cause the drifting of material, can only arise when the "fetch" is considerable, which implies an on-shore wind.

Generally speaking, beaches are formed by the action of the waves in shallow water upon the detritus there occurring. The result is a slender strip of sandy beach remarkable for its straightness, particularly upon its outer side. The axis of such a beach generally follows what probably was a contour line before the existence of the beach. For the ocean, this contour line probably lay 4 or 5 fathoms below ordinary low water; for the Gulf of Mexico 3 or 4 fathoms, and for shallow bays 2 or 3 fathoms. Why a shoal should originate in waters of these depths is a question difficult to answer with certainty; but the following is probably a partial explanation:

Owing to the shelving character of the sea bottom along the coast, an on-shore wind will cause the surface (troughs and crests of waves being averaged) to assume a slope. This will cause the water at the bottom to flow seaward.* This seaward current becomes feebler as the water becomes deeper. At some depth it will fail to drive sand before it, deposition will take place, and a bar be formed along a certain contour line. As the bar grows in height, the current may be somewhat stronger than before immediately over the bar, but the bar itself would serve to intercept the detritus while being driven seaward. Finally, when the shoal approaches the surface of the water, the waves become more like waves of translation and throw up sand and other material as if breaking upon the original shoreline. Such waves produce an evening and compacting effect, thus explaining why the outer side of a beach is more regular than the inner. If separate islands are formed, currents will aid the wind in joining them together through process of beach extension.

The beaches in the following localities are examples of those probably formed chiefly by the waves, but usually modified or cut by the tidal currents. At the mouths of rivers, bays, and harbors, beaches extend from the land. Besides the deposition received from the recoil or wind waves, another usually occurs as a result of wind waves and current driving material along the margins of the narrow strips of land, causing extension:

Islands of Nantucket, Chappaquiddick, and Marthas Vineyard; southern coast of Long Island; the coast of New Jersey; the coast of North Carolina; the coast of

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* Cf. Thomas Stevenson: The Design and Construction of Harbors. 3d Ed., pp. 300–301.

Louisiana; the coast of Texas; Bolinas Lagoon; Humboldt Bay; Coos Bay; Tillamook Bay; mouth of the Columbia River; Willapa Bay; Grays Harbor; Drayton Harbor; Port Clarence; southern coast of England.

If but one cape at the entrance to a bay or river receives an extension, this arm may crowd the channel up close to the opposite bank or even move the mouth of a river some distance along the coast. E. g. Beach at Yarmouth; Oxfordness Beach; beaches at the mouths of several rivers in Oregon. Great Point, Nantucket Island, is a beach extension. It is probable that sand and other material is not driven along the eastern foreshore of the island by tidal currents alone, but that the impact of the wind waves continually drives loose objects northward. Lieut. Charles H. Davis, U. S. Navy, has mentioned several wrecks on the southern shore of the island, and called attention to the fact that coal and even bricks from the wreckage were found inside of Great Point.* These could not have been driven along by tidal currents.

In the following localities are beaches (bars) formed almost wholly by wave action, including beach-extension processes: Sea of Azov; northern portion of the Black Sea; Mediterranean shore east of Alexandria; Prince Edward County, Sodus Bays, Toronto Harbor, and Burlington Bay, on Lake Ontario; Erie Harbor, Long Point Bay, Point Pelee, Sandusky Bay, and Maumee Bay, on Lake Erie; Tawas Harbor, Lake Huron; eastern and southern shores of Lake Michigan; Chequamegon Bay and Duluth Harbor, Lake Superior.

105. *The formation of spits or submerged capes.*

A sandy cape or point upon an alluvial shore is generally supplemented by a shoal or spit extending outward to a considerable distance from the land. The littoral tidal currents have their velocities suddenly diminished in passing the cape, because they are there largely deflected and turned into deeper water. By virtue of both flood and ebb, the spit generally takes a direction nearly normal to the coast line at the cape, thus differing from a beach extension. But these two classes of points are not always distinct, because a shore extension originates at an angle in the coast line. As time goes on more sand is deposited upon the point and shoals, and in this manner the point continues to grow until other agencies or altered conditions cause the growth to cease.

Shoals of this character extend outward from Capes Hatteras, Lookout, Fear, Romain, and Canaveral, the character of the coast favoring the formation of detritus necessary in the building of shoals.

Examples of smaller shoals off capes and even off gentle curves in the shore line which may deflect the streams outward may be found along the northern shore of Long Island. Examples of slender capes, formed like beaches chiefly by wave action, occur around the Peconic Bays and Gardiners Bay, Long Island.

If a spit occurs at the junction of two tidal rivers, it may be regarded as the only portion of a bar off the mouth of the smaller river which the larger river will permit to remain owing to its own considerable currents.

Examples of such spits are: York Spit; Rappahannock Spit; off Cape Virgenes, Argentina.

* A memoir upon the geological action of the tidal and other currents of the ocean. Memoirs of the American Academy of Arts and Sciences, Vol. IV, 1849.

Nearly all matter deposited along rocky coasts is to be found in bays where the velocity of currents is diminished.

The following are a few papers relating to changes in shore line and the formation of beaches:

H. Mitchell: U. S. Coast and Geodetic Survey Reports: 1871, Appendix 9; 1873, Appendices 9, 10; 1876, Appendix 9; 1886, Appendix 8; 1887, Appendix 6.

H. L. Marindin: Ibid., 1889, Appendices 12 and 13; 1891, Appendix 8; 1892, Appendix 6; 1896, Appendix 8.

G. K. Gilbert: U. S. Geological Survey Report, 1883–84.

W. M. Davis: The outline of Cape Cod, Proceedings of the American Academy of Arts and Sciences, Vol. 23 (1896), pp. 303–332.

E. A. Martin: Coast denudation in England, Knowledge, Vol. 3 (1906), pp. 348–350.

106. *Why deposition takes place near the inner shore of a bend.*

If we take, by way of experiment, a circular vessel partially filled with water, we can, by moving a paddle round and round, soon set up a circular motion or vortex. If finely divided material like corn meal or fine sand be scattered upon the moving liquid, it will before long be found to be collecting at the center of the bottom. An inspection of the paths of these particles will show that they are driven along the bottom spirally toward the center. The explanation of this is that because of the friction of the bottom on the liquid, the motion is there somewhat reduced in amount. If there were no resistance in the vessel, the surface would be in equilibrium with the force of gravity and the centrifugal force. Since resistance exists, particularly at the bottom, the centrifugal force is there less than at the surface. The surface adjacent to the vessel is lowered, because of the decreased motion of the underlying strata. Hence it is no longer in equilibrium, but its particles tend outward. Since the surface along the vessel is elevated too much to correspond with the centrifugal force due to the smaller velocity near the bottom, an inward pressure gradient must exist at the bottom. Hence the inward velocity.

If the velocity set up is ascertained by observing particles on the surface of the liquid, it will be found that the theoretical height, section 12, Part IV A, is not realized. This discrepancy is due to the fact that the velocities below the surface are considerably reduced.

Now, the outer shore of a bend in a river corresponds to the edge of the vessel of water, while the inner shore corresponds to an imaginary boundary of the central area.

107. *Power contained in the tide.*

If a natural or artificial reservoir be connected with a tidal body by a narrow channel or sluice, a considerable difference in level between the surfaces of the two bodies will generally exist. This difference reduces to zero once on each rise or fall of tide. If the surface of the reservoir rise or fall 1 foot, it will absorb or give up

$$(5280)^2 \times 64 = 1,784,217,600 \tag{302}$$

foot-pounds of work for each square mile of impounded areas, or

$$(6080)^2 \times 64 = 2,365,849,600 \tag{303}$$

foot-pounds for each square nautical mile, 64 pounds being the assumed weight of a cubic foot of sea water.

The average available fall is generally much less than the range of tide in the reservoir; for, even with sluice gates making it possible to fill the reservoir at nearly the time of outside high tide and to empty it at nearly the time of outside low tide, the average fall for any considerable period of filling or emptying will be much less than the range of tide. When no gates are employed, the difference in level between the two water surfaces at any given phase of tide can be computed by means of section 9, Part IV A. If the inner body is so large and so shallow that its surface does not remain practically level, then the question of available height difference becomes more complicated. A large natural body of water used as a tidal reservoir would generally present difficulties of this kind.

One horsepower requires 550 foot-pounds of work per second, or 1,980,000 foot-pounds per hour or 24,592,790 foot-pounds per half tidal day.

Hence, 1 foot of available fall between reservoir and sea, occurring four times daily, has a maximum possible yield of 145.100 horsepower for each square statute mile, or 192.402 for each square nautical mile.

Some natural bodies of water suitable for tide mills are St. John River, New Brunswick; Great Bay and Piscataqua River, New Hampshire; Vancouver, British Columbia; Burrard Inlet and Narrows, British Columbia.

In estuaries, broad rivers, and shallow bays, artificial bodies of water can generally be formed by means of piers or dikes built across the tidal flats and more or less extended, according to the shape of the coast line.

The following are a few references to the subject of tide mills:

Lord Kelvin: Popular Lectures and Addresses, Vol. II, pp. 437–440.

W. H. Wheeler: A Practical Manual of Tides and Waves (1906), pp. 170–173.

CHAPTER VIII.

CIRCULATION OF THE SEA, AND ANNUAL INEQUALITY IN THE TIDES.

108. *General causes of the winds.*

The heat of the sun causes expansion in the lower strata of air, especially in the Torrid Zone. These cause all superincumbent strata to be elevated above their equilibrium levels. By considering a surface of equal pressure in the higher regions of the atmosphere, it will be seen that the surface must dip poleward, and so the fluid particles at high altitudes must move away from the equator. (See Figs. 18 and 19.)

In section 11, Part IV B, it is shown that a body moving in the Northern Hemisphere is deflected to the right, while a body moving in the Southern Hemisphere is deflected to the left. Consequently, a body moving from the equator toward either pole is deflected to the east. According to this reasoning, the winds in the upper strata of the atmosphere of the Northern Hemisphere should blow from the south in the equatorial regions and southwest and west in higher latitudes; for the Southern Hemisphere the winds should blow from the north, northwest, and west. This is somewhat at variance with experience, especially in the lower latitudes.

The outflow of the air from high altitudes of the equatorial regions tends to diminish the pressure observed there upon the earth's surface. This is seen very near the equator, where the eastward motion is theoretically small, and so does not tend to crowd the matter toward the equator as much as does such motion a little farther north or south.

At the equator and at the poles the meridional motion of particles must be in general comparatively small, since these places mark the limits of the excursions of the particles. Now, the deflecting force due to the earth's rotation varies with the velocity of the particles and the sine of the latitude conjointly. The effect of this force upon the general circulation of the atmosphere is to so divert the pole-seeking particles in the various latitudes that the attainment of velocities exceeding certain values becomes impossible, and consequently to hold a quantity of the upper atmosphere near the equator which would otherwise have gone toward the poles. The velocities of the general atmosphere diminish as the equator is approached, and so in the tropical regions the deflecting force in the higher strata must be very small. From observation it is known that in the Northern Hemisphere a belt of high pressure exists having, over the oceans, its axis along approximately the thirty-fifth parallel of latitude, while the similar belt in the Southern Hemisphere follows approximately the thirtieth parallel. To restore the air carried poleward in high or tolerably high altitudes, return currents of less altitude are necessitated. Between the ridges of high pressure the countercurrents extend to the surface of the earth, and being deflected westward by the earth's rotation, produce the trade winds.

The belts of high pressure cause the lowest layers of the return current in the near-by regions of higher latitude to reverse, and for some distance, to move poleward. It is thus seen that, in the tropics the winds experienced at the earth's surface are counter currents of the movements in high altitudes, while just outside the subtropical high-pressure areas a portion of the countercurrent is reversed.

The connection between wind and pressure at the earth's surface is generally such that the air is flowing away from a high area and toward a low area, but the directions of the movements are greatly influenced by the deflecting force of the earth's rotation acting upon the moving surface air and upon the air in higher altitudes. In fact, the movements of air are often the cause rather than the results of pressure gradients. Near a region of low pressure the directions of the motions may nearly coincide with the directions of the isobars, but farther away directions become approximately normal to each other.

The alternate heating and cooling of large continental areas involves a falling and rising in the atmospheric pressure at that part of the earth's surface. The lower air flows toward such an area during the summer season, and out of it during the winter season. This is the origin of the monsoons.

109. *The prevailing winds over the surface of the oceans.*

The prevailing winds in the Atlantic Ocean between parallels 35° and 60° north come from the southwest or west. In a zone extending for 30° on either side of the equator, the easterly winds are remarkably constant, but not strong, and are known as trade winds. North of the thermal equator they come from northeast, and south of it from southeast. Between parallels 35° and 60° south the winds are generally from the west or a little north of west.

In the Torrid Zone of the Pacific Ocean the prevailing winds are easterly. South of 40° south latitude they come from the west or a little north of west; north of 40° north latitude they come from the southwest.

The winds of the Indian Ocean north of the equator are northeasterly during the winter season and southwesterly during the summer. In the winter a high-pressure area exists over eastern Asia, and in the summer a low-pressure area over southern Asia. South of 40° south latitude they generally blow from the west or northwest.

In all oceans the wind velocity is small near the equator.

Along the coast of Norway the winds are generally southwesterly. In that portion of the Arctic traversed by the *Fram* the winds blow from near the New Siberian Islands toward southeastern Greenland, where a low-pressure area exists. In the part of the Arctic Archipelago just north of Lancaster and Melville Sounds, the wind is from the north. At Point Barrow it is east-northeast. North of Greenland and Grant Land it is westerly or northwesterly during the summer season.

It will be seen upon comparing the isobaric chart with the charts of the winds that the air particles approach and swirl round areas of low pressure and recede, in a similar manner but with less velocity, from areas of high pressure. Rotations against the sun indicate low areas in the northern hemisphere and high areas in the southern, and vice versâ for rotation with the sun.

No. 18.

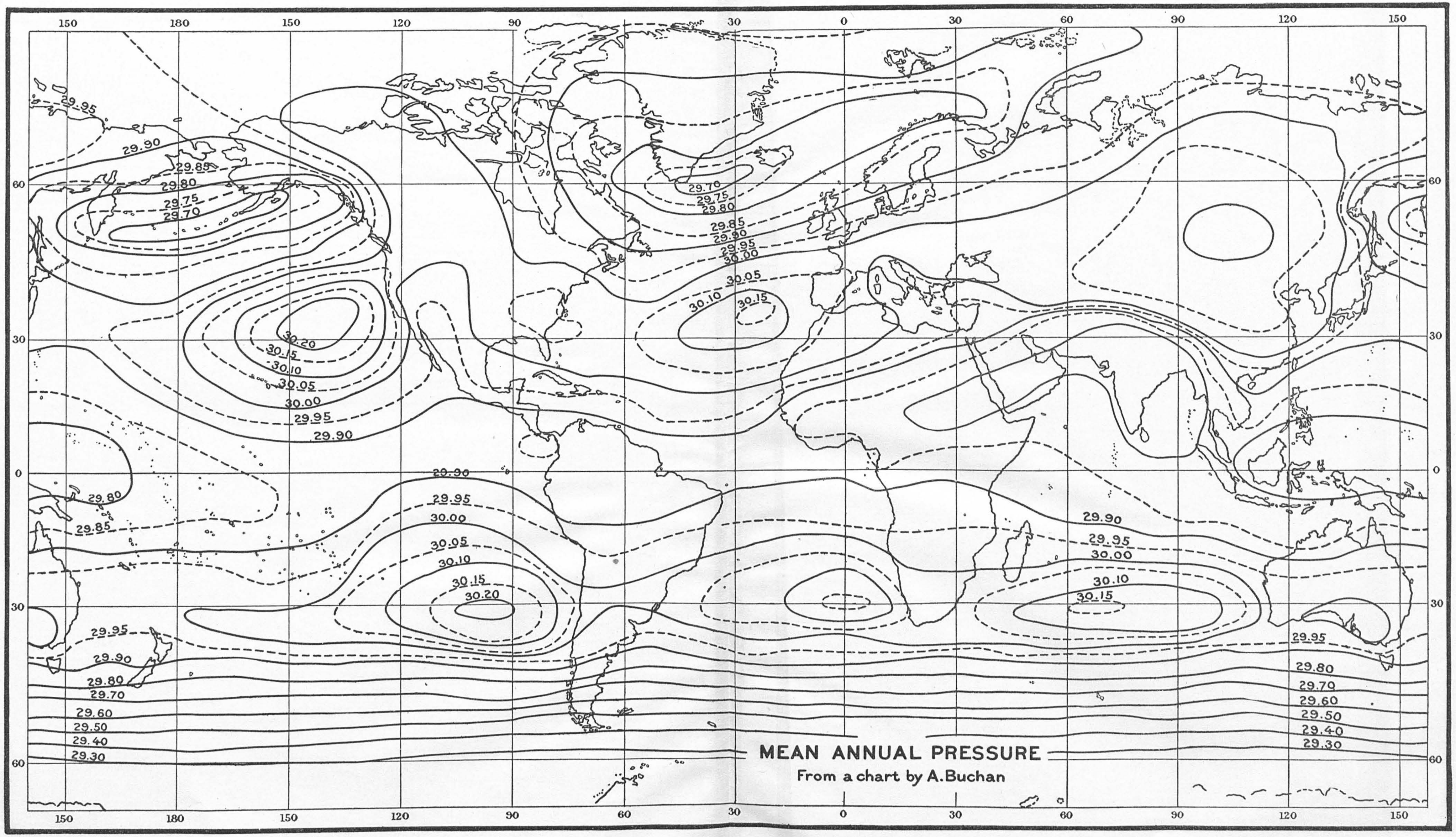


CHART OF ISOBARIC LINES. (FROM BARTHOLOMEW'S PHYSICAL ATLAS.)

No. 19.

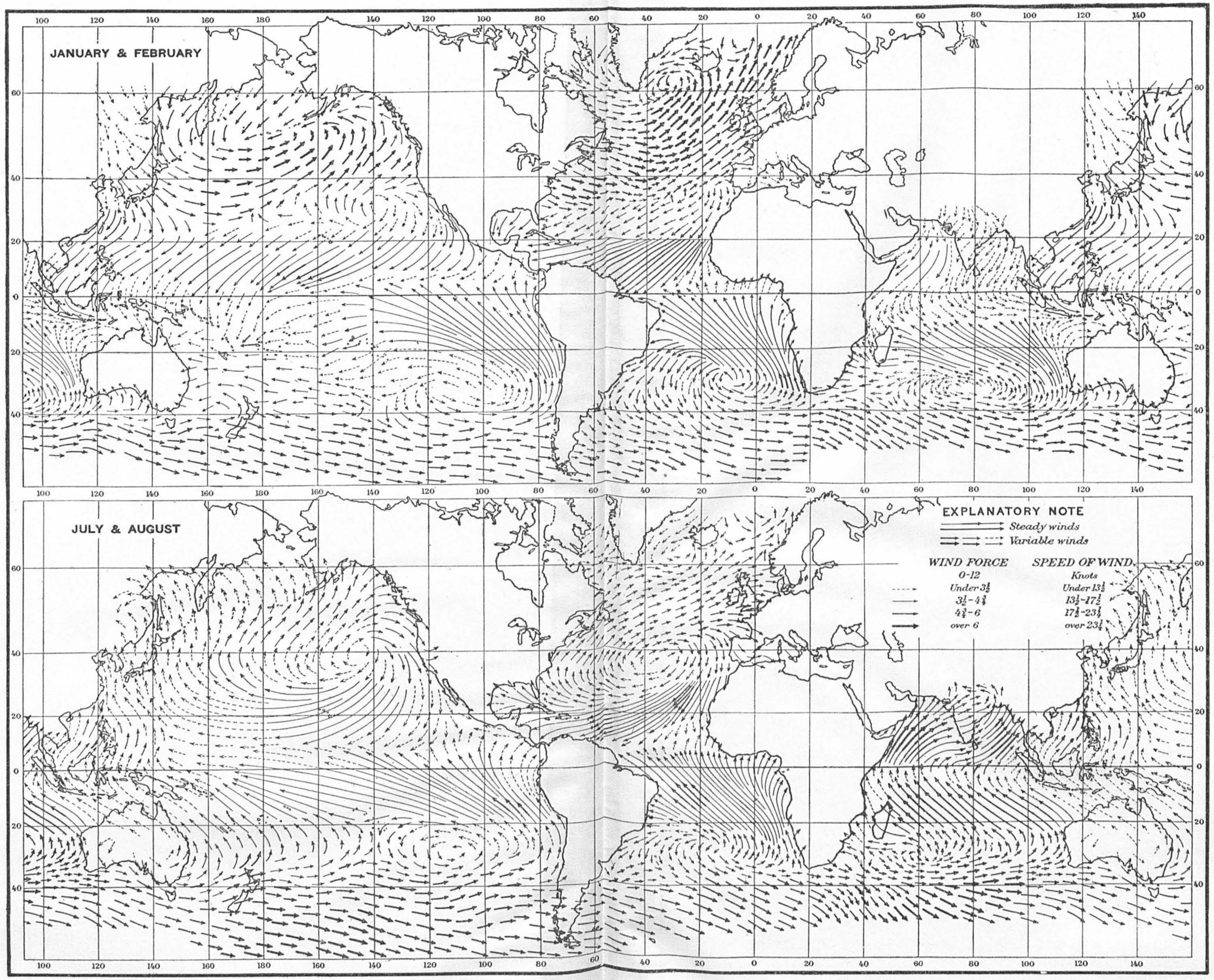


CHART OF PREVAILING WINDS OVER THE OCEANS. (DR. W. KÖPPEN IN BARTHOLOMEW'S PHYSICAL ATLAS.)

No. 20.

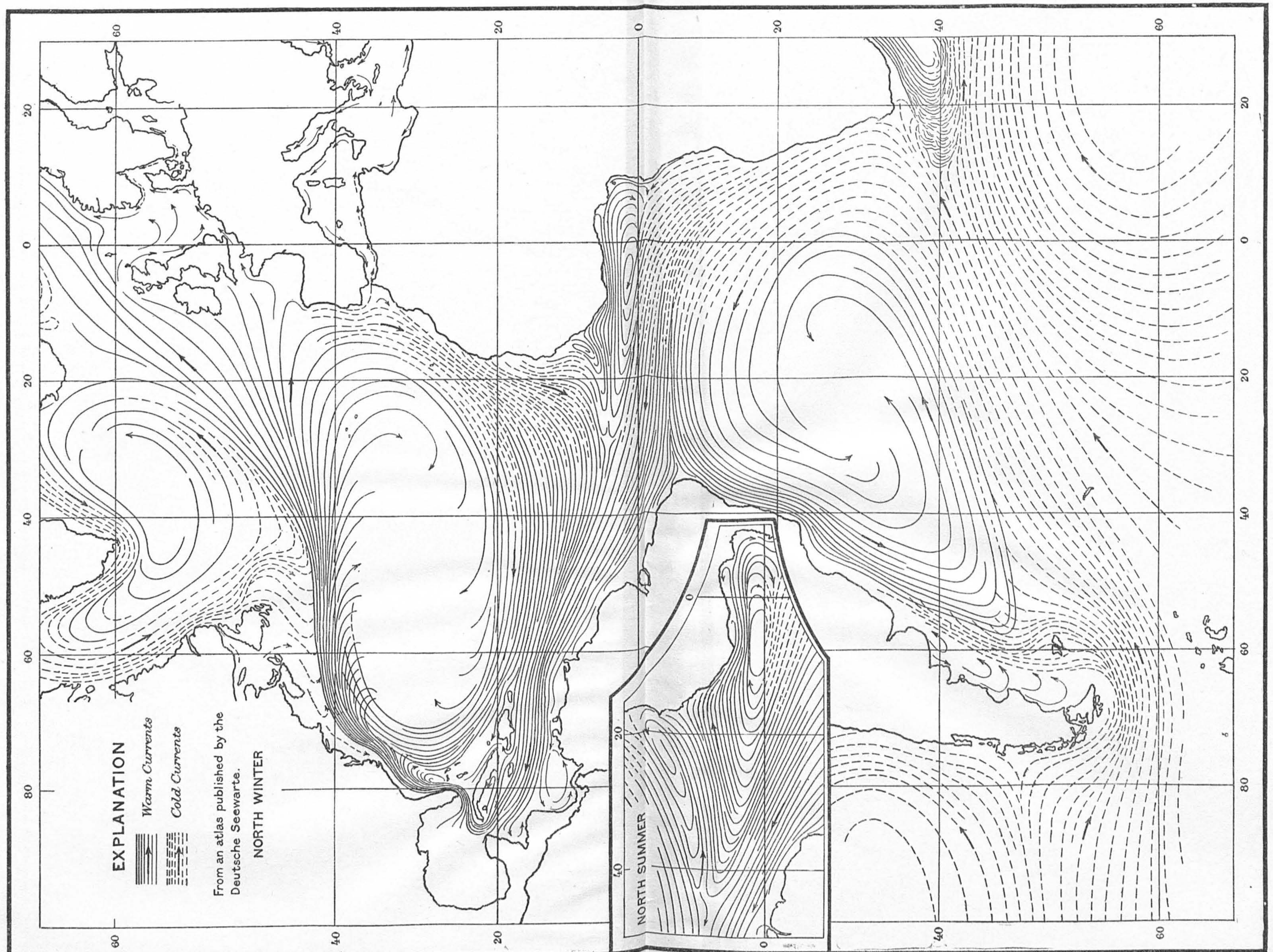


CHART OF NONTIDAL CURRENTS FOR THE ATLANTIC OCEAN, NORTH WINTER. (PROF. O. KRÜMMEL IN ATLAS BY DEUTSCHE SEEWARTE.)

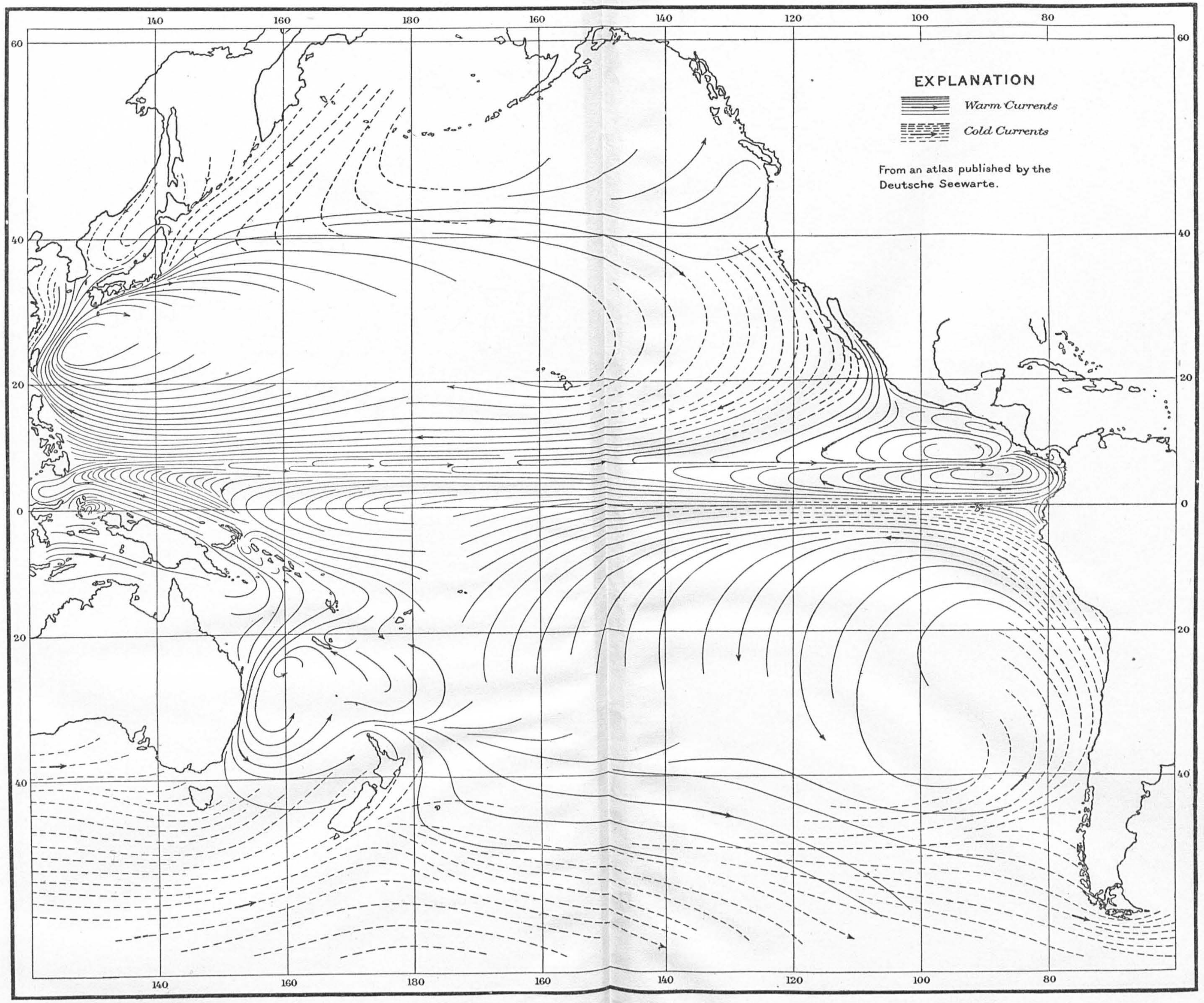


CHART OF NONTIDAL CURRENTS FOR THE PACIFIC OCEAN, JANUARY TO MARCH.

No. 22.

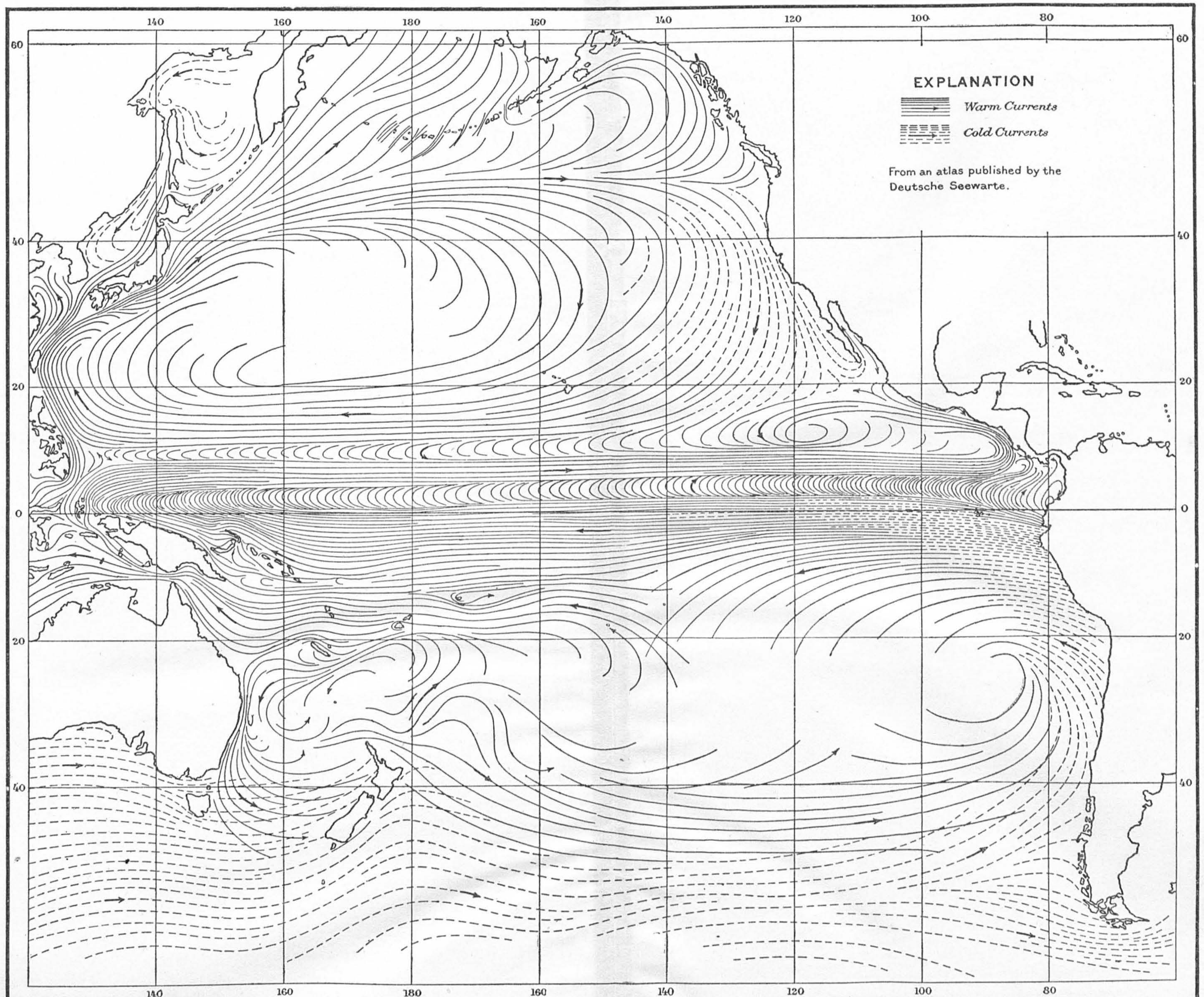


CHART OF NONTIDAL CURRENTS FOR THE PACIFIC OCEAN, JULY TO SEPTEMBER.

No. 23.

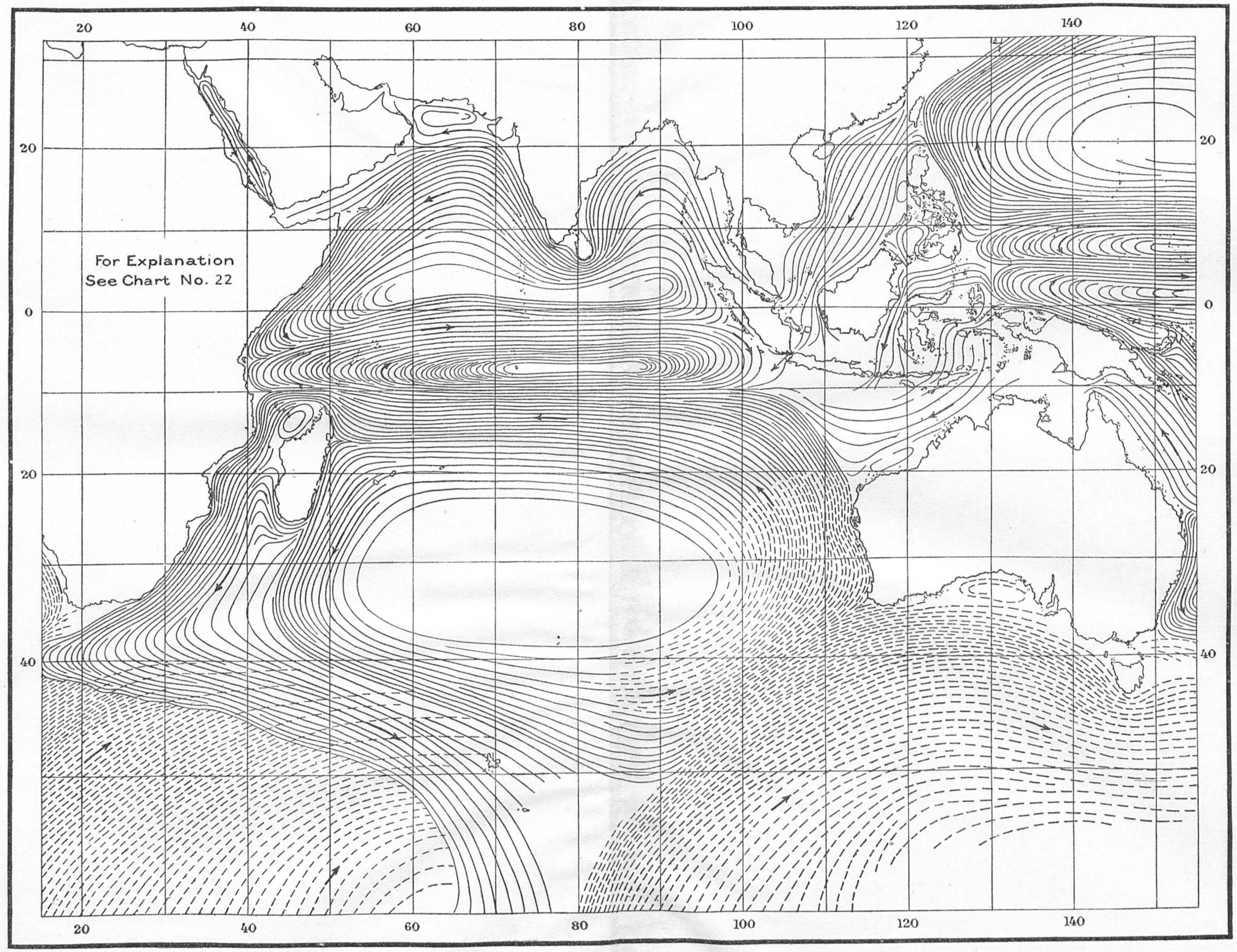


CHART OF NONTIDAL CURRENTS FOR THE INDIAN OCEAN, DECEMBER TO FEBRUARY. (ATLAS BY DEUTSCHE SEEWARTE.)

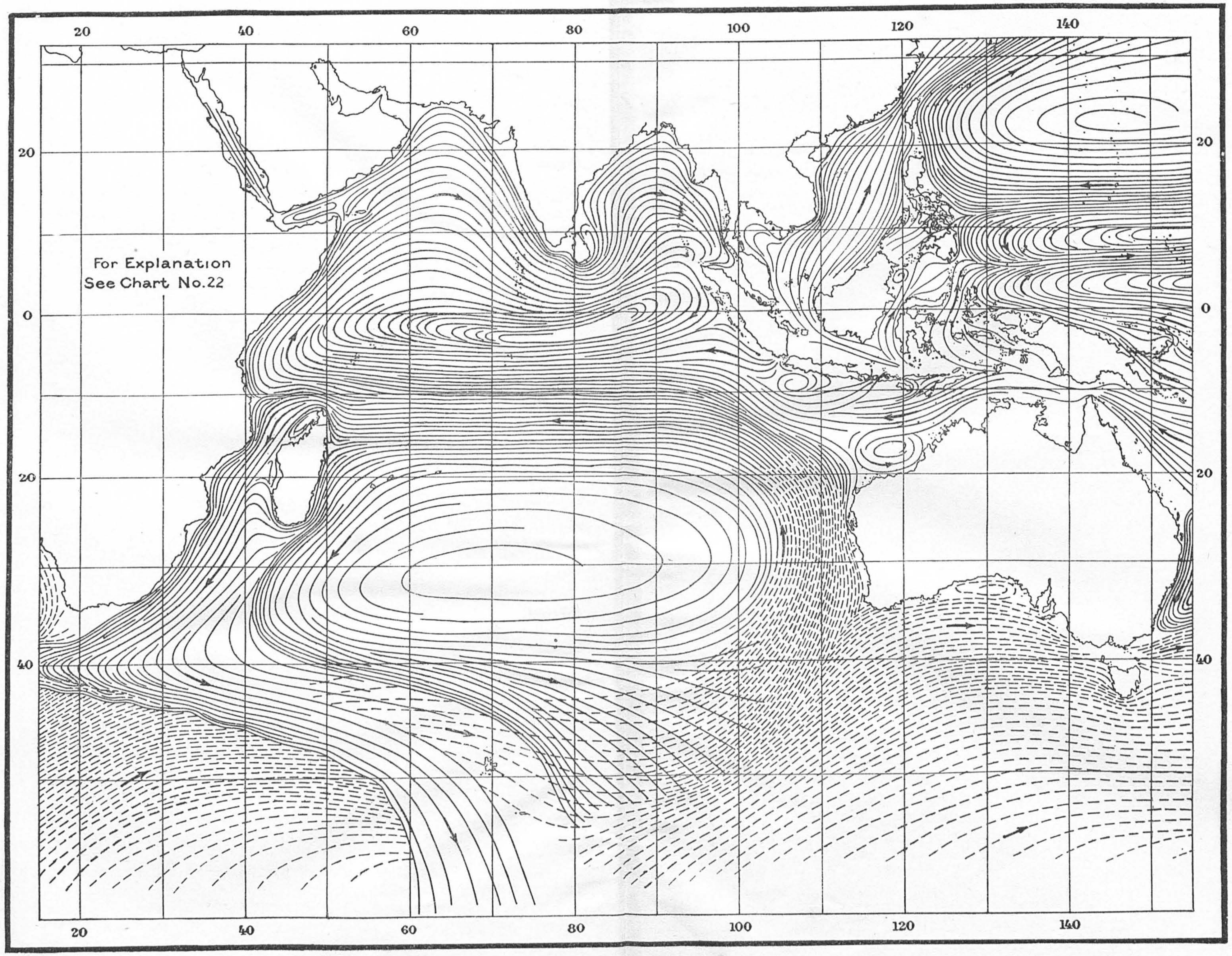


CHART OF NONTIDAL CURRENTS FOR THE INDIAN OCEAN, JUNE TO AUGUST. (ATLAS BY DEUTSCHE SEEWARTE.)

The following are a few works containing matter relating to the movements of the atmosphere:

Buchan: The Isobars and Prevailing Winds of the Globe, 1868.

Ferrel (Wm.): A Popular Treatise on the Winds, New York, 1889.

Deutsche Seewarte: Indischer Ozean, Hamburg, 1891.

Abbe (Cleveland): The Mechanics of the Earth's Atmosphere, A Collection of Translations, Washington, 1891.

Abbe (Cleveland): Article "Meteorology," New Volumes, Encyclopædia Britannica.

Hann (Julius): Berghaus' Physikalischer Atlas, Gotha, 1892.

Waldo (Frank): Elementary Meteorology, New York, 1896.

Deutsche Seewarte: Stiller Ozean, Hamburg, 1896.

Bartholomew's Physical Atlas: Vol. III, Atlas of Meteorology, 1899.

Deutsche Seewarte: Atlantischer Ozean, Hamburg, 1902.

Supan (Alex.): Grundzüge der Physischen Erdkunde, Leipzig, 1903.

110. *The direct effect of the wind.*

If a wind blows for a considerable time in one direction over an inclosed body of water the surface particles are carried or drifted from their original position through the impingement of the air upon them. These particles drag with them those situated immediately below the surface, and in time this dragging influence will be felt down to considerable depths.

The effect of these horizontal forces on the waters of a closed body is to increase the height of water level on the lee shore and to diminish it upon the opposite shore, although not generally by the same amount. In shallow bodies, or along the shelving shores of the ocean, the amount of this elevation may be considerable, as will be seen upon consulting sections 123, 124. In deep bodies with abrupt shores, the piling up is very small although there may be a good surface drift maintained by the wind. The reason for this is that the horizontal forces due to the wind do not act alike upon the particles at all depths, as do the tidal forces; for, they are considerable at the surface and insignificant near the bottom. Consequently the pressure due to the increased depth on the lee shore quickly gives rise to an acceleration in the reverse direction which exceeds, at even moderate depths, the acceleration imparted to the liquid elements by the moving elements situated nearer the surface. Hence the retrograde movement of the water not only near the bottom but for a considerable distance upward. Because of its much greater transverse section, the returning stream is as a rule scarcely perceptible, although the velocity of the surface stream may be considerable. Of course this counter movement also exists in the shallow bodies just referred to, because the wind's action can not be alike at all depths (like tidal forces), and so the body can not be in equilibrium under their action. Consequently there must be a drifting before the wind and a return current along the bottom.

This may be regarded as the circulation in vertical planes due directly to the wind striking the surface of the water. What may be regarded as the horizontal circulation will be briefly considered in describing the ocean currents, sections 111–115.

All the above remarks suppose the wind to be constant for some time, or at least prevailing, in the case of an ocean. If the wind is of comparatively short duration it may give rise to seiche oscillations, which have been described in section 16, Part I, and will be further considered in Chapter IX, Part V.

Circulation in horizontal orbits constitute a very general and obvious effect of the direct action of the winds upon the surface and are considered in several of the immediately following sections.

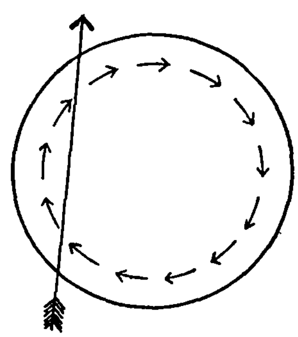
111. *Currents of the Atlantic Ocean.*

The effect which a constantly blowing wind may have in creating and maintaining surface currents or drifts in a given body of water depends largely upon the size, depth, and shape of the body. One of the most simple cases is a circular, elliptical, or oval body across one edge or limb of which the wind acts in approximately the direction of the boundary at this locality. (See Fig. 25.)

If at other edges of the basin the winds follow the direction of the near-by boundary still greater circulation will be imparted to the water, and it will reach to greater depths below the surface. The central portion will be comparatively quiet, forming a sargasso sea.

Examples of this are; the North Atlantic up to about the forty-fifth parallel; the South Atlantic to a line extending from Cape of Good Hope to the Falkland Islands. In either of these cases the body considered is not entirely surrounded by land, but an inspection of the wind directions will readily convince one that the results could hardly have been essentially different had there been a rigid wall extending across the North Atlantic along the forty-fifth parallel, another extending from Cape of Good Hope to the Falkland Islands, and even another along the Equator. In fact, were these walls in existence, then it would be possible for an east wind in the Torrid Zone to alone maintain the circulation in both basins. This is nearly the case which Krümmel* illustrated and established by experiment. (See Fig. 20.)

No. 25.



The north equatorial trade winds of the Atlantic blow from the northeast and east, giving rise to the resulting westerly drift, which was noticed by Columbus in his first voyage to the West Indies. He referred the cause of these motions to the westward motion of the primum mobile.†

The Gulf Stream was encountered by Ponce de Leon in 1513, as he skirted the coast of the peninsula of Florida, from a point north of Cape Canaveral to the Tortugas Islands. Franklin was the first to make a scientific study of the subject.

Its origin in the Straits of Florida is briefly explained in section 116; but its continuance across the Atlantic is due to the prevailing westerly winds, sometimes known as anti-trades. One portion of the stream impinges against Great Britain and Ireland, and probably extends as far to the northeast as Nova Zembla; the other branch continues easterly until it turns southward along the coasts of Portugal, Spain, and Africa.

Along the African coast this branch is called the Canary Stream, and it joins the North Equatorial Drift in the vicinity of the Cape Verde Islands. From here the drift is rapid, averaging about 10 miles a day. Through the Lesser Antilles the surface

* Handbuch der Ozeanographie, p. 358.

† See under Hakluyt and Bacon, this manual, secs. 74–76, Part I.

velocity exceeds 1 knot per hour. A good drift covers the Caribbean Sea and passes, mainly by force of gravity, through the Yucatan Channel. The larger portion of this water is spread out in the Gulf, but the smaller portion at once makes for the Straits of Florida in its effort to seek a lower level.* A portion of the western drift passes to the north of the Greater Antilles, and as a connecting current forms the western boundary of the Sargasso Sea.

According to the maps of Lieutenant Soley, one part of the Gulf Stream upon emerging from the Yucatan Channel turns westward and passes around or across the Campeche Bank—across if north winds prevail. From near Tampico, at the head of the Gulf, the main stream goes northeasterly to a point not far from the Mississippi Delta. An important northwestern branch goes from Yucatan Channel to join the branch just described near the Mississippi Delta. From this locality a stream flows southeasterly to the western end of Florida Strait.

The winds of the Gulf are northerly from October to February, inclusive, and southeasterly during the remainder of the year. The result of the southeasterly wind is to strengthen in the summer time the branch of the Gulf Stream extending from Yucatan Channel nearly to the Mississippi Delta. An eastern branch goes directly from Yucatan Channel to Florida Strait.

A counter current occupies the shallow northwestern corner of the Gulf. In a somewhat similar manner the shallow eastern edge of the Gulf is probably occupied by a weak northerly counter current. A current flows along the northern coast of Cuba and extends around Cape San Antonio, a little beyond the Isle of Pines.

The velocities of the principal streams within the Gulf generally lie between 0.5 knot and 2 knots.

It may be of interest to note here that as long ago as 1856 a bottle was picked up on Loggerhead Key, Florida Reef, by a Coast Survey party, which had been set adrift nearly two years before at a point south of the Mississippi Delta (Coast Survey Report, 1856, p. 279). This indicated the existence of a branch of the Gulf current mentioned above, which Lieutenant Soley has fully established.

The south equatorial trade winds blowing from the south and east, together with the resulting westerly drift, carried the navigator Cabral from his track, projected for rounding Africa, upon the coast of Brazil, thus giving to him the honor of its discovery. Off Cape Roque the drift divides, one branch, known as the Guiana Current, flows northwesterly, joining the north equatorial drift; the other, known as the Brazilian, flows southwesterly toward the Falkland Islands. The east-going stream across the Atlantic in the latitude of Tristan da Cunha, greatly increased in volume by cold water from the south, and the north-going stream west of South Africa, complete the circuit for this South Atlantic area.

112. *Currents around the Antarctic Continent.*

The prevailing winds off the coasts of the Antarctic Continent are westerly. These impart an eastward motion to the surrounding waters. This can be easily detected in the strait between Cape Horn and the South Shetland Islands, where the velocity is 11 miles per day. The general direction and amount of drift can be inferred from the fact that a bottle floated from Cape Horn to Port Phillip, on the south coast of Australia, a distance exceeding 8000 miles, in three and one-half years.

* Cf. A. Lindenkohl: U. S. Coast and Geodetic Survey Report for 1895, pp. 364, 365.

The immediate cause of the Cape Horn Stream is partly gravitational; for, the westerly winds force the waters against the Chilean coast, and the western coast of South Shetland Islands, and an escape to a slightly lower level is through the strait. Another portion of these accumulated waters flows northward, joining the Peruvian Current.

The cold streams from the Antarctic are felt as far north as off the Rio de la Plata, along the western coast of South Africa, and all along the western coast of Chile.*

113. *Currents in the Pacific Ocean.*

The Peruvian or Humboldt Current flows northerly, following the South American coast, sustained by the prevailing winds which here blow from the south; the velocity of this stream along the Peruvian coast lies between one-half and 1 knot. The current leaves the American coast near Cape Blanco, with a velocity perhaps as high as $1\frac{1}{2}$ knots and, much diminished in velocity and increased in width, flows westward under the influence of the south equatorial trade winds of the Pacific. Upon reaching the Pamotu Islands, a portion of this equatorial drift is deflected southerly and joins the general east-going drift referred to above. The remainder of the current has a general westerly direction.

The northern equatorial drift is mainly confined between parallels 10° and 25° north. Near the Hawaiian Islands the currents are variable but their general direction is probably westerly, with a velocity of 1 knot. Among the Marshall Islands the currents are irregular, with perhaps a prevailing westerly direction.

North of the fortieth parallel and across the Pacific Ocean the prevailing wind is from the southwest, and imparts an easterly motion to the waters of this region, and so accounts for the eastward continuation of the Kuro Siwo. This stream impinges upon the American coast, tempering the climate from Alaska to California. A portion of the drift known as the Californian Current flows southward off the coasts of Upper and Lower California, and finally joins the west-going drift.

The Kuro Siwo proper is a continuation and reflex of the north equatorial drift current, and so in part due to the easterly drift in the North Pacific; in other words, it is in part a connecting current. In part its immediate cause is gravitational, at least during the southwest monsoon. At that season the surface of the northern end of the China Sea must be on a higher level than the surface of the Pacific outside. This would account for such annual fluctuation of the intensity of the stream as exists southeast of Formosa.

East of Australia a counter-clockwise circulation exists, caused mainly by southeasterly winds acting upon the waters surrounding New Caledonia and the northwesterly wind acting upon the waters southeast from Tasmania.

114. *Currents in the Indian Ocean.*

North of the equator is the region of monsoons. Here the current has a northeasterly direction during the summer season of the northern hemisphere and a southwesterly direction during the winter season.

Between about 8° and 20° of south latitude is a west-going drift, due to the tolerably constant trade winds.

* The South American Pilot, Part II, ninth edition, under "Currents," pp. 22–25.

In the Indian Ocean south of the parallel of Cape of Good Hope the drift is in an easterly direction, agreeing with the general circulation around the Antarctic Continent. A branch of this drift turned northward by the coast of Australia, and known as the West-Australian Current, finally joins the west-going drift just referred to. The west-going drift is connected with the east-going by southwesterly currents along the coast of Madagascar.

115. *Currents in the Arctic Ocean.*

Some account of the movements of the surface currents of the Arctic from a point near Herald Island toward Cape Farewell, Greenland, has been given in section 46, Part IV B. Generally speaking, the direction of these currents in the open ocean approximately agrees with the direction toward which the winds blow. This was found to be the case by Nansen in the drifting of the *Fram*, and is probably true for most of the waters intersecting the Arctic Archipelago.

Along the northern coast of Greenland and north of Grant Land, Peary found the northwesterly winds and the ice setting easterly. Weyprecht and Payer, in the Tegetthoff, drifted from off Northern Nova Zembla northward and thus, in 1873, discovered Franz Josef Land. These indicate lateral movements toward the channel between Greenland and Spitzbergen and through which the ice escapes from the Arctic.

The southward current through Robeson and Kennedy channels has been well established by Hall, Greely, and others. The cold Labrador Current comes from Hudson Strait and the western side of Baffin Bay. It is felt as far south as Cape Hatteras, being sheltered from the west winds by the American coast, and being crowded against it by the deflecting force of the earth's rotation. A small portion of this stream traverses the Gulf of St. Lawrence, entering through the Strait of Belle Isle and leaving through Cabot Strait, although it is probably lost in the waters of the Gulf.

All of the above currents indicate a general surface movement from a region where the waters are of less density into one having warmer but denser waters. But by section 116 this implies that, save for the effect of the prevailing winds, the surface of the Artic is slightly higher than the surface of the Atlantic. This seems reasonable because of the considerable precipitation and very small evaporation in cold regions. Because of its smaller density, the fresh water tends to remain upon the surface.

It may be noted here that the direction of the prevailing current at Point Barrow is supposed to be eastward, while a long series of observations at the Government station a few miles to the southwest of the point showed that the prevailing wind was from ENE.

As mentioned in section 116, the immediate cause of the reversible currents through Bering Strait is probably gravitational—similar to the flow between Lakes Michigan and Huron, when strong winds blow over their surfaces. When the northern part of Bering Sea is from any cause for some time higher than usual, the flow is northward; and when lower than usual, southward. The southerly winds in the summer bring about the first condition and the northerly winds during the remainder of the year, the second.

More detailed information concerning ocean currents can be obtained from the maps, Figs. 20–24.

116. *Currents whose immediate cause is a difference in surface-levels, in water-densities, or in both combined.*

Bodies of water, or two portions of the same body, may, through prevailing winds, evaporation, precipitation, or influx of water from the land, assume slightly different surface-levels or possess different densities.

These conditions give rise to currents, and may be divided into four cases, real or hypothetical, viz.: Like densities but different surface-levels, like surface-levels but different densities, the denser body having the higher surface-level, the lighter body having the higher surface-level.

Case 1.—Like densities and different surface-levels.

In attempting to restore equilibrium, the water will continually flow from the higher body (i. e., the body whose surface is the higher) into the lower. If the connecting strait is sufficiently small for enabling a sensible difference in surface-level to be maintained, the velocity may there be considerable. The velocity at the narrowest part of the strait and in the swiftest thread of the stream will be approximately equal to $\sqrt{2g\ (z_{,}-z_{,,})}$ where $z_{,}$, $z_{,,}$, denote the heights of the surfaces of the two bodies above a fixed datum.

The effect of the north-equatorial trade winds is to elevate the water in the Carribbean Sea and the Gulf of Mexico above the general level of the Atlantic. Levels run across Florida between Cedar Keys and St. Augustine indicate a difference of level amounting to probably at least 0.8 foot. This implies a velocity of 7.2 feet per second, or 4.3 knots per hour, for the swiftest thread—an amount not greatly in excess of the observed value 3.4 knots (sec. 97). The above is in substantial agreement with Franklin's explanation. He says:

> This stream is probably generated by the great accumulation of water on the eastern coast of America between the tropics by the trade winds which constantly blow there. It is known that a large piece of water, 10 miles broad and generally only 3 feet deep, has, by a strong wind, had its water driven to one side and sustained so as to become 6 feet deep, while the windward side was laid dry. This may give some idea of the quantity heaped upon the American coast, and the reason of its running down in a strong current through the islands into the Bay of Mexico and from thence proceeding along the coasts and banks of Newfoundland where it turns off toward and runs down through the Western Islands.*

Case 2.—Like surface-levels, different densities.

So long as this condition can be maintained, it is evident that the surfaces of equal pressure in the connecting strait (the free surface excepted) all slope downward toward the lighter body; hence any liquid element will be driven toward that body. The accelerating force will increase in going downward, but this does not mean that the velocity will be comparatively small at the surface; for, by the viscosity of water the under layers would finally impart their velocities to the waters above.

Case 3.—The denser body having the higher surface-level.

Here the flow at all depths is obviously from the higher and denser to the lower and less dense body.

An example of this is the current through Bering Strait from the Bering Sea to the Arctic during the summer season when the surface of the former stands at a higher level than the surface of the latter.

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* Pillsbury: U. S. Coast and Geodetic Survey Report for 1890, p. 489.

Case 4.—The lighter body having the higher surface-level.

Since the surface of the less dense body or region is slightly higher than the surface of the one more dense, the water near the surface will flow toward the lower but denser body.

If at some depth below the surface the pressure due to depth be equal in the two bodies (that is, if there the surface of equal pressure be horizontal) there will be no tendency to flow in either direction. Below this surface, the surfaces of equal pressure will slope downward toward the lighter body; hence near the bottom the water will flow toward the lighter body notwithstanding the fact that its free surface is on a higher level.

The surface water of the Arctic Ocean moves toward the Atlantic through Denmark and Davis straits. The considerable precipitation, the influx from several large rivers, and especially the small evaporation, all go to maintaining a rather low density for Arctic waters as well as an increased, but of course very small, elevation of the surface.

The difference in the densities as actually existing is less than that indicated upon charts, because the chart values have been reduced to standard temperatures, and the polar seas, all depths considered, are in reality several degrees colder than the equatorial waters. But near the land, where the amount of fresh water greatly reduces the density, the water's surface is considerably elevated and may give rise to strong and cold currents, particularly in channels and on the right-hand side of the sea or body traversed. This crowding against the land, and prevention of the stream from dispersion, is due to the deflecting force of the earth's rotation. Doubtless a considerable amount of water passes as an undercurrent from the Atlantic into the Arctic through the straits east and west of Iceland. That such is the case can be inferred from the fact that the density of the Arctic, well below the surface, about equals the density found in these straits.

Another example of this case is the Gulf of St. Lawrence and the Atlantic Ocean. Strong surface currents exist in Cabot Strait, the velocity near Cape North being 2 knots.

The Atlantic Ocean and the Mediterranean Sea constitute another example. The surface current nearly always sets easterly in the axis of the strait, the velocity being about 3 knots; but below the surface this eastward flow is less marked. (See section 84, Part IV B.) It is certain that at the bottom the flow is westerly; for, the waters of the Mediterranean must be sufficiently dense through the evaporation of ocean water for causing the lines of equal pressure near the bottom of the strait to slope westerly, otherwise the Mediterranean would be continually deriving salt from the Atlantic.*

According to a report of M. Ch. Lallemand in the Comptes-Rendus of the twelfth general conference of the International Geodetic Association on the general leveling in France it appears that mean sea level for Biarritz, at the head of the Bay of Biscay, is 21 centimeters above that at Marseilles. It also appears that the mean sea level at the capes upon which Brest and Cherbourg are situated is somewhat lower than the level at Marseilles. These are conditions which might result from the action of the prevailing westerly winds.

By analogy it is reasonable to suppose that the sea level off the western end of the Strait of Gibraltar is elevated a few inches by the action of the prevailing winds upon the bay forming the approach to the strait; but this difference of level must be small,

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* Cf. Boguslawski: Handbuch der Ozeanographie, Vol. 1, pp. 37, 38.

because the pressure at the depth of the bottom of the strait is known to be greater in the Mediterranean than in the Atlantic (in order to produce an outward flow), and the difference in density is not very great (section 120).

From page 21 of the Red Sea and Gulf of Aden Pilot, fifth edition, the following, concerning the currents in the strait of Bab el Mandeb, is quoted:

> From about May to September, while the southwest monsoon is blowing in the Indian Ocean, the water runs out of the Red Sea; but, during the northeast monsoon, from October to March, it runs in; thus accounting for the difference of level before remarked upon, which has been observed to depend upon the season of the year.
>
> In the strait of Bab el Mandeb these currents often have a rate of 30 or 40 miles a day, but their strength is much diminished a few miles up the sea; and in the strait it is somewhat confused through the irregular tidal influence there felt. At the change of the monsoon there is little or no current.

This is in accord with the general rule for the annual inequality in sea level in the western part of the Indian Ocean; for, upon referring to section 124 it will be seen that high water for this part of the ocean occurs in north winter while low water occurs in north summer.

In this strait the surface current has been observed to go in the direction toward which the wind blows, while near the bottom there was a contrary setting.

A fresh-water stream discharging into the ocean may cause counter currents at the bottom of the channel of the stream and for some distance along the bottom of the outer body.

Examples of this are the straits and sounds connecting the Baltic Sea with the North Sea, the Hudson River, and off the Mississippi River.

For the Baltic, see papers referred to below by F. L. Ekman, V. W. Ekman, and A. W. Cronander. For the Hudson, see a paper by Henry Mitchell, U. S. Coast and Geodetic Survey Report for 1887, pp. 301 311.

It has long been known that off the mouth of the Mississippi the colored surface water takes a different direction from that taken by the clear or blue water below. The existence of a counter current has not been established by observation. In fact observations made by R. Platt while engaged in work for this survey off the delta indicate chiefly that the under currents take a variety of directions with reference to the surface currents. In the river proper, the volume of fresh water is so great that salt water does not enter, and so counter currents do not there occur.

117. *Currents in lakes and bays.*

The Great Lakes of America have main currents moving toward their outlets. The position of such a current with reference to either shore of a lake is determined chiefly with reference to the directions of discharge. In case of Lakes Superior, Michigan, or Huron, the main current lies nearer to the right side than to the left. This suggests the deflecting force of the earth's rotation upon a freely moving body, as the influence governing the position of the axis of the stream. But as this tendency to crowding to the right is not conspicuous in either Lake Erie or Lake Ontario, where the velocity of the current proper must be much greater than that belonging to the upper lakes, it seems almost certain that the influence of this force is too small to be of importance in any of the other lakes.

Currents, especially at the surface, are caused by winds. In this region, the prevailing wind direction is westerly and so the currents produced directly by them, particularly in exposed places, take an easterly direction. On account of the limited size of any one of these lakes, it is not probable that in any forced current produced by the winds the paths of the water particles will show any general deviation to the right of the direction of the paths of the air particles.

The swiftest of all surface currents in the Great Lakes proper are probably those produced by the winds acting upon the waters of Lakes Michigan and Huron, causing the surfaces of the two bodies of water to differ in level by a considerable amount. This greatly increases for a time the discharge of water through the Strait of Mackinac. Observations off Manistee, Lake Michigan, showed a northerly current of from 1½ to 4 statute miles per hour.

In protected places, and particularly along the more irregular shore, counter currents due chiefly to wind currents may exist.

The circulation of the Great Lakes is described in a paper by Mark W. Harrington, entitled "Currents of the Great Lakes, as deduced from the Movements of Bottle Papers during the seasons of 1892 and 1893," and in Sailing Directions, published by the U. S. Hydrographic Office (1900–1902), numbered 108 A, and 108 B, 108 C, and 108 D.

The winds which chiefly cause the currents in the Black Sea appear to take various directions over different parts of it.

A recent discussion of the currents of this sea is made by Walther Wissemann on pages 162–180 of the Annalen der Hydrographie, Volume 34, 1906.

A counterclockwise circulation takes place in the Mediterranean Sea, including the Ægean and the Adriatic seas. There is a dependent current or eddy in the gulf off Tripoli. The influx of water through the Strait of Gibraltar, the straightness of the African coast, and the prevailing westerly winds, account, in the main, for the eastward current very near the southern border of the sea; while the irregularity of the European coast favors a return current protected from the prevailing winds. The deflecting force of the earth's rotation probably causes the return current to enter the Ægean and Adriatic seas.

Currents dependent upon contact with others are of common occurrence in partially inclosed bodies of water. If the outer currents flow clockwise in their circuit, the dependent current will flow counterclockwise, and vice versâ. The current in the southwestern corner of the Caribbean Sea and that in the Bay of Honduras are examples of this. Other examples are the Gulf of Guinea and near-by waters, the waters lying between Iceland and southern Greenland. The currents in the Japan Sea consist of a branch of the Kuro Siwo, and a counter current necessitated by it flowing southerly along the continental coast line.

The currents of the Greenland Sea and northern extremities of the Atlantic Ocean have recently been ascertained with considerable precision through the agency of bottles set adrift and afterwards recovered. The results of such observations are given in a paper by C. Ryder in the Nautical Meteorological Annual for 1904 (Copenhagen, 1905).

It will be noticed that the north-going streams hug the coast to their right or the east, while those going southward, the coast to their right or the west. This agrees with what might have been anticipated from a knowledge of the deflecting force due to the earth's rotation.

But it appears that north winds prevail down the eastern coast of Greenland and southerly ones between Norway and Iceland, due to the fact that a region of low barometer lies between these two coasts. Hence it is probable that the circulation between Iceland and Norway and between Iceland and Southern Greenland is chiefly to be explained by Krümmel's experiment; but that the deflecting force of the earth's rotation causes the streams, whether free or under the action of the sustaining winds, to crowd upon the shores of Norway and southern Greenland.

The openness of these bodies of water would preclude the explanation given for return streams against the winds in lakes and land-locked seas, from applying here.

The deflecting force of the earth's rotation accounts for the fact that the currents flow inward along the eastern shores of the Adriatic and Red seas and Baffin Bay, and outward along the western shores.

118. *Note on recent theoretical work.*

The influence of the earth's rotation upon ocean currents is mentioned by Maclaurin in his prize essay upon the tides.* The equations of motion for a liquid upon a rotating sphere lie at the foundation of Laplace's dynamical theory of tides. Ferrel makes constant use of the principle, following at once from Laplace's equations, that a moving particle is deflected to the right in the northern hemisphere and to the left in the southern. Before the work of V. Bjerknes the ocean currents were treated as free currents, i. e., as if they would move onward by their own inertia after the forces ceased to act. Nansen suspected from observation, and V. W. Ekman confirmed by computation, that forced or sustained currents take, if circumstances permit, a direction to the right of the sustaining force in the northern hemisphere. Moreover, as wind action is from the surface downward (each layer moving the one underneath it) the direction of the lower layer will likewise be to the right of the one imparting the motion.

Supposing all motions in an indefinitely large body of water acted upon by the winds to be steady and horizontal, then the equations of motion become very simple. The external forces for a given water element are the components of the earth's deflecting force, and the only other forces acting are the components of the resistance due to viscosity. Integrating these equations and determining the arbitrary constants to suit the assumed problem, it follows, that in the northern hemisphere, the surface currents take a direction 45° to the right of the direction of the wind, and that this angle increases with the depth.

Ekman also considers currents caused by pressure-gradient and the earth's rotation alone, and wind currents influenced by the continents, currents which arise from a difference of density, and the action of both wind and density variation. See references to Ekman below.

On account of the actual distribution of land and water, it is difficult to say at this time to what extent Ekman's theory of forced currents accounts for the existing ocean currents. The fact that there is a tendency for the water to flow to the right or left of the direction toward which the wind blows will doubtless be brought out for many regions.

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*This Manual, Part I, sec. 95.

The hydrodynamical problems involving the motions of waters of different densities, treated by V. Bjerknes and V. W. Ekman, are of fundamental importance in the mathematical treatment of the motions of the sea and adjacent waters.

119. *A few references to observations and discussions of permanent currents.*

General and theoretical.

F. L. Ekman: On the general causes of ocean currents, Nova Acta, Roy. Soc. Sc. Ups., Ser. III (1876).

K. Zöppritz: Zur Theorie der Meeresströmungen, Annalen der Physik, Vol. III (1878).

Boguslawski and Krümmel: Handbuch der Ozeanographie, Vol. II, Stuttgart, 1887.

M. F. Maury: Physical Geography of the Sea.

James Croll: Climate and Time, 1887.

H. Berghaus: Physikalischer Atlas, Gotha, 1892.

Atlases by the Deutsche Seewarte for the Indian, Pacific, and Atlantic Oceans.

V. W. Ekman: Ein Beitrag zur Erklärung und Berechnung des Stromverlaufs an Flussmündungen, Kongl. Vetenskaps-Akademiens Förhandlingar, 1899, pp. 479–507.

A. Supan: Grundzüge der Physischen Erdkunde, Leipsic, 1903. (See references there given on pp. 308-309).

A. Lindenkohl: Encyclopedia Americana (1904), Article Oceanography.

Charts published by the British Admiralty and by the U. S. Hydrographic Office.

V. W. Ekman: On the influence of the earth's rotation on ocean-currents, Arkiv.-för Mathematik, Astronomi och Fysik, Vol. 2, No. 11 (1905).

O. Pettersson: On the influence of ice-melting upon oceanic circulation, Svenska Hydrografisk Biologiska Kommissionens, Skrifter.

J. W. Sandström: On icemelting in seawater and currents raised by it, Ibidem.

V. W. Ekman: Beiträge zur Theorie der Meeresströmungen, Annalen der Hydrographie und Maritimen Meteorologie, Vol. 34 (1906), pp. 423–430, 472–484.

Gulf Stream.

Coast and Geodetic Survey Reports: 1846, App. 4; 1853, p. 46; 1854, App. 52; 1856, App. 46; 1858, App. 32; 1860, App. 17; 1868, App. 11; 1884, App. 32; 1885, App. 14; 1886, App. 11; 1887, App. 8; 1889, App. 16; 1890, App. 10; 1891 (2), App. 10; 1895, App. 6.

A. Petermann: Der Golfström und Standpunkt der thermometrischen Kenntnis des Nordatlantischen Ozeans und Landgebiets in Jahre, 1870, Petermann's Geographische Mitteilungen, Vol. 16 (1870).

Der Golfström von 10. mai bis zun 10. Juni, 1904, Annalen der Hydrographie u. Maritime Meteorologie, Vol. 33, 1905, pp. 314–320.

J. C. Soley: Annalen der Hydrographie u. Maritime Meteorologie, 1907, pp. 84–87, and Pilot Charts North Atlantic Ocean, issued by U. S. Hydrographic Office, 1907.

Labrador Current.

The Newfoundland and Labrador Pilot, published by the Admiralty. Sailing Directions for Nova Scotia, Bay of Fundy, etc., U. S. Hydrographic Office. Dawson's Reports on Survey of Tides and Currents in Canadian Waters.

Indian Ocean.

Atlas by Deutsche Seewarte. Pilots for Africa, Red Sea, and Gulf of Aden, Hindustan, Bay of Bengal, and Islands in the Southern Indian Ocean, published by the Admiralty.

Arctic Ocean.

Bathymetrical Features of the North Polar Sea, F. Nansen, Christiania, 1904. The Norwegian North Polar Expedition, 1893–96, Scientific Results, London, 1902. F. Nansen.

Pacific Ocean.

Atlas by Deutsche Seewarte. Pacific Islands (Sailing Directions), by the Admiralty. Vols. I, II, III. A. Lindenkohl in Petermanns Geog. Mitteilungen. 1897, Heft XII. Papers by H. C. Russell and by H. A. Lenehan in Jour. and Proc. Roy. Soc. N. S. W.

Kuro Siwo (Japan Stream).

The China Sea Directory, by the Admiralty. Vol. IV.

Northern portion of Atlantic Ocean and North and Baltic Seas.

C. Ryder: Some investigations relating to the ocean currents in the sea between Norway, Scotland, and Greenland.

Nautical Meteorological Annual for 1904, Copenhagen, 1905.

Svenska Hydrografisk Biologiska Kommissionens Skrifter, Vols. I and II.

A. W. Cronander: On the Laws of Movement of Sea-Currents and Rivers, Norrköping, 1898.

120. *Note on density observations.*

Density observations are easily made to a fair degree of precision by means of a hydrometer. One form of this instrument consists of a glass bulb terminated by a slender graduated stem, and a cup or can into which the specimen of sea water is placed and within which is mounted a thermometer for ascertaining the water's temperature. If the range of density is considerable, several bulbs should be provided so that the range of each need not much exceed 1 per cent.

Recent observations have in many cases been reduced to the temperature 15° C. (= 59° F.) for the sea water and the standard temperature of the distilled water is taken as 4° C. (= 39°.2 F.). Results obtained by the U. S. Coast and Geodetic Survey prior to 1892, suppose both sea water and the standard distilled water to have the temperature 60° F. See report by Buchanan, Physics and Chemistry, Volume 1, Challenger Reports. In the Atlases of the Deutsche Seewarte both standard temperatures are 17°.5 C.

Tables for reducing the observed densities to standard temperatures are given on page 155, Coast and Geodetic Survey Report for 1874, and page 277, Report for 1891.

In making the observations care must be taken to secure the water at the assumed position and depth, to give the attached thermometer time to adjust itself to the temperature of the water, and to see that the bulb is not in contact with the walls of the cup, but floats freely.

In tidal rivers the stage of the tide should be noted.

Doctor Boguslawski, on page 147 of his Handbuch der Ozeanographie, gives the following densities of the surface waters, which are taken from British source:

Region.	Specific gravity reduced to 16°.7 C.=62°F.
North Atlantic Ocean up to 50° north latitude	1.02664
South Atlantic Ocean up to 50° south latitude	1.02676
North Pacific Ocean up to 50° north latitude	1.02548
South Pacific Ocean up to 50° south latitude	1.02658
Indian Ocean between 0° and 50° south latitude	1.02630
Mediterranean Sea	1.02689
Black Sea	1.01430
North Sea	1.02610
Baltic Sea	1.00860
Red Sea	1.02860

Recent density maps are given in the Atlases of the Pacific, Indian, and Atlantic Oceans, published by the Deutsche Seewarte.

The principal sources of information used in the construction of these charts are given in the texts of the Atlases, and to these the reader is referred.

References to densities measured by the Coast and Geodetic Survey:

Hudson River, Report 1871, p. 130; 1887, p. 303.

Mississippi River (South Pass), Report 1875, opp. p. 190, and p. 192.

Chesapeake Bay, Report 1877, p. 189 (results not published).

Chesapeake Bay, Report 1881, p. 303, Figs. 56–62.

Atlantic Ocean, Report 1882, last figure.

Gulf of Mexico, Report 1895, App. 6.

Northeastern Pacific Ocean and Bering Sea, Report 1898, p. 239.

A considerable number of density observations, not published, have been made at Sandy Hook, New Jersey; Delaware Breakwater, Delaware; Tybee Island, Georgia; in the Gulf Stream, and in the Northern Pacific Ocean.

A few references not included in the texts of the Atlases of the Deutsche Seewarte are as follows:

A. Lindenkohl: Das specifische Gewicht des Meerwassers in Nordöst-Pacifischen Ozean, etc., Petermanns Geogr. Mitteilungen, 1897, Heft XII.

A. J. Robertson: Temperature and salinity of the surface waters of the North Sea in the year 1903, North Sea Fisheries Investigation Committee, 1903.

Fridtjof Nansen: The Oceanography of the North Polar Basin, The Norwegian North Polar Expedition, 1893–6, Vol. III (No. IX), 1901–2. The Bathymetrical Features of the North Polar Seas, etc., The Norwegian North Polar Expedition, Vol. IV (No. XII), 1904.

N. M. Knipowitsch: Grundzüge der Hydrologie des Europäischen Eismeers, 1906, pp. 1439–1464.

Svenska Hydrografisk Biologiska Kommissionens Skrifter, Vols. I and II.

THE ANNUAL FLUCTUATION OF WATER LEVEL.

121. *River fluctuations.*

In most fresh-water streams the surface height and the velocity of flow are subject to variations through a yearly period, although great irregularities generally exist. Only the average, or somewhat regular, fluctuation will be here considered. The principal causes are the varying amounts of rain and evaporation, and the melting of snow in higher latitudes.

The annual rising of the Nile had an important bearing upon early civilization and its cause was a subject of much speculation.* The brief description of the phenomenon by Herodotus finds itself in perfect accord with observations made at the dam below Cairo during the years 1849–1878. Herodotus says that the river begins to rise at the summer solstice and reaches its maximum height in about one hundred days. Figure 121 in Supan's Grundzüge der Physischen Erdkunde shows this agreement.

From the discussion of observations covering the seven years 1872–1878, it appears that the fluctuation in the surface of the Mississippi River at New Orleans resembles a sine curve whose maximum height is near the middle of May and whose minimum is near the middle of November; also that the range of this regular curve is 10 feet.

The fluctuations in the upper portions of the river and its tributaries is less regular in its character, and the range of the rise and fall is usually much greater than at New Orleans.

The stages of the Mississippi River are shown in the hydrographs published in the Reports of the Mississippi River Commission, which forms a supplement to the recent Reports of the Chief of Engineers (United States Army). From these it will be seen that there are often several well-defined maxima and minima each year. The times of the principal maximum and minimum at Carrollton, La., may be given as about April 20 and November 25, respectively, the average range being about 16 feet. The lesser maxima perhaps occur about February 1 and June 15.

It will be noticed that, as a rule, the rivers of the Atlantic slope of the United States north of Georgia, and gauged above tidal influences, will attain their regular annual maximum height and discharge in February, March, or April, and their minimum in August, September, or October. See next section.

From the known geography and climatology of a given river basin some estimate can generally be made of the times when floods and freshets may be expected, also when the contributing streams should run unusually low. If these times are at variance with those given by the annual inequality in the water level as observed at some tidal station upon the river, one may be reasonably certain that the floods and freshets are, at that station, of secondary importance in producing this inequality.

For instance, at Port Eads, situated on South Pass of the mouth of the Mississippi, the regular annual maximum height (sec. 124) occurs in October, the range being 0.9 foot, whereas, as already stated, the same river at New Orleans reaches its maximum height in April or May, the range being 10 feet or more.

On the other hand, if the range of the annual fluctuation much exceed 1 foot, excepting certain regions of shallow water, and those parts of the earth where monsoons

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* This manual, Part I, secs. 64, 67, *ad finem.*

prevail, it is probable that the upper-river stages control the annual fluctuations unless known meteorological facts are to the contrary. But what part is due to the efflux of river water and what to periodic winds is often difficult to determine. For example, at the river stations Calcutta and Rangoon, the annual high stage occurs about the first of September. But for southeastern Asia the rainy season occurs during the summer months and the dry season during the winter and spring. Consequently the heights of the rivers at these stations are governed by the efflux of the rivers. If this fluctuation were due to the monsoons only, it is probable, as will be noted in the next section, that the maximum height would occur not later than August.

The Great Lakes have an annual fluctuation of from 1 to 2 feet. They stand highest in August and lowest in February. Records extending over more than forty years are published in the Reports of the Chief of Engineers (United States Army).*

* E. g., Report for 1904, Part IV, p. 4057.

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122. *Table showing average discharge in cubic feet per second.**

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
St. Croix River at Sprague Falls, Me., 1902 (1 month), 1903, 1904 (9 months), 1905 (3 months)......................	6 463	4 998	7 684	5 131	3 909	2 466	2 902	1 666	932	1 046	1 066	2 172	3 370
Penobscot River at the Sunk Haze Rips, Me., 1899 (4 months), 1900 (9 months)..	14 876	37 262	43 828	52 407	56 632	20 435	13 769	10 722	3 658	2 764	7 170	9 014	22 711
Kennebec River at Waterville, Me., 1893-1902, 1905..............................	2 939	3 291	8 163	23 783	19 169	9 729	5 984	3 727	2 901	2 868	4 472	3 655	7 557
Androscoggin River at Rumford Falls, Me., 1892 (8 months), 1893, 1894-1895 (4 months), 1896-1902, 1905................	2 242	1 927	2 530	9 342	9 895	4 992	3 240	2 514	2 217	2 408	2 942	2 438	3 891
Merrimac River at Lawrence Mass., 1890-1899	6 284	6 347	13 976	17 091	9 967	5 739	3 604	3 011	3 196	4 208	5 948	5 869	7 103
Connecticut River at Holyoke, Mass., 1896-1898	8 744	7 850	25 723	35 695	17 096	13 024	10 313	6 238	4 835	8 949	14 945	13 031	13 870
Housatonic River at Gaylordsville, Conn., 1900 (3 months), 1901, 1902 (11 months), 1903, 1905 (11 months)	2 502	3 455	6 504	4 434	2 208	2 045	1 328	1 346	1 389	1 620	1 231	2 668	2 561
Hudson River at Mechanicsville, N. Y., 1890-1901, 1902 (11 months), 1903, 1904-1905 (10 months)......................	7 004	6 411	13 449	19 716	10 677	6 582	4 370	4 388	4 415	5 128	6 814	6 971	7 994
Mohawk River at Dunsbach Ferry Bridge, 1901, 1902, 1903 (8 months), 1904, 1905....	3 314	1 670	15 800	10 592	4 990	6 142	3 792	2 899	3 872	6 401	3 854	6 746	5 839
Delaware River at Lambertville, N. J., 1897 (6 months), 1898-1901, 1902 (11 months)	17 333	22 320	32 972	25 112	16 451	8 736	11 053	11 265	8 228	10 263	11 480	21 510	16 477
Schuylkill River at Fairmount Dam, Pa., 1898 (11 months), 1904, 1905	3 743	2 788	5 743	3 068	2 539	1 399	634	2 720	2 166	1 570	2 115	2 226	2 559
Susquehanna River at Harrisburg, Pa., 1891-1904, 1905 (11 months).............	43 610	58 266	98 340	75 024	41 914	27 182	18 396	16 672	13 965	19 372	21 084	37 877	39 308
Octoraro Creek at Rowlandsville, Md., 1896 (2 months), 1897, 1898, 1899 (9 months)	426	723	436	400	411	253	203	261	214	183	380	461	363

* From measurements made by the U. S. Geological Survey.

Table showing average discharge in cubic feet per second—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Patapsco River at Woodstock, Md., 1896 (5 months), 1897, 1898–1899 (11 months), 1901 (11 months), 1902–1904, 1905 (11 months)	492	742	670	488	376	340	357	330	189	202	260	466	410
Potomac River at Point of Rocks, Md., 1895 (11 months), 1896 (10 months), 1897–1906.	11 999	16 462	23 477	18 055	11 090	7 958	6 057	6 350	2 891	5 283	4 001	9 432	10 255
Monocacy River at Frederick, Md., 1897–1906	1 554	1 876	2 562	1 630	915	764	650	755	313	524	525	1 568	1 136
James River at Cartersville, Va., 1899–1904, 1905 (11 months)	11 289	12 845	16 061	12 030	8 485	8 205	5 314	5 404	3 551	3 201	3 310	7 712	8 117
Appomattox River at Mattoax, Va., 1900 (4 months), 1901–1905	1 158	1 647	1 478	1 460	951	601	469	937	483	376	396	1 078	920
Roanoke River at Neal, N. C., 1896 (5 months), 1897–1902, 1903 (5 months)	13 110	19 562	21 487	17 069	10 934	7 767	6 459	7 616	5 195	6 696	5 336	9 677	10 909
Tar River at Tarboro, N. C., 1896 (6 months), 1897–1900	2 124	5 941	5 867	4 005	2 009	1 393	1 337	1 034	796	670	1 022	2 137	2 361
Cape Fear River at Fayetteville, N. C., 1889–1902, 1903 (5 months)	6 919	10 571	8 657	6 811	4 017	3 264	4 706	5 742	3 143	2 884	2 607	3 468	5 232
Yadkin River at Norwood, N. C., 1896 (4 months), 1897–1899	7 137	13 092	14 520	8 034	6 127	4 672	4 637	4 129	4 106	4 027	4 002	5 064	6 629
Wateree River at Camden, S. C., 1904 (4 months), 1905	4 828	11 100	5 206	4 358	7 205	3 025	8 617	10 880	2 929	1 960	2 244	6 333	5 724
Broad River at Alstar, S. C., 1897–1903, 1905	7 175	15 233	14 260	12 041	6 809	8 830	5 242	8 502	5 917	4 455	4 110	8 308	8 407
Saluda River at Waterloo, S. C., 1897–1905	1 699	3 402	2 984	2 520	1 596	1 997	1 549	1 981	1 452	1 226	1 183	1 771	1 947
Savannah River at Augusta, Ga., 1898–1905	9 990	22 168	18 665	13 358	8 617	10 799	8 362	11 041	9 811	6 862	6 234	11 120	11 419
Ocmulgee River at Macon, Ga., 1893–1905	2 765	5 665	5 391	3 825	1 991	2 375	2 528	2 656	2 127	1 599	1 594	2 683	2 933
Oconee River at Dublin, Ga., 1898 (11 months), 1899–1905	5 852	10 344	8 735	7 605	3 599	4 015	3 252	3 586	3 828	2 654	2 699	4 860	5 086
Ohoopee River at Reidsville, Ga., 1904, 1905	903	2 194	2 346	1 060	344	900	916	1 501	708	266	408	650	1 016
Flint River at Albany, Ga., 1902–1905	7 622	15 266	11 796	9 145	6 710	5 052	4 233	6 228	4 592	2 798	3 331	6 827	6 966

Table showing average discharge in cubic feet per second—Continued.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
Chattahoochee River at West Point, Ga., 1896 (5 months), 1897–1905	6 059	10 907	10 953	8 170	5 077	5 238	4 685	5 326	3 773	3 001	3 087	5 766	6 004
Alabama River at Selma, Ala., 1900–1905	34 920	58 699	53 109	47 041	22 163	19 584	15 898	17 093	10 821	8 947	9 095	24 114	26 790
Cohaba River at Centerville, Ala., 1902–1905	1 626	3 696	2 822	1 459	1 266	533	544	675	349	393	344	1 034	1 228
Black Warrior River at Tuscaloosa, Ala., 1895–1902	14 392	15 679	27 602	16 831	3 849	5 373	2 594	1 787	936	1 226	1 351	5 992	8 134
Tombigbee River at Epes, Ala., 1901, 1905	19 384	29 164	17 194	14 456	9 190	3 840	2 804	13 876	2 602	2 214	1 954	10 162	10 570
Mississippi River at mouth of Red River, 1881 (4 months), 1882, 1883, 1884 (8 months)*	848 979	1 752 929	1 304 354	1 009 433	925 451	868 211	613 107	333 677	212 933	316 419	497 978	533 430	768 075
Sabine River, near Longview, Tex., 1905	385	1 251	3 134	5 511	16 640	4 470	9 777	1 934	195	461	1 332	6 388	4 290
Neches River at Evadale, Tex., 1904 (6 months), 1905	5 090	7 171	10 210	12 870	15 070	7 865	5 604	3 003	724	448	2 213	3 178	6 121
Trinity River at Riverside, Tex, 1903, 1904, 1905	3 063	6 828	12 239	10 848	14 043	10 767	10 013	5 227	821	2 436	2 035	4 100	6 868
Brazos River at Richmond, Tex., 1903, 1904, 1905	3 651	8 855	16 698	9 018	25 032	8 653	9 183	6 538	2 123	3 687	2 104	2 347	8 157
Colorado River at Columbus, Tex., 1904, 1905	797	942	2 351	3 910	8 701	4 910	2 898	2 066	2 036	1 862	1 504	1 520	2 792
Rio Grande at Eagle Pass, Tex., 1900 (8 months), 1902–1905	2 495	2 503	3 365	3 131	5 678	10 530	8 468	7 909	16 118	9 177	5 349	4 566	6 607
Colorado River at Yuma, Ariz., 1902–1905	4 645	9 806	16 884	16 598	34 891	53 988	25 841	11 074	7 180	8 115	6 934	7 408	16 947
Sacramento River at Collinsville, Cal., 1878–1884	30 500	38 167	60 833	93 867	93 867	62 667	23 833	10 250	7 083	7 917	8 700	15 067	37 729

*From measurements made by Mississippi River Commission.

123. *Direct action of winds in causing the annual height inequality.*

In shallow arms of the ocean the direct action of the wind in altering the height of the surface is very apparent.

Along the eastern coast of the United States the prevailing wind is northwesterly during the winter season and southwesterly, south, or southeasterly during the summer season. As a consequence the height of the sea is considerably lowered in the winter season and, at least in many localities, increased during the summer season. This explains the annual inequality at Governors Island, Baltimore, Old Point Comfort, Savannah River Entrance, and Fernandina, and in the main that for Philadelphia, Washington, and Wilmington (N. C.), although the upper-river stages are factors of some importance at these stations.

At Philadelphia the high water of the annual fluctuation occurs about September 1 and the low water in December or January. There seems to be, however, a secondary high water in March and low water in May. According to river gaugings made by the U. S. Geological Survey at Lambertville, N. J., the greatest monthly discharge of the Delaware River takes place during the month of March, the least during the month of September.

At Washington, D. C., the high water of the annual fluctuation occurs in June or July, the low water about March 1. According to river gaugings made at Point of Rocks, Md., the greatest monthly discharge takes place during the month of March, the least during the month of September.

At Wilmington, N. C., the high water of the annual fluctuation occurs in September or October, the low water about March 1. Gaugings at Fayetteville show that the months of greatest and least discharge nearly coincide with February and November.

At gauging stations situated above tidal influence, an increase of height in the water-level is accompanied by an increase of discharge and the empirical relation between the two constitutes a rating table for the stream with reference to which it has been constructed.

The northerly winds across the Gulf of Mexico produce low water at Galveston in February, while the southerly winds produce high water in October, the range being 1.5 feet. (The inundation and destruction of Galveston resulting from a West India hurricane occurred September 8, 1900.)

According to observations made by the Coast Survey in 1847 and 1848, the average effect of a north wind is to depress the waters of Albemarle Sound, North Carolina, between one and two tenths of a foot, and the effect of a south or southwest wind is to raise the level by about the same amount.* The fact that the result was the same for both sides of the Sound indicates clearly that the action of the winds upon Pamlico Sound is the principal cause of the fluctuation in level.

According to observations made in 1848 the average effect of southeasterly winds at Cat Island is to elevate the surface of the water 0.3 foot and that of north or northwest winds to depress the level 0.2 foot.†

Along the coast of New England, Canada, and Newfoundland the annual inequality is small and uncertain, the winds there having a less marked annual change than farther southward.

At Boston the prevailing winds at all seasons of the year are westerly, a little north of west in the winter, and somewhat southwesterly in the summer.‡

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* Report for 1856, p. 271. † Report for 1856, p. 278.

‡ See Appendix No. 6, U. S. Coast Survey Report for 1871. Here Ferrel shows the connection between the fluctuations of the sea and the variations of the barometer and the winds.

The winter winds along the Atlantic coast of the United States are the strongest of the year; consequently the water is most diminished in height during that season.

The prevailing summer winds of the southern and eastern coasts of Asia are nearly opposite in direction from the prevailing winter winds. (See Figs. 18, 19, and table in section 124.) The southwest monsoon draws the water away from Aden and the Red Sea in the summer season, but tends to pile it up on the coast of Baluchistan and the upper India; it diminishes the height in the neighborhood of Minikoi and Ceylon, but increases the height at Bengal and the southwestern coast of Farther India. This explains the semiannual reversal of currents observed in the Strait of Bab-el-Mandeb and mentioned in section 116. The southeasterly trend of the Malabar coast prevents the southwest monsoon from actually increasing much the height along the western coast, as the long series of observations at Karachi shows.

At Dublat, the mouth of the Hooghly River, the maximum occurs late in July with a range of 1.8 feet; farther up, at Diamond Harbor, it occurs early in August with a range of 2.1 feet; while at Calcutta (Kidderpore), where the effects of the river stages are apparent, the maximum occurs about September 1, the range being 6.1 feet.

The coast stations Chittagong and Akyab have annual inequalities of 3.2 and 1.9 feet, respectively, with maxima occurring in July, thus agreeing with the monsoon season.

For Elephant Point, a coast station at the mouth of the Rangoon River, the range of the annual inequality is 1.7 feet, while at Rangoon it is 2.7 feet. The maximum at the former place occurs about July 27 and at the latter place about August 26. Other coast stations are Port Blair (Andaman Islands), Mergui, and Amherst, with ranges 0.5, 1.2, 1.6 feet, respectively, and with maximum falling in or near August. The increase of range in going from the Andaman Islands to the main land is in accordance with what would necessarily result from wind effects.

For details concerning the tidal stations and tides of India, see Account of the Operations of the Great Trigonometrical Survey of India, Volume 16, Tidal Observations.

By the southwest monsoon the water level is elevated during the summer season along the western coast of Luzon and especially in the Yellow Sea. Water is, however, drawn away from the southern portion of the China Sea. Among the East Indies the effects are various, because water can drift in or out from either the Indian or the Pacific Ocean. Although it is difficult to infer the time of maximum height from the known monsoons, there is little doubt that the annual fluctuation along the coast is chiefly a wind effect.

The shallow and northern part of Bering Sea is elevated by southerly winds, which blow over Bering Sea during the summer season, and depressed by the northerly winds in winter.

The southwesterly winds of autumn produce high water along the shores of the Gulf of Alaska, while the easterly winds of spring and summer produce low waters.

The easterly wind is strongest for the eastern coast of Australia in March, and in consequence the sea level at Sydney, Ballina, and Newcastle is highest in the (north) spring season.

At Panama southwesterly winds prevail through the greater part of the year; but during the month of February, the winds are northeasterly. The annual fluctuation attains its maximum on about November 1 and its minimum on about February 20. The range of the oscillation is 2.0 feet.

By consulting the table given in section 124, it will be seen that for the Atlantic coast of Europe annual high water occurs from about September to December and low water from March to June. The range of the fluctuation is 1.0 foot at Greenock, 0.9 foot at Liverpool, but only 0.4 foot at Edinburgh, 0.5 at Sheerness, and 0.4 at London, and 0.3 at Ramsgate. Since greater ranges of annual tide occur on the western side of Great Britain and around Ireland than on the eastern side, the inference most readily drawn is that the winds are the controlling factor in its production. By consulting Pls. 21–24 of the Atlas of the Atlantic Ocean, by the German Seewarte, also Pl. 12 of Bartholomew's Physical Atlas (Meteorology), it will be seen that the west winds along the coasts of Europe are strongest in the autumn and weakest in the spring.

As pointed out by Lentz in his Fluth and Ebbe, Chapter III, the annual tide of the Baltic coast of Germany is governed by the winds. In September it has a maximum height and in May a minimum. The minimum coincides in time with the maximum amount of northeasterly winds, which blow the water out of the Baltic into the North Sea.

Levels run from Helder to Memel prove the existence of a permanent displacement of level produced by the winds, and comparable in order of magnitude with the annual fluctuation. It increases in height from Kiel to Memel.*

At Wilhelmshaven the maximum height occurs about October 1, and the minimum early in April.

The foregoing statements and the table in section 124 indicate that as a rule the water at most tidal stations stands highest in the summer or autumn and lowest in the winter or spring. This suggests that the annual fluctuation may be due to the alternate heating and cooling of the ocean waters, causing alternate expansion and contraction of the volumes. This possibility will be considered in the next section. Here it may be noted that as sea breezes at the earth's surface occur by day and land breezes by night, so the wind blows from the ocean in summer and from the land in winter. Without further assumptions we thus have an agency for producing the annual fluctuation and whose potency in many instances can not be doubted.

High-pressure areas are formed on the lands in winter and in the oceans in summer. Hence, the annual inequality can not be directly due to this cause. Moreover, the annual barometric fluctuations are too small to account for the annual inequality in sea level at most places. It seldom has a range of more than 0.3 of an inch, and this could give only about 0.3 of a foot for the range of the annual inequality.† In some instances it undoubtedly increases the annual inequality, as at St. Paul, Kodiak Island, Alaska, where the minimum pressure occurs in winter and the maximum in summer.

Since winds along the surface of the earth are in a general way setting from high-pressure areas toward low-pressure areas, it follows that indirectly these annual fluctuations in the barometer do in this sense greatly influence and even occasion the annual inequality in sea level. But as already intimated, the direct effect is often at variance with the indirect and far more important effect, viz., that due to resulting winds.

* Hugo Lentz: Fluth and Ebbe, und die Wirkungen des Windes auf den Meeresspiegel, Hamburg, 1879, pp. 120, 121.

Cf. P. G. Rosen: Om hafsytans höjdförhållande vid några punkter af Sveriges kuster under tiden 1887–1900, Vol. 1, Sv. Hydro. Biol. Kom. Skrifter.

† Berghaus' Physikalischer Atlas, Charts Nos. 33, 34. Coast Survey Report 1875, Figs. 33, 34.

124. *Long-period tides and*

No.	Station	Latitude	Longitude	Mf	Mf°	Mm	Mm°	Sa	
		° ′	° ′	*Feet*	°	*Feet*	°	*Feet*	°
	EAST COAST OF AMERICA.	*North*	*West*						
28	St. Johns, Newfoundland	47 34	52 41					0.200	268
32	Quebec	47 49	71 12	0.122	76	0.303	34	.490	65
36	St. Paul Island	47 14	60 08					.073	164
40	Halifax	44 40	63 35	* .025 † .042	* 324 † 178	* .029 † .113	* 215 † 64	.150	252
42	St. John, New Brunswick	45 14	66 04	.056	184	.047	137	.115	93
44	Eastport, Me	44 54	66 59					.105	338
45	Pulpit Harbor	44 09	68 53	.043	88	.053	22	.163	172
46	Portland, Me	43 39	70 15					.200	178
50	Boston	42 22	71 03					.094	116
58	Newport	41 29	71 20					.144	153
59	Bristol	41 40	71 16					.194	151
60	Providence	41 49	71 24					.244	106
63	New London	41 21	72 05					.242	153
66	Willets Point	40 48	73 46					.153	110
67	New York, Governors Island	40 41	74 01					.244	127
70	Sandy Hook	40 27	74 00					.068	208
77	Philadelphia	39 57	75 09					.417	146
85	Old Point Comfort	37 00	76 19					.320	126
90	Washington Navy Yard	38 52	77 01					.272	128
95	Baltimore	39 17	76 35					.260	123
98	Wilmington	34 14	77 57					.302	173
101	Charleston, Custom-house Wharf	32 47	79 55					.288	186
193	Savannah Entrance, Tybee Island Light	32 02	80 51					.217	124
105	Fernandina, Fort Clinch	30 41	81 28					.237	105
106	Fernandina, Dade St	30 41	81 28					.406	186
113	Key West, Fort Taylor	24 33	81 48					.377	216
125	Pensacola, Warrington Navy Yard	30 21	87 16					.244	92
131	Port Eads	29 01	89 10					.361	173
140	Galveston	29 19	94 47					.528	170
154	Nassau, Bahamas	25 05	77 21					.312	144
		South							
186	Buenos Ayres	34 36	58 22					.389	321
	WEST COAST OF AMERICA.								
200	Cape Horn, Orange Bay	55 31	68 05					.156	92
205	Valparaiso, Chile	33 02	71 39					.151	351
		North							
210	Panama, Naos Island	8 55	79 32					.685	170
215	Mazatlan, Mexico (west coast)	23 11	106 27					.126	153
221	San Diego	32 42	117 14					.231	189
224	San Francisco, Entrance	37 49	122 29					.398	156
225	Sansalito	37 50	122 28					.150	244
226	San Francisco, Presidio, Cal	37 48	122 27					.149	156
227	Astoria, Oreg	46 11	123 50					.244	284
230	Port Townsend	48 07	122 45					.270	288
241	Sand Heads, Fraser River	49 05	123 16	.081	121	.101	354	.169	264
250	Sitka	57 03	135 20					.260	284
265	Kodiak (St. Paul), Alaska	57 48	152 21					.899	216

* Two years. † One year.

computed annual fluctuation.

Ssa		No. of years observed	Principal				Secondary				No.
			Maximum		Minimum		Maximum		Minimum		
			Time	Height	Time	Height	Time	Height	Time	Height	
Feet	°			*Feet*		*Feet*		*Feet*		*Feet*	
0.071	217	‡8	Dec. 31	0.26	May 12	−0.19	....	....	....	....	28
.428	110	6	May 19	0.91	Jan. 30	−0.58	Nov. 12	−0.05	Sept. 3	−0.41	32
.143	273	....	Aug. 12	0.21	May 2	−0.18	Feb. 3	0.08	Nov. 14	−0.11	36
.158	146	5	Dec. 4	0.31	Mar. 19	−0.18	June 5	0.01	Aug. 21	−0.17	40
.160	125	8	May 30	0.26	Feb. 14	−0.22	Nov. 7	0.06	Sept. 3	−0.11	42
.044	309	1	Feb. 26	0.15	Oct. 21	−0.08	Aug. 25	−0.06	July 5	−0.07	44
.086	87	5	Oct. 18	0.21	Feb. 16	−0.22	June 11	0.02	July 4	0.02	45
.016	181	1	Sept. 18	0.18	Mar. 21	−0.22	....	....	....	....	46
.081	99	1	May 25	0.13	Feb. 4	−0.17	Oct. 23	0.06	Aug. 20	0.00	50
.067	145	1	July 3	0.12	Mar. 7	−0.21	Oct. 28	0.09	Sept. 14	0.07	58
.059	87	1	Sept. 28	0.17	Feb. 12	−0.25	....	....	....	....	59
.044	17	1	July 26	0.21	Jan. 4	−0.29	....	....	....	....	60
.124	100	1	Oct. 12	0.24	Feb. 11	−0.35	June 13	0.11	July 19	0.10	63
.113	111	2	May 31	0.22	Feb. 7	−0.24	Oct. 26	0.04	Sept. 2	0.00	66
.173	47	3	Sept. 26	0.27	Jan. 18	−0.41	May 8	0.16	July 8	0.07	67
....	....	....	Oct. 19	0.07	Apr. 20	−0.07	....	....	....	....	70
.342	325	....	Aug. 31	0.74	Dec. 20	−0.51	Mar. 13	−0.05	May 16	−0.28	77
.106	161	2	July 3	0.37	Feb. 21	−0.37	....	....	....	....	85
.194	163	1	June 25	0.40	Mar. 2	−0.41	Nov. 22	0.04	Oct. 2	−0.02	90
.060	35	1	Aug. 23	0.23	Jan. 16	−0.31	....	....	....	....	95
.027	94	2	Sept. 25	0.30	Mar. 7	−0.32	....	....	....	....	98
.165	84	1	Oct. 23	0.41	Feb. 18	−0.37	May 29	−0.03	July 4	−0.05	101
.103	245	1	Sept. 10	0.22	Jan. 10	−0.31	May 16	0.09	June 8	0.08	103
.168	37	1	....	....	....	....	....	....	....	....	105
.308	207	1	July 24	0.42	Apr. 3	−0.71	Dec. 15	0.32	Oct. 9	0.09	106
.075	86	1	Oct. 30	0.45	Apr. 10	−0.30	....	....	....	....	113
.212	359	1	Sept. 4	0.26	Dec. 21	−0.46	Apr. 8	0.24	June 20	0.03	125
.180	87	1	Oct. 18	0.45	Feb. 17	−0.49	June 19	0.03	June 24	0.03	131
.332	44	1	Oct. 4	0.80	Jan. 29	−0.67	May 2	−0.07	June 17	−0.15	140
.101	33	1	Sept. 15	0.34	Jan. 26	−0.38	....	....	....	....	154
.166	336	1	Feb. 28	0.53	July 3	−0.42	....	....	....	....	186
.013	226	1	June 30	0.17	Dec. 15	−0.13	....	....	....	....	200
.091	228	1	Jan. 31	0.19	Oct. 6	−0.22	June 18	−0.04	May 7	0.02	205
.478	114	1	Nov. 1	0.85	Feb. 20	−1.12	June 11	0.33	Aug. 5	0.12	210
.133	248	1	July 31	0.25	Apr. 15	−0.20	Jan. 17	0.03	Nov. 7	−0.08	215
.114	280	3	Aug. 28	0.29	Apr. 28	−0.31	....	....	....	....	221
.184	221	4	July 29	0.50	Mar. 27	−0.51	....	....	....	....	224
.043	233	1	Dec. 23	0.15	May 5	−0.17	....	....	....	....	225
.076	277	4	Aug. 15	0.22	Apr. 16	−0.15	Jan. 22	−0.06	Dec. 14	−0.07	226
.267	151	2	Dec. 12	0.49	Aug. 26	−0.40	May 30	0.06	Mar. 21	−0.17	227
.131	225	3	Jan. 11	0.40	May 14	−0.22	July 19	−0.14	Sept. 10	−0.18	230
.204	217	2	Jan. 5	0.36	Apr. 20	−0.29	July 17	0.05	Sept. 28	−0.15	241
.055	336	1	Jan. 30	0.25	June 23	−0.31	....	....	....	....	250
.495	49	1	Oct. 19	1.38	June 22	−0.85	Apr. 6	−0.37	Feb. 13	−0.54	265

‡ Months.

Long-period tides and

No.	Station	Latitude	Longitude	Mf	Mf°	Mm	Mm°	Sa	
		° ′	° ′	*Feet*	°	*Feet*	°	*Feet*	°
	EAST COAST OF ASIA.	*North*	*East*						
342	Yokohama, Japan	35 27	139 39	......	......	......	......	0.341	190
430	Shanghai	31 21	121 30	......	......	......	......	1.518	128
436	Swatow	23 23	116 39	0.069	120	0.050	298	.467	270
438	Whampoa	23 05	113 26	......	......	......	......	.484	171
440	Hongkong	22 18	114 10	.083	310	.073	101	.450	234
490	Singapore	1 17	103 51	......	......	......	......	.308	209
	OCEANICA.	*South*							
506	Pulu Besar Strait	2 54	106 06	......	......	......	......	.394	262
507	Telok Betong	5 27	105 16	......	......	......	......	.184	263
512	Padang	1 00	100 18	......	......	......	......	.258	144
		North							
513	Ajerbangies	0 12	99 24	......	......	......	......	.256	122
515	Natal	0 36	99 06	......	......	......	......	.244	112
516	Gunung Sitoli	1 18	97 36	......	......	......	......	.381	156
517	Siboga	1 42	98 48	......	......	......	......	.180	88
518	Baros	2 00	98 24	......	......	......	......	.157	284
523	Oleh-leh	5 36	95 18	......	......	......	......	.289	65
524	Sabang Bay	5 54	95 20	......	......	......	......	.302	165
625	Segli	5 18	96 00	......	......	......	......	.472	153
527	Edi	4 54	97 48	......	......	......	......	.436	136
528	Belawan Deli	3 48	98 42	......	......	......	......	.364	116
529	Tandjong Tiram	3 18	99 30	......	......	......	......	.958	108
531	Bengkalis	1 30	102 06	......	......	......	......	1.194	201
		South							
533	Kuala Ladjan	1 24?	103 36	......	......	......	......	.755	286
535	Tandjong Buton	0 12	104 36	......	......	......	......	.384	273
541	Edam Island	5 58	106 51	......	......	......	......	.056	172
544	Boompjes Island	5 54	108 24	......	......	......	......	.112	103
547	Semarang	7 00	110 24	......	......	......	......	.374	77
552	Sembilangan	7 06	112 42	......	......	......	......	.364	103
553	Surabaya	7 12	112 36	......	......	......	......	.112	292
554	Gading	7 12	112 54	......	......	......	......	.049	79
555	Karang Kleta	7 18	112 48	......	......	......	......	.075	33
556	Pasuruan	7 38	112 54	......	......	......	......	.075	40
557	Zwaantjes-droogte	7 30	113 06	......	......	......	......	......	......
559	Pulu Sapudi	7 06	114 18	......	......	......	......	.289	67
560	Meinderts-droogte	7 36	114 24	......	......	......	......	.272	10
565	Labuan, Java	6 24	105 12	......	......	......	......	.121	324
566	Java Fourth Point	6 06	105 54	......	......	......	......	.354	218
570	Pulu Langkuas	2 30	107 36	......	......	......	......	.676	283
571	Ondiepwater Island	3 18	107 12	......	......	......	......	.282	184
580	Sukadana	1 12	109 54	......	......	......	......	.842	283
582	Pontianak	0 00	109 18	......	......	......	......	.440	308
		North							
584	Pemangkat	1 12	109 00	......	......	......	......	.458	267
590	Boeloengan	2 50	117 22	......	......	......	......	.416	347
		South							
593	Moera Djawa	0 38	117 18	......	......	......	......	.267	317

computed annual fluctuation—Continued.

Ssa		No. of years observed	Principal				Secondary				No.
			Maximum		Minimum		Maximum		Minimum		
			Time	Height	Time	Height	Time	Height	Time	Height	
Feet	°			*Feet*		*Feet*		*Feet*		*Feet*	
.100	118	1	Oct. 27	0.38	Mar. 11	−0.40	....	....	....	....	342
.478	73	1	Sept. 7	1.11	Jan. 28	−1.99	June 24	1.05	July 21	1.03	430
.258	96	1	Nov. 18	0.64	July 26	−0.61	Apr. 10	−0.01	Mar. 12	−0.03	436
.135	92	1	Oct. 10	0.51	Feb. 23	−0.57	....	....	....	....	438
.190	94	2	Nov. 11	0.64	July 6	−0.37	Apr. 26	−0.25	Mar. 20	−0.28	440
.312	234	1	Jan. 4	0.36	Apr. 20	−0.62	Aug. 3	0.34	Oct. 14	−0.01	490
.079	180	5	....	....	....	....	....	....	....	....	506
.312	120	....	Nov. 24	0.48	Aug. 14	−0.39	May 19	0.14	Mar. 1	−0.25	507
.214	120	2	June 9	0.28	Feb. 19	−0.47	Nov. 3	0.23	Aug. 24	0.04	512
.151	106	4	June 5	0.28	Feb. 7	−0.40	Oct. 20	0.12	Aug. 30	0.08	513
.226	32	2	Sept. 22	0.28	Jan. 8	−0.47	Apr. 24	0.23	July 6	0.02	515
.131	108	1	Oct. 9	0.32	Feb. 19	−0.51	....	....	....	....	516
.190	166	1	June 16	0.37	Mar. 2	−0.23	Dec. 13	0.01	Sept. 28	−0.20	517
.082	261	3	Jan. 23	0.23	May 24	−0.18	Aug. 23	−0.04	Oct. 1	−0.05	518
.223	145	3	June 2	0.51	Sept. 22	0.30	Dec. 7	−0.06	Feb. 13	−0.23	523
.279	114	....	Nov. 4	0.41	Feb. 21	−0.58	June 5	0.22	Aug. 12	0.00	524
.226	147	1	July 3	0.42	Mar. 3	−0.69	Nov. 3	0.28	Sept. 14	0.23	525
.223	143	1	June 25	0.48	Feb. 23	−0.63	Oct. 26	0.15	Sept. 27	0.13	527
.161	305	1	Aug. 11	0.48	Dec. 13	−0.43	....	....	....	....	528
.161	71	1	June 21	0.82	Jan. 12	−1.10	....	....	....	....	529
.266	194	1	Nov. 11	1.03	Apr. 6	−1.43	....	....	....	....	531
.289	85	1	Dec. 1	0.78	July 24	−0.99	....	....	....	....	533
.052	53	1	Dec. 7	0.35	July 4	−0.42	....	....	....	....	535
.075	143	3	Nov. 22	0.09	Mar. 6	−0.13	June 14	0.07	Aug. 31	−0.02	541
.052	107	5	June 3	0.14	Dec. 31	−0.15	....	....	....	....	544
....	....	....	June 9	0.37	Dec. 8	−0.37	....	....	....	....	547
.184	150	4	June 16	0.52	Feb. 15	−0.41	Nov. 11	−0.10	Oct. 15	−0.11	552
.217	165	1	Dec. 17	0.32	Sept. 8	−0.28	June 10	0.12	Mar. 22	−0.17	553
.128	154	1	June 9	0.18	Mar. 4	−0.13	Dec. 8	0.08	Sept. 14	−0.13	554
.105	126	1	May 21	0.17	Sept. 2	−0.15	Nov. 30	0.04	Feb. 14	−0.07	555
.098	142	1	May 29	0.16	Sept. 11	−0.14	Dec. 9	0.04	Feb. 21	−0.07	556
.115	106	2	....	....	....	....	....	....	....	....	557
.144	167	5	June 10	0.42	Oct. 10	−0.28	Jan. 4	−0.12	Feb. 8	−0.14	559
.180	136	....	May 15	0.36	Sept. 8	−0.42	Dec. 24	0.08	Feb. 11	0.03	560
.217	174	1	Dec. 25	0.29	Sept. 14	−0.32	June 12	0.16	Mar. 25	−0.12	565
.210	169	5	Dec. 2	0.48	Mar. 30	−0.49	July 10	0.02	Aug. 24	−0.01	566
.066	138	4	Dec. 26	0.71	July 17	−0.66	....	....	....	....	570
.098	86	5	Oct. 18	0.34	Feb. 26	−0.32	....	....	....	....	571
.210	135	2	Dec. 18	1.00	Aug. 1	−0.87	....	....	....	....	580
.210	155	3	Dec. 27	0.54	Aug. 26	−0.58	....	....	....	....	582
.079	104	2	Dec. 5	0.51	July 9	−0.46	....	....	....	....	584
.188	28	1	Mar. 27	0.57	July 29	−0.45	....	....	....	....	590
.101	73	1	Mar. 25	0.22	Aug. 3	−0.37	Dec. 27	0.15	Dec. 30	0.15	593

Long-period tides and

No.	Station	Latitude	Longitude	Mf.	Mf°	Mm	Mm°	Sa	
		° ′	° ′	*Feet*	°	*Feet*	°	*Feet*	°
	OCEANICA—continued.	*South*	*East*						
594	Bay of Balik	1 16	116 48					.315	19
597	De Bril	6 06	118 54						
598	Makasser	5 08	119 24					.088	326
600	Donggala	0 40	119 44					.068	315
		North							
002	Tontoli	1 00	120 53					.367	242
603	Kema	1 24	125 06					.955	107
604	Gorontalo	0 30	123 06					.328	231
		South							
605	Posso	1 24	120 54					.341	16
607	Kadjang	5 24	120 18					1.552	359
608	Bonthain	5 36	119 54					.453	259
609	Saleyer	6 06	120 30					.226	224
612	Bima	8 24	118 42					.121	291
614	Kupang	10 12	123 36					.075	54
620	Banda	4 30	129 54					.489	351
		North							
626	Gamsungi	0 12	128 48					.198	256
627	Ternate	0 48	127 24					.226	357
628	Galela	1 48	127 48					.541	340
632	Taruna	3 42	125 30					.850	64
640	Manila, P. I	14 36	120 57					.451	162
641	Olongapo, P. I.	14 50	120 16					.480	162
660	Honolulu	21 18	157 52					.215	197
		South							
680.2	Auckland	36 51	174 48					.357	88
680.5	Wellington, New Zealand	41 17	174 46					.241	54
681	Port Chalmers	45 50	172 30					.080	2
681.5	Port Darwin	12 23	130 37					.970	76
682	Cooktown	15 27	145 15					.346	320
682.5	Cairns Harbour	16 35	145 47					.202	9
683	Brisbane Bar	27 31	153 00					.109	8
683.5	Ballina	28 52	153 33	.097	314	.102	2	.413	7
684	Newcastle	32 57	151 44	.051	105	.082	198	.232	70
685	Sydney	33 52	151 12					.093	16
689	Port Adelaide	34 51	138 30	.06	181	.07	200	.305	126
689.5	Princess Royal Harbour	35 08	118 00	.064	175	.065	135	.328	111
690	Freemantle	32 03	115 45	.082	25	.079	147	.537	27
	INDIAN OCEAN.	*North*							
710	Mergui (Bay of Bengal)	12 26	98 36	.043	19	.067	14	.589	146
720	Amherst, Moulmein River	16 05	97 34	.067	327	.071	2	.758	136
722	Moulmein, Moulmein River	16 29	97 37	.328	39	.366	12	2.330	149
725	Elephant Point, Rangoon River	16 30	96 18	.108	35	.096	355	.842	140
726	Rangoon, Rangoon River	16 46	96 10	.181	34	.206	12	1.315	147
730	Diamond Island	15 52	94 15						
735	Akyab	20 08	92 54	.064	190	.045	321	.944	145
740	Chittagong	22 20	91 50	.141	17	.192	356	1.567	134

computed annual fluctuation—Continued.

Ssa		No. of years observed	Principal				Secondary				No.
			Maximum		Minimum		Maximum		Minimum		
			Time	Height	Time	Height	Time	Height	Time	Height	
Feet	°			*Feet*		*Feet*		*Feet*		*Feet*	
.092	208	1	May 15	0.24	Oct. 8	−0.41					594
.344	354	4									597
.021	229	5	Feb. 2	0.11	Sept. 12	−0.10					598
.018	307	4	Feb. 15	0.08	July 6	−0.06					600
.331	215	4	Dec. 30	0.61	Apr. 19	−0.61	July 24	0.11	Sept. 25	−0.10	602
.085	289	1	July 18	0.99	Dec. 28	−0.95					603
.141	208	1	Dec. 16	0.38	Apr. 20	−0.43					604
.049	137	1	Apr. 25	0.34	Sept. 25	−0.37					605
.413	155	1	Apr. 24	1.30	Sept. 14	−1.96					607
.564	275		Jan. 29	0.83	May 14	−0.96	Aug. 19	0.37	Oct. 31	−0.19	608
.167	37	1	Oct. 17	0.38	June 25	−0.29	Mar. 29	−0.03	Jan. 31	−0.11	609
.157	226	1	Jan. 14	0.28	Apr. 26	−0.17	July 16	0.04	Oct. 3	−0.16	612
.128	188	1	June 21	0.19	Oct. 1	−0.18	Jan. 1	0.07	Mar. 20	−0.08	614
.161	4	1	Mar. 20	0.64	July 30	−0.41					620
.114	100		Nov. 19	0.30	July 24	−0.23	Apr. 28	0.05	Mar. 7	−0.07	626
.059	145		Apr. 25	0.20	Sept. 11	−0.28					627
.141	97	1	Apr. 2	0.49	Aug. 21	−0.65					628
.180	48	1	May 10	0.95	Dec. 16	−0.90					632
.102	58	1	Sept. 25	0.49	Feb. 13	−0.50					640
.136	31	1	Sept. 21	0.57	Feb. 4	−0.51					641
.090	331	1	Oct. 8	0.30	June 1	−0.16	Apr. 9	−0.12	Feb. 13	−0.15	660
.185	266	2	July 21	0.47	Nov. 19	−0.47	Mar. 13	0.00	Mar. 29	0.00	680.2
.035	240	1									680.5
.064	168	1									681
.540	58	1	May 6	1.30	Jan. 6	−1.31	Sept. 20	0.06	Aug. 20	0.01	681.5
.051	36	1	Feb. 28	0.34	July 31	−0.38					682
.050	157	1	May 1	0.19	Sept. 20	−0.25					682.5
.005	156	1	Apr. 4	0.10	Sept. 27	−0.11					683
.063	257	1	Mar. 13	0.40	Oct. 11	−0.46					683.5
.074	201	1	June 19	0.29	Oct. 30	−0.24					684
.008	97	*6	Apr. 17	0.10	Sept. 28	−0.09					685
.225	88	2	May 26	0.32	Feb. 3	−0.53	Oct. 15	0.24	Aug. 10	0.08	689
.235	97	1	May 26	0.43	Feb. 2	−0.54	Oct. 18	0.14	Aug. 24	0.04	689.5
.175	126	1	May 10	0.65	Sept. 19	−0.58					690
.158	113	5	Sept. 9	0.44	Feb. 16	−0.74	July 29	0.43	Aug. 13	0.43	710
.149	145	5	July 18	0.68	Feb. 17	−0.88					720
.616	286	6	Aug. 18	2.94	Mar. 21	−1.82					722
.129	150	5	July 27	0.93	Feb. 20	−0.77					725
.160	339	17	Aug. 26	1.45	Feb. 3	−1.21					726
											730
.194	160	5	July 13	0.83	Feb. 27	−1.11					735
.153	195	5	July 27	1.64	Feb. 17	−1.55					740

*Months.

Long-period tides and

No.	Station	Latitude	Longitude	Mf	Mf°	Mm	Mm°	Sa	
		° ′	° ′	*Feet*	°	*Feet*	°	*Feet*	°
	INDIAN OCEAN—continued.	*North*	*East*						
745	Dublat, Hoogly River	21 38	88 06	0.061	60	0.037	89	0.876	151
746	Diamond Harbor, Hoogly River	22 11	88 12	.153	42	.117	10	1.058	142
747	Calcutta (Kidderpore)	22 32	88 20	.263	35	.287	4	2.852	156
748	False Point	20 23	86 47	.075	29	.046	67	.829	166
755	Vizagapatam	17 41	83 17	.054	14	.043	21	.694	184
756	Cocanada	16 56	82 15	*.084	*11	.063	321	.720	202
763	Madras	13 05	80 18	.043	22	.034	28	.394	216
765	Negapatam	10 46	79 51	.066	1	.049	335	.444	234
770	Pamban Pass	9 16	79 09	.043	355	.048	27	.149	302
772	Tuticorin	8 48	78 09	.041	357	.044	93	.299	310
773	Trincomalee, Ceylon	8 33	81 13	.054	14	.042	*352	.251	263
775	Point de Galle, Ceylon	6 02	80 13	.038	19	.039	14	.350	309
776	Colombo, Ceylon	6 56	79 50	.043	358	.037	27	.313	308
780	Port Blair, Andaman Islands	11 41	92 45	.048	11	.025	7	.200	144
785	Cochin	9 58	76 15	.056	356	.041	92	.337	302
787	Beypore	11 10	75 48	.068	†23	.081	50	.308	311
793	Kárwár	14 48	74 06	.042	5	.065	27	.352	310
795	Goa or Mormugóa	15 25	73 48	.059	*359	.030	369	.269	313
800	Bombay (Apollo Bandar)	18 55	72 50	.049	5	.052	5	.110	350
801	Bombay (Prince's Dock)	18 57	72 50	.053	13	.054	322	.102	303
802	Bhávnagar	21 48	72 09	.063	356	.109	0	.246	108
805	Port Albert Victor	20 58	71 33	.032	26	.045	126	.162	243
807	Porbandar	21 37	69 37	.016	......	......	......	.078	289.8
809	Okha Point and Bet Harbor	22 28	69 05	.050	44	.066	312	.162	3
810	Navanar	22 44	69 42	......	......	......	......	......	......
811	Hanstal	22 55	70 21	.101	37	.121	14	.024	195
815	Karachi	24 47	66 58	.036	1	.051	25	.130	68
820	Minikoi Light	8 16	73 01	.052	8	.038	56	.357	354
825	Bushire	29 00	50 52	.027	179	.073	47	.283	149
830	Muscat	23 37	58 35	.036	5	.047	28	.138	97
840	Aden	12 47	44 59	.042	16	.035	20	.378	356
845	Suez	29 58	32 32	‡(.042	‡171	‡.106	‡53)	§(.499	§312
850	Perim	12 38	43 24	.046	20	.030	197	.362	342
		South.							
870	Port Louis, Mauritius Island	20 08	57 29	.036	350	.047	297	.211	346
	WEST COAST OF AFRICA AND EUROPE.								
900	Cape Town	33 54	18 25	......	......	......	......	.124	256
908	Duala (Kamerun)	4 03	9 40	......	......	......	......	.361	206
		North							
925	Toulon, France	43 07	5 56	.061	159	.057	196	.123	254
926	Marseilles, France	43 18	5 23	.019	229	.010	293	.151	185
			West						
938	Socoa, France	43 24	1 40	.015	166	.056	327	.180	217
942	Boyard, France	46 00	1 13	.028	148	.049	203	.240	192
943	Rochelle, France	46 09	1 09	.033	26	.110	239	.401	257
944	St. Nazaire, France	47 16	2 12	.061	268	.099	37	.423	256
946	Brest, France	48 23	4 29	.043	173	.085	315	.203	229

* Four years. † Five years. ‡ Two years. § Three years.

computed annual fluctuation—Continued.

Ssa		No. of years observed	Principal				Secondary.				No.
			Maximum		Minimum		Maximum		Minimum		
			Time	Height	Time	Height	Time	Height	Time	Height	
Feet	°			*Feet*		*Feet*		*Feet*		*Feet*	
0.195	141	5	July 30	0.72	Feb. 26	−1.07	....	....	....	....	745
.097	129	5	Aug. 7	0.97	Feb. 16	−1.15	....	....	....	....	746
.930	331	16	Sept. 2	3.76	Jan. 17	−2.32	....	....	....	....	747
.279	151	4	Oct. 19	0.60	Mar. 9	−1.11	July 28	0.58	Sept. 3	0.55	748
.340	118	6	Nov. 2	0.82	Mar. 3	−0.96	....	....	....	....	755
.392	105	5	Nov. 4	1.04	Mar. 3	−0.85	June 9	−0.15	July 11	−0.19	756
.314	124	12	Nov. 17	0.68	Mar. 9	−0.53	June 5	−0.02	Aug. 5	−0.20	763
.344	128	5	Nov. 23	0.78	Mar. 14	−0.48	May 30	−0.09	Aug. 6	−0.34	765
.157	108	4	Nov. 27	0.22	Aug. 12	−0.30	May 2	0.12	Feb. 21	−0.02	770
.140	84	5	Dec. 5	0.23	Aug. 3	−0.43	Apr. 1	0.21	Feb. 5	0.16	772
.203	134	5	Dec. 2	0.45	Aug 13	−0.31	May 22	−0.03	Mar. 19	−0.17	773
.127	116	6	Dec. 21	0.32	Aug. 12	−0.45	....	....	....	....	775
.133	111	6	Dec. 15	0.30	Aug. 11	−0.44	....	....	....	....	776
.111	182	17	July 10	0.26	Mar. 12	−0.28	Nov. 20	0.03	Oct. 20	0.02	780
.118	150	6	Dec. 27	0.39	Aug. 19	−0.40	....	....	....	....	785
.166	205	6	Jan. 13	0.45	Sept. 14	−0.36	June 11	−0.08	May 9	−0.09	787
.068	228	5	Jan. 24	0.41	Aug. 24	−0.31	....	....	....	....	793
.116	138	5	Dec. 22	0.27	Aug. 18	−0.37	....	....	....	....	795
.134	201	19	Jan. 13	0.18	Sept. 30	−0.24	June 23	0.10	Apr. 9	−0.04	800
.140	181	9	Dec. 26	0.24	Sept. 13	−0.19	June 17	0.05	Apr. 3	−0.11	801
.153	149	8	June 16	0.37	Feb. 19	−0.32	Nov. 16	−0.03	Oct. 3	−0.06	802
.149	136	3	Nov. 28	0.31	Mar. 16	−0.18	June 1	0.01	Aug. 13	−0.16	805
.144	144.7	2	Dec. 8	0.21	Aug. 29	−0.19	May 30	0.08	Mar. 12	−0.10	807
.121	145	1	May 19	0.20	Sept. 9	−0.28	Dec. 25	0.09	Feb. 23	0.02	809
....	....	....	....	....	....	....	....	....	....	....	810
.090	156	1	Dec. 6	0.10	Mar. 13	−0.11	June 14	0.08	Sept. 7	−0.07	811
.152	149	25	June 5	0.28	Sept. 18	−0.18	Dec. 7	0.02	Feb. 22	−0.15	815
.138	244	4	Feb. 14	0.41	Oct. 8	−0.45	....	....	....	....	820
.122	224	3	July 28	0.37	Mar. 25	−0.33	....	....	....	....	825
.140	187	2	June 26	0.28	Mar. 12	−0.16	Dec. 24	0.00	Oct. 10	−0.15	830
.128	131	18	Apr. 25	0.36	Sept. 5	−0.49	....	....	....	....	840
§.157	§110)	....	Dec. 26	0.42	Aug. 11	−0.65	(........	....	....	....	845
.166	111	2	Apr. 21	0.35	Aug. 23	−0.52	Dec. 29	0.17	Jan. 25	0.16	850
.118	118	1	Apr. 29	c.22	Aug. 26	−0.32	Dec. 21	0.11	Feb. 6	0.08	870
.111	76	1	Nov. 7	0.21	July 19	−0.20	Apr. 17	0.02	Feb. 14	−0.05	900
.154	58	3	Oct. 20	0.51	Feb. 24	−0.28	Apr. 25	−0.21	June 13	−0.25	908
.108	114	3	Nov. 22	0.23	Aug. 4	−0.16	May 7	−0.01	Mar. 7	−0.09	925
.170	118	1	Nov. 11	0.27	Feb. 26	−0.30	June 2	0.09	Aug. 11	−0.05	926
.167	80	1	Oct. 31	0.35	Feb. 16	−0.20	May 3	−0.01	July 16	−0.18	938
.063	129	1	Oct. 29	0.25	Mar. 16	−0.28	....	....	....	....	942
.080	123	....	Dec. 1	0.47	July 3	−0.35	....	....	....	....	943
.190	65	....	July 8	0.54	Nov. 9	−0.52	....	....	....	....	944
.086	154	3	Nov. 28	0.27	Apr. 8	−0.22	....	....	....	....	946

§ Three years.

Long-period tides and

No.	Station	Latitude	Longitude	Mf	Mf°	Mm	Mm°	Sa	
		° ′	° ′	*Feet.*	°	*Feet*	°	*Feet*	°
	WEST COAST OF AFRICA AND EUROPE—con.	*North*	*West*						
948	St. Servan (St. Malo)	48 39	2 02	.085	230	0.064	154	0.320	222
950	Cherbourg	49 39	1 37	.010	102	.032	100	.169	200
			East						
952	Havre	49 29	0 06	.010	359	.101	273	.311	218
953	Thurso, Scotland	58 37	3 32					.265	219
954	Edinburgh, Scotland	55 59	3 10					.177	220
956	West Hartlepool, England	54 41	1 12	.046	205	.127	93	.265	219
958	Sheerness, England	51 27	0 45					.209	196
			West						
960	London Bridge, England	51 30	0 07					.124	112
			East						
962	Ramsgate, England	51 20	1 25	.044	288	.029	45	.127	181
			West						
968	Pembroke, Wales	51 41	4 56					.392	250
970	Helbre Island	53 24	3 00						
971	Liverpool, England	53 24	3 00	.041	282	.126	278	.362	238
978	Greenock, Scotland	55 57	4 45					.485	240
980.5	Queenstown, Ireland	51 51	8 16					.265	234
981	Galway, Ireland	53 14	9 04					.261	234
			East						
982	Ostende, Belgium	51 14	2 55					.161	222
983	Hook of Holland	51 59	4 09					.223	219
984	Ymuiden, Holland	52 28	4 34					.315	221
985	Helder, Holland	52 58	4 46					.341	213
1000	Christiania, Norway	59 55	10 44	.144	166	.154	235	.449	185
1001	Oscarsborg	59 41	10 37	.197	228	.177	182	.449	179
1002	Arendal	58 27	8 46	.092	223	.098	229	.322	195
1003	Stavanger	58 59	5 44	.075	205	.121	229	.246	221
1004	Bergen	60 24	5 08	.113		.134	166	.302	217
1005	Trondhjem	63 27	10 24					.446	252
1006	Bodö	67 17	14 23	.121	189	.089		.359	245
1007	Fineide	67 17	15 30	.010	206	.079	8	.348	213
1008	Kabelvaag	68 13	14 30	.125	78	.094	171	.374	264
1011	Vardö	70 20	31 06	.092	227	.061	193	.482	249

computed annual fluctuation—Continued.

Ssa		No. of years observed	Principal				Secondary.				No.
			Maximum		Minimum		Maximum		Minimum		
			Time	Height	Time	Height	Time	Height	Time	Height	
Feet	°			*Feet*		*Feet*		*Feet*		*Feet*	
0.128	92	1	Nov. 5	0.45	Mar. 15	−0.25	May 16	−0.19	June 26	−0.21	948
.061	158	1	Nov. 15	0.18	Mar. 25	−0.22	....	....	....	....	950
.148	151	....	Nov. 24	0.42	Mar. 27	−0.38	....	....	....	....	952
....	....	....	Oct. 31	0.26	May 1	−0.26	....	....	....	....	953
.082	113	3	Nov. 11	0.25	Mar. 15	−0.17	June 9	−0.08	July 8	−0.09	954
.097	223	3	Dec. 11	0.24	Apr. 17	−0.35	....	....	....	....	956
.046	155	1	Nov. 12	0.27	Mar. 24	−0.26	....	....	....	....	958
.131	197	3	July 3	0.25	Mar. 18	−0.17	Dec. 26	0.01	Oct. 14	−0.12	960
.075	288	1	Aug. 27	0.18	May 1	−0.16	Jan. 21	−0.01	Dec. 14	−0.02	962
....	....	....	Dec. 1	0.39	June 2	−0.39	....	....	....	....	968
....	....	....	....	....	....	....	....	....	....	....	970
.142	189	4	Dec. 11	0.46	Apr. 18	−0.41	....	....	....	....	971
.058	183	1	Dec. 1	0.52	May 9	−0.47	....	....	....	....	978
....	....	....	Nov. 15	0.26	May 16	−0.26	....	....	....	....	980.5
....	....	....	Nov. 15	0.26	May 16	−0.26	....	....	....	....	981
....	....	3	Nov. 3	0.16	May 4	−0.16	....	....	....	....	982
.079	236	1	Dec. 13	0.19	Apr. 24	−0.30	....	....	....	....	983
.098	210	1	Dec. 5	0.31	Apr. 19	−0.40	....	....	....	....	984
.135	205	4	Dec. 5	0.33	Apr. 12	−0.46	....	....	....	....	985
177	218	....	Aug. 12	0.40	Apr. 5	−0.62	....	....	....	....	1 000
.115	223	....	Aug. 21	0.42	Apr. 2	−0.55	....	....	....	....	1 001
.121	180	....	Nov. 18	0.29	Mar. 29	−0.44	....	....	....	....	1 002
.089	198	....	Dec. 5	0.26	Apr. 14	−0.31	....	....	....	....	1 003
.102	143	....	Nov. 17	0.37	Mar. 29	−0.32	....	....	....	....	1 004
.220	174	....	Dec. 13	0.65	Apr. 15	−0.42	July 4	−0.19	Aug. 14	−0.23	1 005
.147	189	....	Dec. 14	0.48	Apr. 20	−0.39	....	....	....	....	1 006
.226	202	....	Dec. 14	0.41	Apr. 9	−0.56	July 28	0.16	Sept. 19	0.08	1 007
.187	218	....	Jan. 1	0.54	May 3	−0.41	Aug. 6	−0.12	Sept. 1	−0.13	1 008
.200	188	....	Dec. 16	0.65	Apr. 21	−0.50	....	....	....	....	1 011

12770—07——30

125. *On the possibility of the annual height inequality being due to fluctuations in the temperature of sea water.*

In an ocean or portion of an ocean lying upon one side of the equator, the heat directly radiated from the sun will be absorbed most rapidly at the time of the summer solstice. The maximum rate of deriving heat from the earth's atmosphere and from inflowing streams must generally occur somewhat later. From the same sources least is being absorbed by the ocean soon after the winter solstice. From these considerations one may perhaps infer that the assumed body of water, all depths being considered, would contain the greatest amount of heat not earlier than the autumnal equinoxes, and the least not earlier than the vernal. For portions of the ocean lying in low latitudes these times will be accelerated, and the range of the annual temperature fluctuations will be less.*

While it is undoubtedly true that the surface of the water in high latitudes stands on a slightly higher level than in low latitudes (as was pointed out in sec. 115), and is higher in the early autumn than in the early spring, it can be easily seen that this annual fluctuation can not be considerable, i. e., it can scarcely be a measurable quantity.

Suppose the surface of the water at a point in high latitude to be 0.1 foot above the surface at a point 8000 miles away in the opposite hemisphere. The instantaneous slope will be 2 one-billionths. And so the accelerating force per unit mass will be $2g$ divided by one billion (Eq. 91, Part IV A). But this acting through, say, three months will give rise to a velocity of 0.52 foot per second at the surface. The velocity will diminish in going downward and the flow near the bottom will generally be opposite in direction to that at the surface. If the assumed distance were less than 8000 miles, this velocity would be increased in proportion.

As no such alternation of surface flow from one hemisphere to the other has been observed, it is practically certain that the results due to annual temperature changes in the water can not cause an annual inequality in sea level with a range as great as 0.1 of a foot, and so this portion of it may be neglected.

In an inclosed body of water the annual temperature changes may easily produce an annual height inequality, but this would be concealed by the much greater changes due to the varying amounts of evaporation and of tributary waters. In going from 0° to 15° centigrade, pure water expands only about three-fourths of a one-thousandth part of the original bulk or depth, while sea water having a density of 1.028 at 0°, has a density of 1.026 at 15°.

* See temperature maps in the Atlases of the Oceans published by the Deutsche Seewarte.

CHAPTER IX.

SEICHES IN LAKES, BAYS, ETC.

126. The problem of seiches in variously-shaped bodies of water is one of peculiar interest to the mathematician because it presents analytical difficulties which have not been overcome save in a few simple cases. The problem is to find the free periods and natural modes of oscillation for given bodies of water. No attempt will be made here to go into an elaborate mathematical treatment of the subject.

Chapters III and IV, Part IV A, show how to ascertain oscillations in square, triangular, and circular areas whether the uniform depth be very small in comparison with a wave length or not. A few questions relating to long-wave motion in bodies of variable depth are briefly considered in Chapter IV. A number of experimental tests are described in Chapter V of the same part.

For a rectangular body $\frac{1}{2}\lambda$ in length, the period τ of the slowest oscillation is given by the equation

$$\tau^2 = \frac{2\pi\lambda}{g} \Big/ \tanh\frac{2\pi h}{\lambda}; \tag{304}$$

$$\therefore \tau = \frac{\lambda}{\sqrt{gh}}\left[1 + \frac{1}{6}\left(\frac{2\pi h}{\lambda}\right)^2 - \frac{1}{40}\left(\frac{2\pi h}{\lambda}\right)^4 + \ldots\right] \tag{305}$$

For long-wave motion,

$$\tau = \frac{\lambda}{\sqrt{gh}} = \frac{\text{twice length of lake}}{\sqrt{gh}} = \frac{4L}{\sqrt{gh}} \tag{306}$$

where $2L$ denotes the length of the lake.

Tables 46–52 facilitate the computation of τ. The theory of simple wave motion is given in Chapter II, Part I, and brief mention of the seiches is made in section 16, Part I.

127. *Long-wave motion in a canal of variable cross section.**

Let Ω denote the area of a cross section and b the breadth at the surface, then the equation of continuity is

$$\zeta = -\frac{1}{b}\frac{\partial}{\partial x}(\Omega\xi), \tag{307}$$

because the variation in the sectional volume whose length is ξ (i. e., its change for a small unit length of x) must be equal to the volume of a horizontal layer whose length

* Taken mainly from Lamb's Hydrodynamics.

is unity, whose breadth is b, and whose height is ζ. This becomes

$$\zeta=-\frac{1}{b}\frac{\partial}{\partial x}(hb\xi) \tag{308}$$

if $\Omega=hb$ and h denote the mean depth for the section. The dynamical equation is

$$\frac{\partial^2\xi}{\partial t^2}=-g\frac{\partial\zeta}{\partial x}. \tag{309}$$

Upon differentiating (308) twice with respect to t and substituting for $\frac{\partial^2\xi}{\partial t^2}$ its value from (309), we have

$$\frac{\partial^2\zeta}{\partial t^2}=\frac{g}{b}\frac{\partial}{\partial x}\left(hb\frac{\partial\zeta}{\partial x}\right). \tag{310}$$

If

$$\zeta=F(x)\cos(at+\alpha),$$

(310) becomes

$$\frac{g}{b}\frac{\partial}{\partial x}\left(hb\frac{\partial\zeta}{\partial x}\right)+a^2\zeta=0. \tag{311}$$

The stationary wave in a canal communicating with a tided sea is found by writing b, h, or both, as functions of x. If b be proportional to x, and h remain constant, the amplitude will vary as $J_0(kx)$ where $k=a^2/(gh)$; if the h be proportional to x, and b remain constant, the amplitude will vary as $J_0(2\kappa^{\frac{1}{2}}x^{\frac{1}{2}})$ where $\kappa=a^2 L/(gh_0)$. In both cases the origin is the head of the canal.

Consider a canal of uniform breadth and whose mean depth varies uniformly from zero at either end to h_0 at the center; i. e. suppose $h=ix=\frac{h_0}{L}x$ where L is the distance from either end to the center, the origin being taken at one edge.

Equation (311) now becomes

$$x\frac{\partial^2\zeta}{\partial x^2}+\frac{\partial\zeta}{\partial x}+\kappa\zeta=0 \tag{312}$$

where

$$\kappa=\frac{a^2}{gi}=\frac{a^2L}{gh_0}. \tag{313}$$

writing ζ in the form

$$\zeta=A+Bx+Cx^2+Dx^3+Ex^4+\ldots, \tag{314}$$

and substituting in (312) we have finally

$$\zeta=A\left(1-\frac{\kappa x}{1^2}+\frac{\kappa^2x^2}{1^2 2^2}-\frac{\kappa^3x^3}{1^2 2^2 3^2}+\frac{\kappa^4x^4}{1^2 2^2 3^2 4^2}-\ldots\right) \tag{315}$$

$$=AJ_0(2\kappa^{\frac{1}{2}}x^{\frac{1}{2}}) \tag{316}$$

since

$$J_0(y)=1-\frac{y^2}{2^2}+\frac{y^4}{2^2 4^2}-\frac{y^6}{2^2 4^2 6^2}+\dots \tag{317}$$

For the slowest mode of oscillation ζ must be zero at the center;

$$\therefore J_0(2\kappa^{\frac{1}{2}}L^{\frac{1}{2}})=0. \tag{318}$$

From any table of Bessel's functions the roots of J_0 are

$$\begin{aligned}&0.7655\pi,\ 1.7571\pi,\ 2.7546\pi,\ \dots;\\ &\therefore 2\kappa^{\frac{1}{2}}L^{\frac{1}{2}}=0.7655\pi;\end{aligned} \tag{319}$$

$$\therefore \tau_1=\frac{2\pi}{a}=1.306\,\frac{4L}{(gh_0)^{\frac{1}{2}}}=1.306\,\frac{\text{twice length of body}}{(gh_0)^{\frac{1}{2}}} \tag{320}$$

where $1.306=1/0.7655$.

Hence the period is about 1.3 times as great as that of a rectangular basin of equal length and whose uniform depth is h_0, or 0.9235 times as long as one having a uniform depth of $\frac{1}{2}h_0$.

For a binodal oscillation,

$$\frac{\partial\zeta}{\partial x}=0$$

where $x=L$;

$$\therefore J'_0(2\kappa^{\frac{1}{2}}L^{\frac{1}{2}})=-J_1(2\kappa^{\frac{1}{2}}L^{\frac{1}{2}})=0 \tag{321}$$

The roots of J'_0 are

$$1.2197\pi,\ 2.2330\pi,\ 3.2383\pi;$$

$$\therefore \tau_2=\frac{2\pi}{a}=0.820\,\frac{4L}{(gh_0)^{\frac{1}{2}}}=0.820\,\frac{\text{twice length of body.}}{(gh_0)^{\frac{1}{2}}} \tag{322}$$

This mode of oscillation evidently applies to either half of the given body.

$$\therefore \tau_2=1.640\frac{2L}{(gh_0)^{\frac{1}{2}}}=1.640\,\frac{\text{twice length of half body.}}{(gh_0)^{\frac{1}{2}}} \tag{323}$$

Hence the period of the half body is about 1.64 times as great as that of a rectangular basin of equal length whose uniform depth is h_0 or 1.16 times as great as one having a uniform depth of $\frac{1}{2}h_0$.

To calculate the position of the node in this case, find a from (322) and substitute this value in (313). The result will be

$$\kappa=\frac{(1.2197)^2\pi^2}{4L}.$$

Since x must be such at the node that ζ vanishes,

$$\begin{aligned}J(2\kappa^{\frac{1}{2}}x^{\frac{1}{2}})&=0.\\ 2\kappa^{\frac{1}{2}}x^{\frac{1}{2}}&=0.7655\pi;\\ \therefore\frac{x}{L}&=\left(\frac{0.7655}{1.2197}\right)^2=0.3940\end{aligned}$$

Next suppose the origin to be taken at the center of a canal of uniform width whose length is $2L$ and whose depth varies from h_0 at the middle to zero at either end in accordance with the law

$$h=h_0\left(1-\frac{x^2}{L^2}\right). \tag{324}$$

This value of h substituted in (311) gives, since b is constant,

$$\frac{\partial}{\partial x}\left[\left(1-\frac{x^2}{L^2}\right)\frac{\partial\zeta}{\partial x}\right]+\frac{a^2}{gh_0}\zeta=0. \tag{325}$$

If we put

$$a^2=n(n+1)\frac{gh_0}{L^2},$$

this equation becomes of the form

$$\frac{d}{d\mu}\left[(1-\mu^2)\frac{dP_n}{d\mu}\right]+n(n+1)P_n=0 \tag{326}$$

where $\mu=x/L$.

Since ζ must remain finite, the n must be integral in the solution

$$\zeta=CP_n\left(\frac{x}{L}\right)\cos(at+\alpha). \tag{327}$$

Now

$$P_0(\mu)=1,\ P_1(\mu)=\mu,\ P_2(\mu)=\frac{3}{2}\mu^2-\frac{1}{2},\ \ldots. \tag{328}$$

For $n=1$, the profile of the surface is a straight line. The period

$$\tau_1=\frac{2\pi}{a}=\frac{\pi}{2\sqrt{2}}\cdot\frac{4L}{(gh_0)^{\frac{1}{2}}}=1.111\frac{4L}{(gh_0)^{\frac{1}{2}}}. \tag{329}$$

128. An extensive mathematical treatment of bodies of variable depths has been recently given by Professor Chrystal * and his theories have been experimentally tested by Messrs. Peter White and William Watson,† and applied to lakes Earn and Treig in Scotland by himself and E. Maclagan-Wedderburn ‡. The computed periods of Loch Earn are 14.50, 8.14, 5.74 minutes and for Loch Treig, 9.09, 5.07, 3.59, the corresponding observed quantities are 14.55, 8.10, ———, 9.18, 5.15, ———.

Professor Chrystal considers small longitudinal oscillations in a body of water whose depth, $h(x)$, cross section, $A(x)$, and surface breadth, $b(x)$, vary slowly from point to point. As is usually done in treatment of long-wave motion, the vertical acceleration is here neglected. If v denotes the surface area extending from $x=0$ to $x=x$, $\sigma(v)$, a function of v, known from the given body of water, viz. $A(x)\ b(x)$; and n, the natural seiche frequency; then n is determined by the equation.

$$A(x)\xi=P\sin nt+Q\cos nt \tag{330}$$

* Proc. Roy. Soc. Edinburgh, Vol. 25, I (1904), pp. 328–337; Vol. 25, II (1905), pp. 637–647. Trans. Roy. Soc. Edinburgh, Vol. 41, III (1905), pp. 599–649.

† Proc. Roy. Soc. Edinburgh, Vol. 26, I (1906), pp. 142–156.

‡ Trans. Roy. Soc. Edinburgh, Vol. 41, III (1905), pp. 823–850.

where P and Q are solutions of

$$\frac{d^2P}{dv^2}+\frac{n^2P}{g\sigma(v)}=0. \tag{331}$$

If $\sigma(v)$ be a linear function of v, the differential equation is found to depend upon Bessel's Functions; if $\sigma(v)=h\ (1\mp v^2/a^2)$, the differential equations takes the form

$$(1\mp w^2)\frac{d^2P}{dw^2}+cP=0. \tag{332}$$

Integrating by series, two new transcendents for each sign are encountered. He calls those obtained when the upper sign is used *seiche-cosine* and *seiche-sine*, and when the lower, *hyperbolic seiche-cosine* and *hyperbolic seiche-sine*. If w is small, the above equation approximates

$$\frac{d^2P}{dw^2}+cP=0. \tag{333}$$

If $c=1$, this is satisfied by cos w, or sin w; if $c=-1$, by cos h w, or sin h w. The seiche-cosine and seiche-sine functions apply to lakes whose longitudinal section is concave along the bottom, and the hyperbolic forms to convex bottoms. While the assumed form of $\sigma(v)$ may appear to be very special. Professor Chrystal shows how, by properly combining the simple geometrical bodies permitting of treatment, good approximations can frequently be made to lakes which at first sight would defy analysis.

If the breadth be constant and the depth $h(x)$ be a quartic function of x such that

$$h(x)=h(a^2\mp x^2)^2, \tag{334}$$

the differential equation to be satisfied is

$$\frac{d^2P}{dx^2}+\frac{cP}{(a^2\mp x^2)^2}=0. \tag{335}$$

the upper or lower sign to be used according as to whether the bottom of the longitudinal section is concave or convex.

In the case of a symmetric rectilinear lake shelving at both ends the periods of the secondary oscillations in terms of the period of the principal oscillation are found to be 0.6276, 0.4357, 0.3428, 0.2779, 0.2365, etc.; while the distances of the corresponding nodal lines from the center are the following fractions of the length of half of the body, viz 0.6057; 0.0, 0.8102; 0.3809, 0.8825; 0.0, 0.5930, 0.9228; 0.3763, 0.9441.

For a lake with one end vertical, and shelving to zero depth at the other end, the periods of the secondary oscillations in terms of the period of the principal, are found to be 0.5462, 0.3767, 0.2883, etc.; while the distances of the corresponding nodal lines from the vertical end are in terms of the lake length, 0.6057; 0.3809, 0.8825; 0.3763, 0.7056, 0.9441.

The corresponding period ratios for a parabolic lake are found to be 0.577, 0.408, 0.316, 0.258, 0.218, etc., and for a semiparabolic lake, 0.548, 0.378, 0.289, 0.234, 0.196, etc.

Professor Chrystal concludes his paper in the Transactions (Vol. LXI, III) with an important bibliography of the subject.

A review of Chrystal's work is given by Dr. W. Halbfass.*

Mr. D. Isitani ascertains "the change of period due to a slight alteration in the area and volume of the oscillating liquid."†

Mr. T. Terada shows analytically "that any contraction or expansion at the middle part of the canal prolongs or shortens its natural period respectively, and that at the end shortens or prolongs it respectively." He tests his work experimentally and also by application to Lake Hakone.‡

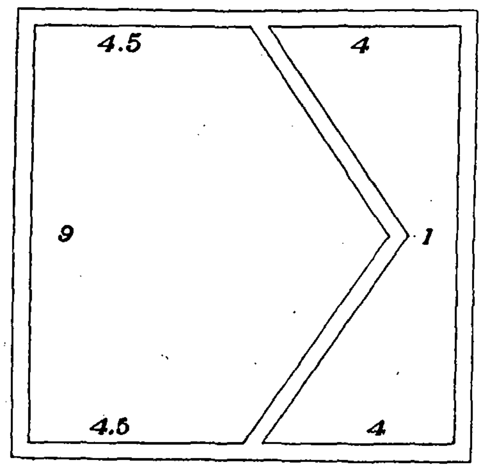
In order to show the relative periods of bodies having the same total lengths, I performed the following experiment:

A box 9 inches square on the inside was partitioned off by a portion in the manner indicated in the diagram. When the depth of water was 2 inches the observed number of periods a minute in the two parts were 91 and 63½. The calculated number for a rectangular area 9 inches long is 86. The respective periods are, therefore, in seconds 0.66, 0.94½, 0.70. Hence the period of the area narrow at the middle, is one-third greater than the period of a rectangular area of the same length.

129. *Classification of seiches.*

So far only completely surrounded bodies of water have been considered in reference to seiche movements. But it is not difficult to see that bodies having incomplete boundaries may also possess free oscillations having periods suited to their dimensions (Cf. sec. 29, Part IV A). As a rule the more broken the boundary, the smaller will be the amplitude of the motion, *cæteribus paribus*. The existence of fractional oscillating areas is not so obvious; but it will be shown that the seiches due to them are common and important.

No. 26.



For convenience, seiche movements may be divided into the classes mentioned below. The names of these classes generally refer to the forms of the bodies or areas in which the seiche is produced, and, as a rule, scarcely require formal definition.

Name	Character of oscillations	General character of body of water
Lake seiche	Regular to irregular	Oscillating area.
Open-lake seiche	Fairly regular	Do.
Parallel-wall seiche	Fairly regular	Do.
Strait-and-harbor seiche	Irregular	Do.
Cul-de-sac seiche	Regular	Fractional area.
Shelving seiche	Irregular	Do.

* Zeitschrift der Gesellschaft für Erdkunde zu Berlin, 1907, pp. 5–24.

† Proceedings of the Tôkyô Mathematico-Physical Society, Vol. III (1906), pp. 170–173.

‡ Proceedings of the Tôkyô Mathematico-Physical Society, Vol. III (1906), pp. 174–181. See also paper in same journal, Vol. I, pp. 115–, by S. Nakamura and Y. Yoshida.

The most common cause of these periodic movements is the wind blowing over the bodies of water in which they occur. The sudden variations in barometric pressure may cause seiches in lakes and other nearly inclosed bodies of water. Earthquakes frequently produce seiches along the coast and in maritime harbors by means of the disturbance transmitted through the sea.

By "strait-and-harbor" seiche is meant an irregular oscillation caused by reflections of disturbances between irregular or nonparallel shores, lying generally only a few miles asunder. The markings on a tide curve resembles irregular saw teeth. An example of such a body is the Golden Gate, California.

The seiches belonging to the last two classes are generally found along open coasts. The tide curves from certain places contain at times quite regular oscillations, and from most places irregular saw-teeth markings whenever a considerable disturbance takes place, such as that produced by an earthquake or a strong wind. The regular oscillations are generally formed in a cul-de-sac or small bay suddenly terminated. The irregular ones are formed where the sea bottom is shelving and where the lengths, and so the periods, of the fractional areas are not as fixed as are those in the case just referred to. As will be presently pointed out, the oscillating strip of water in these two cases is about $\frac{1}{4}\lambda$ long; and so the more definite its boundary, the more perfect the oscillation.

A familiar illustration is a steam or air whistle closed at one end. The jet of steam or air forced across or into the mouth of the whistle causes the contained column of fluid, which is $\frac{1}{4}\lambda$ in length, to be thrown into a state of intense vibration in accordance with the well known principle of resonance. If the form of the interior of the resonator were not tolerably simple, the tones given out would be less certain, and would to a certain extent be selected in accordance with the intensity of the blast.

Suppose that a suspended pendulous body be exposed to the action of the wind. It will be found to oscillate almost incessantly, and in its own period, because the impinging current of air is not exactly uniform. So, under favorable conditions, a seiche of this kind may exist for days at a time, sustained by the variable action of the wind upon the oscillating arm of water and the larger body with which it is connected, the effect upon the latter being probably of greater importance.

Experiment No. 1.—Take a glass tube, open at both ends, about 20 inches long and one-half inch in diameter. Mark a point distant one-fourth of the length of a second's pendulum from the lower end of the tube. Immerse the tube up to this mark in a tank of water. By suction elevate a column of water, and then suddenly release it. The column will perform oscillations having a period of one second and a continually decreasing amplitude. The following are the elevations or amplitude in inches as found by experiment beginning with the first elevation occurring after letting go the column sustained by suction; the values in parentheses are the ratios of neighboring values: 4, (0.55), 2.20, (0.64), 1.40, (0.66), 0.93, (0.69), 0.64, (0.67), 0.43, (0.70), 0.30, (0.77), 0.23, (0.74), 0.17. From the nature of the case it is difficult to determine these quantities with precision; but they show that the amplitude decreases somewhat more slowly as it becomes smaller. If no attention is paid to the amplitude, it is easy to so time the sustaining suction impulses imparted from time to time that the natural period of oscillation shall be but little interferred with. In this way the number of oscillations per minute can be found with considerable accuracy (say to 1 per cent). The result will be 60 per minute very nearly.*

*Cf. Dr. Thomas Young: A Course of Lectures on Natural Philosophy (1845), p. 217.

Let L denote the length of the column of water, ζ the vertical displacement of the surface of the upper end; let Ω denote the area of the tube, and $\frac{\gamma}{g}$ the density of the liquid. Then by d'Alembert's principle the impressed force of gravity is equal to effective force;

$$\therefore\ -\zeta\Omega\gamma = M\frac{d^2\zeta}{dt^2} = L\Omega\frac{\gamma}{g}\frac{d^2\zeta}{dt^2}, \tag{336}$$

$$-\zeta g = L\frac{d^2\zeta}{dt^2}. \tag{337}$$

This equation is obviously satisfied by writing

$$\zeta = A\cos\left(\sqrt{\frac{g}{L}}\,t + \alpha\right). \tag{338}$$

The period of this oscillation is $2\pi \div \sqrt{\frac{g}{L}} = 2\pi\sqrt{\frac{L}{g}}$; the half-period of a pendulum of length l is $\pi\sqrt{\frac{l}{g}}$. If these two times are equal, L must be equal to $\frac{1}{4}l$.

Experiment No. 2.—Take a trough of rectangular cross section closed at one end, about 20 inches long, and containing a movable partition whereby various lengths can be readily secured. Place this in a tank of water so that the depth in the trough is from a fraction of an inch at the head to 2 inches at the mouth. By giving the water off the mouth of the trough an horizontal impulse, an oscillation will take place in the trough, which will continue for a few periods. These oscillations can be sustained by subsequent impulses, care being taken to not disturb the regularity of the motion. The period of the oscillation will be found to be approximately

$$4\times\frac{\text{length of trough}}{\sqrt{gh}}, \tag{339}$$

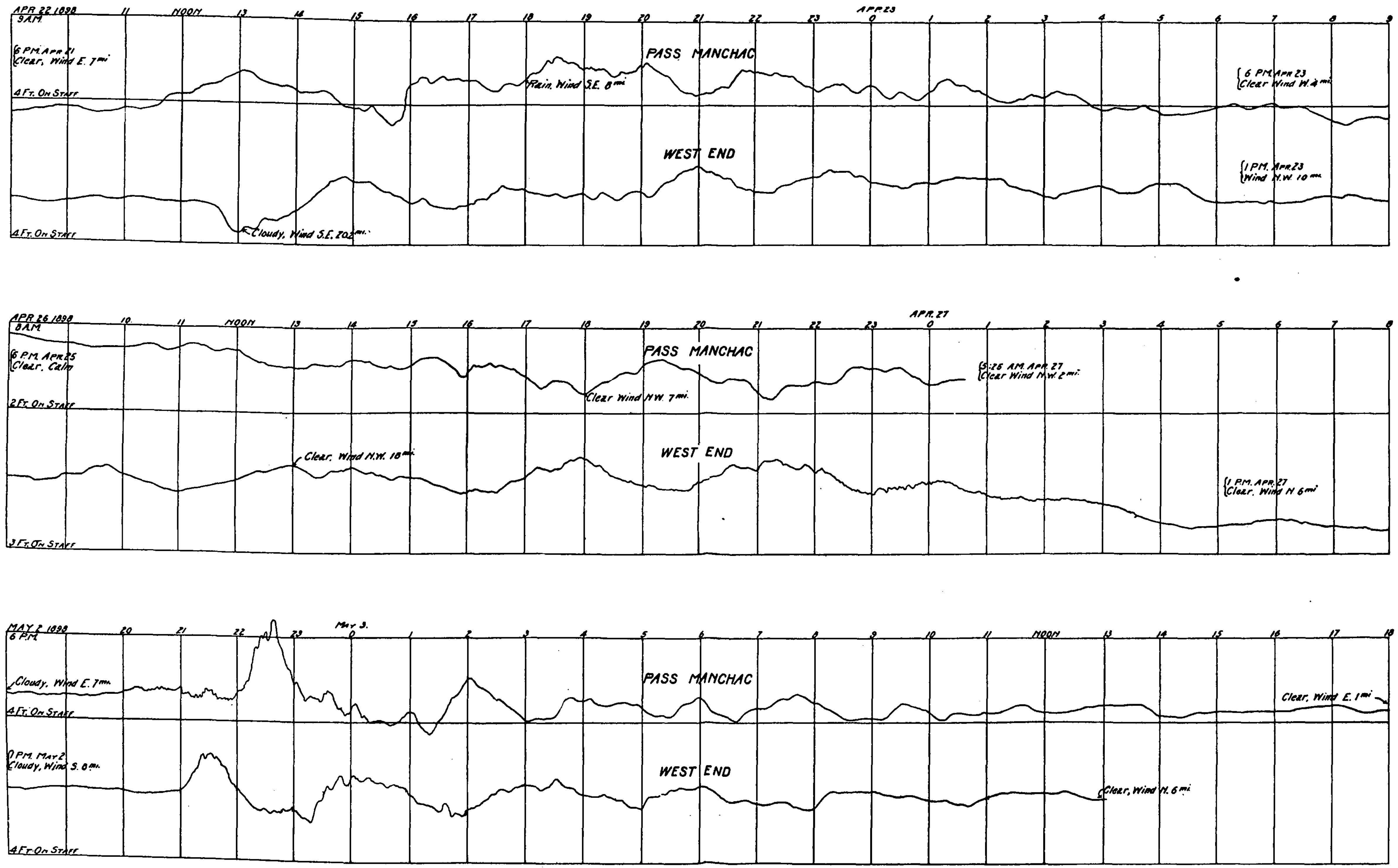
g being 386 inches (see Table 52).

Since the period of a rectangular lake whose depth decreases uniformly from the center to either end is nearly equal to what it would have been had the depth been constant and equal to its average depth, the period of an arm of water becoming shallow near the end must differ but little from the period calculated upon the assumption of a constant depth equal to its mean depth (see sec. 127).

130. *Examples of lake seiches.*

Dr. Forel was the first person to make an extensive and careful study of seiche phenomena (1876–1885). He found that Lake Geneva, upon whose northern shore he resided, had both longitudinal and transverse oscillations, and that the former often possessed more than a single nodal line; in fact, the record was far from being simple in character. The periods of the longitudinal seiches were found to be 73 and 35 minutes, and the period of the transverse seiche about 10 minutes. These periods agree fairly well with those computed by the simple formula

$$\tau = \text{twice length of lake} \div \sqrt{gh}.$$



IMPERFECT SEICHES IN LAKE PONTCHARTRAIN.

He devised and used a delicate form of tide gauge which he styled "limnimeter" ($\lambda i \mu \nu \eta$=pool).

A list of Forel's papers on this subject is given by Darwin in his book entitled "The Tides and Kindred Phenomena in the Solar System," end of Chapter II; also by Chrystal, in the bibliography already alluded to.

Numerous modes of oscillation in the small lake Chiemsee, southern Bavaria, have been recently investigated and the corresponding periods carefully determined by A. Endrös.*

In a paper issued by the U. S. Weather Bureau entitled "Wind Velocity and Fluctuations of Water Level on Lake Erie," Prof. Alfred J. Henry finds the theoretical period of the lake to be 18 hours, while observations made at Buffalo and Amherstburg indicate an actual period of 14 hours or a little more.† In a note in the Monthly Weather Review ‡ I have called attention to the shortening of the free period due to the narrowing ends of the lake and to the fact that actual depth is somewhat in excess of that used by Professor Henry. In fact, in a sharply-pointed convex lake, such as might be bounded by the lines of motion shown in Fig. 9, Part IV A, the period would be $1/\sqrt{2}=0.707$ times the period of a rectangular body having as length the extreme length of the lake. The mean between the period given on this assumption and that given by the assumption of a rectangular body is 14¼ hours, the length of the body in either case being 214 sea miles and the mean depth 10 fathoms.

The period of the longitudinal seiche of Lake Ontario is said to be four hours and forty-nine minutes.§

As will be noted in section 136, Lapham in 1852 observed oscillations at Milwaukee having a period of 2 hours, which is the theoretical period of an east-and-west oscillation across Lake Michigan.

The average depth of Lake Pontchartrain, La., is 14 feet. Calling the virtual length 30 miles and the width 20 miles, the two periods obtained for Table 50 are

$$\frac{30}{12.57}=2.4 \text{ hours and } \frac{20}{12.57}=1.6 \text{ hours.}$$

No regular seiches occur in this lake; Fig. 27 is given to show that a southeasterly wind may make the lake uncommonly low at New Orleans (West End), while it is uncommonly high at Pass Manchac, and vice versâ; similarly for a northwest wind. Moreover, it shows a very rough oscillation at times with a period of about 2 hours.

In 1885 seiches were observed on Lake George, New South Wales, Australia, and described by H. C. Russell in his anniversary address.** They were found to have a period of 2 hours, very nearly. This is nearly the theoretical period for a longitudinal uninodal oscillation of a body having the length of the lake and a depth equal to the lake's mean depth.

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* Zeitschrift für Instrumentenkunde, Vol. 24 (1904), pp. 180, 181.

† No. 262 (1902) Bulletin J. See also paper by same author in Monthly Weather Review, Vol. 28 (1900), pp. 203–205.

‡ Vol. 30 (1902), p. 312.

§ Monthly Weather Review, Vol. 26 (1898), pp. 261–262.

** Journal and Proceedings of the Royal Society of New South Wales, Vol. 19 (1885), pp. 13–19, and plates between pp. 82, 83.

One of the most regular seiches known occurs at times upon Lake Chiuzenji, a small lake in Japan. It was observed by Mr. K. Honda in 1906, by aid of two limnimeters of his own design.* He placed an instrument at each end of the lake and found low water at one end when it was high water at the other, and the period to be 7.70 minutes. The curves on the record are nearly perfect sine curves. By trial he found a point near the middle of the northern shore of the lake where the pencil of the limnimeter traced a straight line. The simple formula giving too short a period, Mr. Honda constructed a model of the lake and by means of it found the period of the lake to be 7.68 minutes. It seems probable that the period of the lake is slightly in excess of the period of a rectangular lake of the same length because of the somewhat dumb-bell shape of the lake.

131. *Examples of open-lake seiches.*

The celebrated tidal currents in the Euripus are chiefly due to the seiches in the Gulf of Talanta. The principal oscillation of the gulf has an observed period of $1\frac{3}{4}$ hours and a range of 6 inches or less. This period agrees fairly well with computation. The extreme length of the gulf is 54 miles, the average depth 52 fathoms. These dimensions imply a period of 1.8 hours.

The fact that at some points of this gulf the period of the oscillation is but little more than one hour indicates that a binodal seiche also exists.†

The oscillation in Narragansett Bay is remarkable in that the 10 miles extending from Providence to Bristol (the average depth being $2\frac{1}{2}$ fathoms) has a seiche of the binodal type, while the 10 miles extending from Bristol to Newport (the average depth being 11 fathoms) has one of the uninodal type. This is as it should be when depths are considered. By Table 50 the period of the binodal part is 0.77 hour and of the uninodal 0.74 hour.

Fig. 28 shows the period to be 0.75 hour. It shows that the oscillation is in approximately like phases at Providence and Bristol, while at Bristol and Newport the phases are nearly opposite.

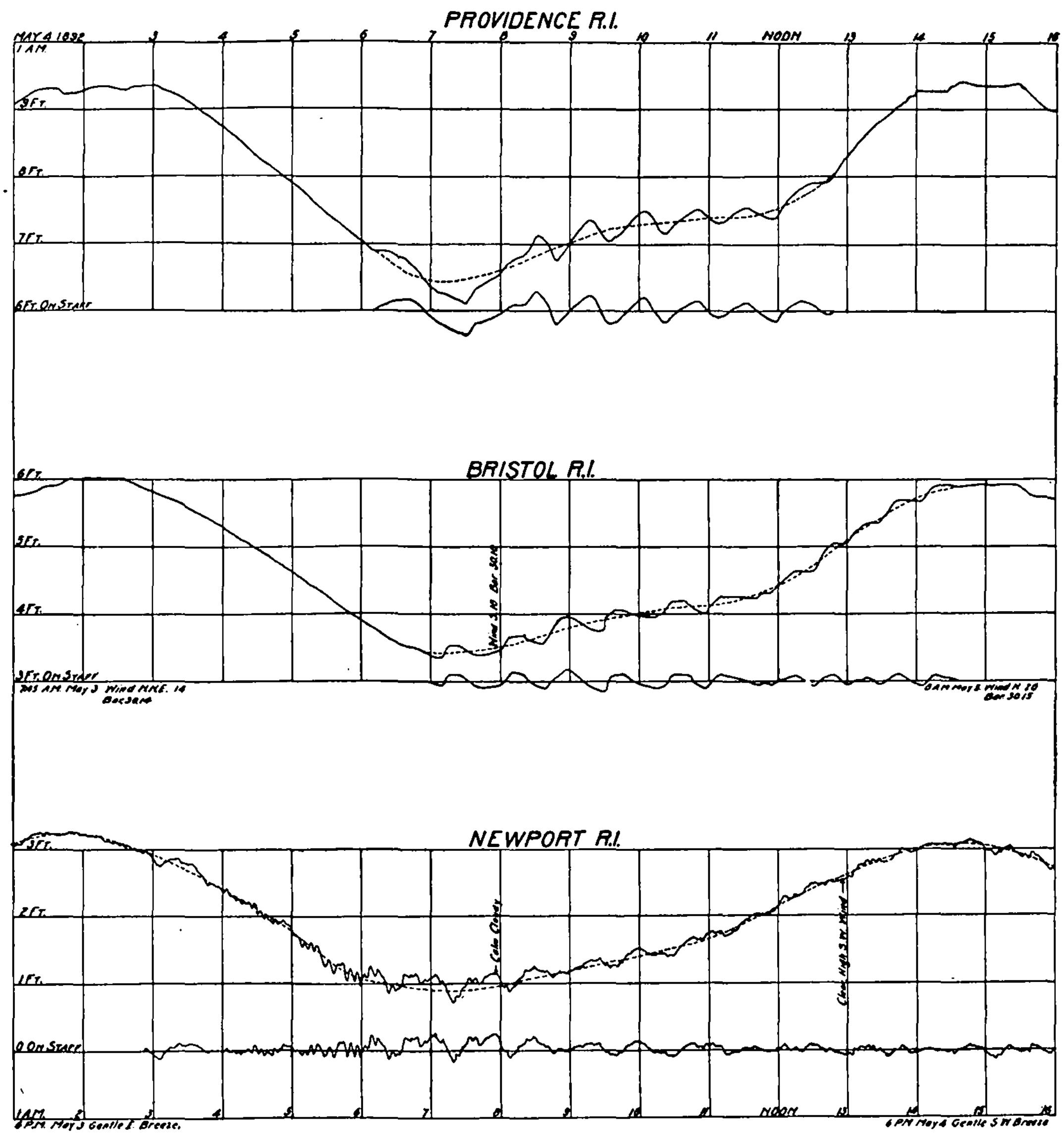
At Weeks, Louisiana, an imperfect seiche in Vermillion Bay and of considerable amplitude occurs during heavy winds. The observed period is about 3 hours; the period of two hours may be occasionally observed. The average depth of the bay is 8 feet. The virtual length is about 15 miles and virtual breadth about 10 miles. These dimensions give as periods

$$\frac{30}{9.5} = 3.2 \text{ hours, and } \frac{20}{9.5} = 2.1 \text{ hours.}$$

At Fort Point, Galveston, Tex., a small wave oscillation having a period of about $1\frac{1}{4}$ hours and an ordinary maximum range of about 0.2 foot has been observed. Now a partially enclosed body of water lies between Galveston, Pelican Island, and the mainland to the west. The virtual length of this body is about 5 miles, and the average

* Proceedings of the Tôkyô Mathematico-Physical Society, Vol. III (1907), pp. 220–223.

† The following are a few references to the seiches of the Euripus: F. J. P. Babin: Phil. Trans. 1671, Abr. Vol. I, p. 592. Barlow: An Exact Survey of the Tide, Ch. V, sections 4, 5. Lalande: Astronomie, Vol. IV, pp. 148–151. F. A. Forel: Comptes Rendus, Vol. 39 (1879), pp. 859–861. Nature, Vol. 21 (1879), p. 186. Krümmel: Handbuch der Ozeanographie, Vol. II, pp. 143–146. *A. A. Μιαούλης: Περὶ τῆς Παλλιροίας τοῦ Εὐρίπου* (1882). See Fig. 37, Part IV A, and under Aristotle, Strabo and Pliny, secs. 64, 67, 69, Part I, this manual.



SEICHES IN NARRAGANSETT BAY.

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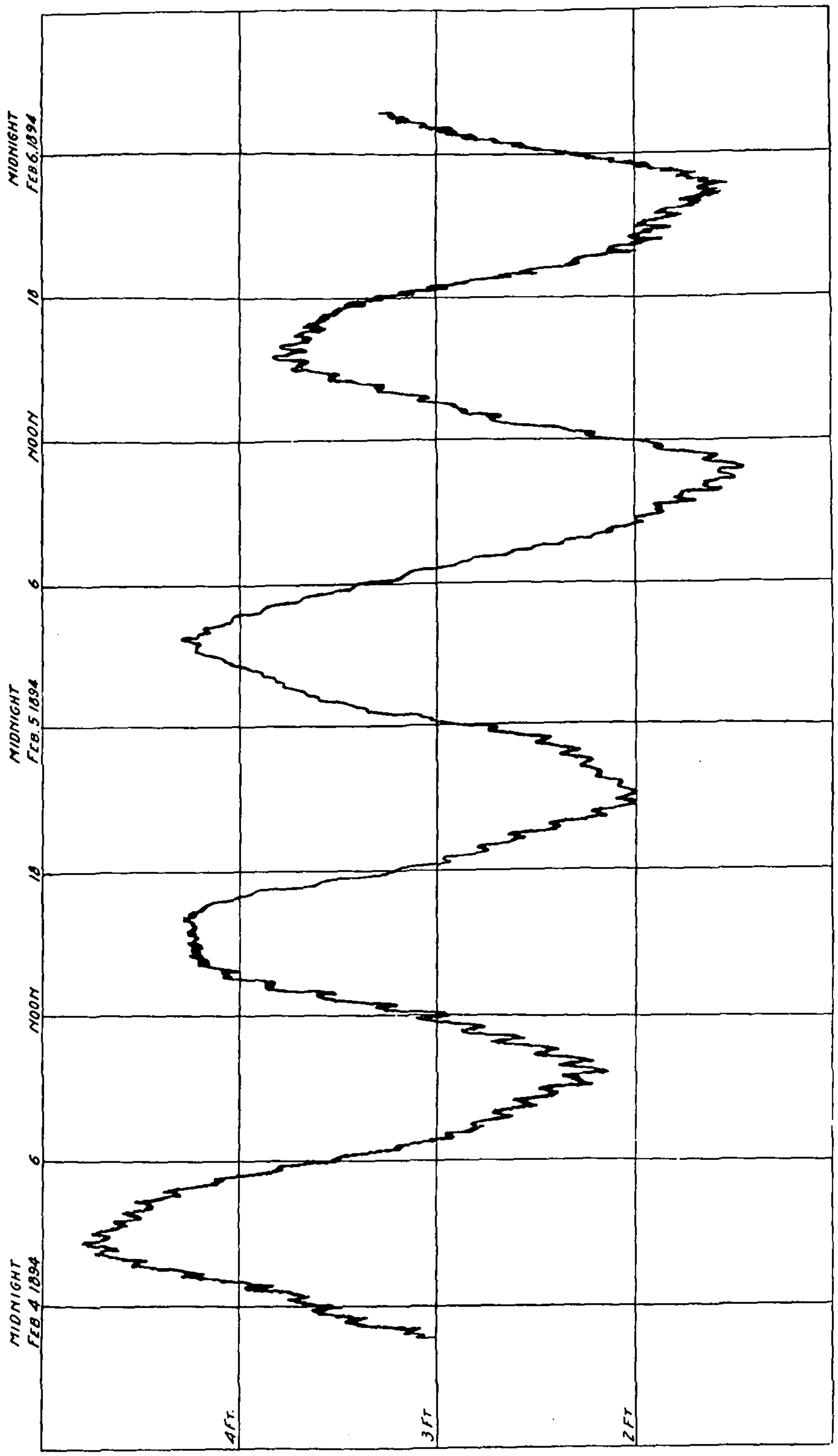


SEICHES AT WELLINGTON, NEW ZEALAND.

depth at a mean stage of the tide is 5½ feet; these dimensions give 1.27 hours for the free period of the body. By means of the channel along the city front the oscillation is propagated to Fort Point.

At Wellington, New Zealand, the observed period of the seiche oscillation is 28 minutes. The length of the harbor in a northeasterly and southwesterly direction is 6½ miles and in a northwesterly and southeasterly direction 5 miles. The average depth for either direction is 10 fathoms. The computed period of the first is 30 minutes and of the second 23 minutes. Hence, it is probable that the seiche extends in a northeasterly and southwesterly direction; the period may be somewhat less than 30 minutes because the virtual length of an oval body is less than its extreme length and because the depth increases gradually for some distance from the shores.

A few small oscillations are shown upon the tide-record for Williamstown, Port Phillip, published in connection with the Krakatoa eruption. This body is 33 miles long in a north-and-south direction, its average depth being about 10 fathoms. The period of a binodal seiche in a rectangular body of these dimensions is 1.27 hours. On account of the oval shape of Port Phillip this value should be shortened somewhat. Observation seems to give about 1.20 hours for the period. An east-and-west seiche would have a slightly greater period, but it is probable that this could hardly be felt at Williamstown. However, the irregularity of the observed period indicates that either the mode of oscillation is not fixed or two or more motions coexist.

132. *Examples of parallel-wall seiches.*

On November 1, 1870, during a severe storm, a series of seiches were observed at Fiume, Austria.* Their average period was 2.7 hours and the maximum range about 1 foot. Now, the open portion of the Adriatic just below the bay upon which Fiume is situated is 67 sea miles in width; the depth is about 30 fathoms. This gives, by Table 50, 2.9 solar hours as the free period of a uninodal seiche.

Seiches have been observed at Ischia, by G. Grablovitz,† having an average period of 13¾ minutes and an average maximum range of perhaps 0.2 foot. The oscillating strip of water may be assumed to extend from the coast of Ischia to the middle of the opposing coast of Porcida. This distance is 2.6 miles, and the mean depth 9 fathoms. These dimensions give 0.211 hour = 12.7 minutes as the period of the uninodal oscillation.

The eruption of Krakatoa, on August 27, 1883, produced a great disturbance in the waters of Sunda Strait, which was transmitted through the narrow part of the strait, and recorded on the tide gauge at Tandjong Priok, Batavia. Here the maximum range of the seiche was over 6 feet; the period was 2.20 hours.‡

The calculated period for uninodal seiche across the broad portions of Sunda Strait in a northwesterly and northeasterly direction is about 2.2 hours.

The tide curve at Tutticorn, Gulf of Manar, has at times an oscillation whose period is 3 hours and range about 0.5 foot.§ The distance across the gulf at this place is 92

* E. Stahlberger: Die Ebbe und Fluth in der Rhede von Fiume, Budapest, 1874

† Ricerche sulle mare d'Ischia, Rendiconti delle sedute della R. Accademia dei Lincei, Vol. 6 (1890), pp. 26–32.

‡ The Eruption of Krakatoa and Subsequent Phenomena, London, 1888

§ Account of the Operations of the Great Trigonometrical Survey of India, Vol XVI (1901); Details of Tidal Observations, II, opp. page 57 miles, and the average depth of the upper end of the gulf may be taken as 55 fathoms. These values give a period of 3 hours.

133. *Examples of cul-de-sac seiches.*

The seiches at Malta are described by Airy in the Philosophical Transactions.* He finds the average observed period to be 21 minutes; the range to vary from nothing to a little more than 1 foot. The body of water responsible for this seiche he considers to be the deep arm of the sea lying between Sicily and Tunis, the shoals playing only a subordinate part.

From Figure 37, Part IV A, it is evident that the period of the transverse oscillation might vary from 1 to 2 or even more hours according to the amount of shoal water included in the estimate. Hence it is difficult to say how many nodal lines are present when the period of the oscillation is 21 minutes. Their number may be anywhere from 3 to 7.†

As Valetta, the place of observation, is situated upon the northeastern coast of the island, while the area in which the seiche arises in accordance with this hypothesis lies mainly to the west of the island, Airy says, "Such waves, once created, would be propagated to regions of the sea somewhat beyond those in which they are formed."

It seems probable that these oscillations are caused by the configuration of the harbor. For, the length of the harbor is 1.6 miles, and, if we call the average depth $6\frac{1}{2}$ fathoms, the period of the dependent oscillation would be $4 \times \frac{1.6}{20.8} = 0.31$ hour = 18 minutes.

Tidal observations made at St. Thomas Island, West Indies, show that oscillation is going on in the harbor most of the time. The most regular ones have a period of 0.45 hour and a range varying from 0.5 foot to nothing—it generally being 0.1 or 0.2 foot. At times there is an oscillation whose period is about 0.7 hour.

The harbor is about 1.3 miles long, measuring from the head to the capes at the mouth. The average depth is $3\frac{1}{2}$ fathoms. This gives $4 \times \frac{1.3}{15.3} = 0.34$ hour for the period of the oscillation. The broadening of the harbor near the head, and the contraction near the mouth due to Rupert Rock, must cause the period to be somewhat greater than the one just calculated. It is probable that the arm of water taken as $\frac{1}{4}\lambda$ does really extend outside of the mouth of the harbor proper.

The less perfect oscillation having a period of 0.7 hour may be caused by the strip of shallow water lying between St. Thomas Island, West Indies, and deep water to the south. The width of this strip is 8 miles and the average depth 20 fathoms. This gives $4 \times \frac{8}{36.8} = 0.9$ hour.

The seiches in St. John Harbor, an arm of the Bay of Fundy, has been briefly described by W. Bell Dawson ‡ and more fully by A. W. Duff, the point of observation of the latter being a short distance above the narrows.§

Duff gives 42.2 minutes as the length of the average period of the oscillations. Off St. John the bay is 32 miles wide. The average depth being 40 fathoms, it might be concluded from Table 50 that the period of the uninodal seiche is 1.23 hours

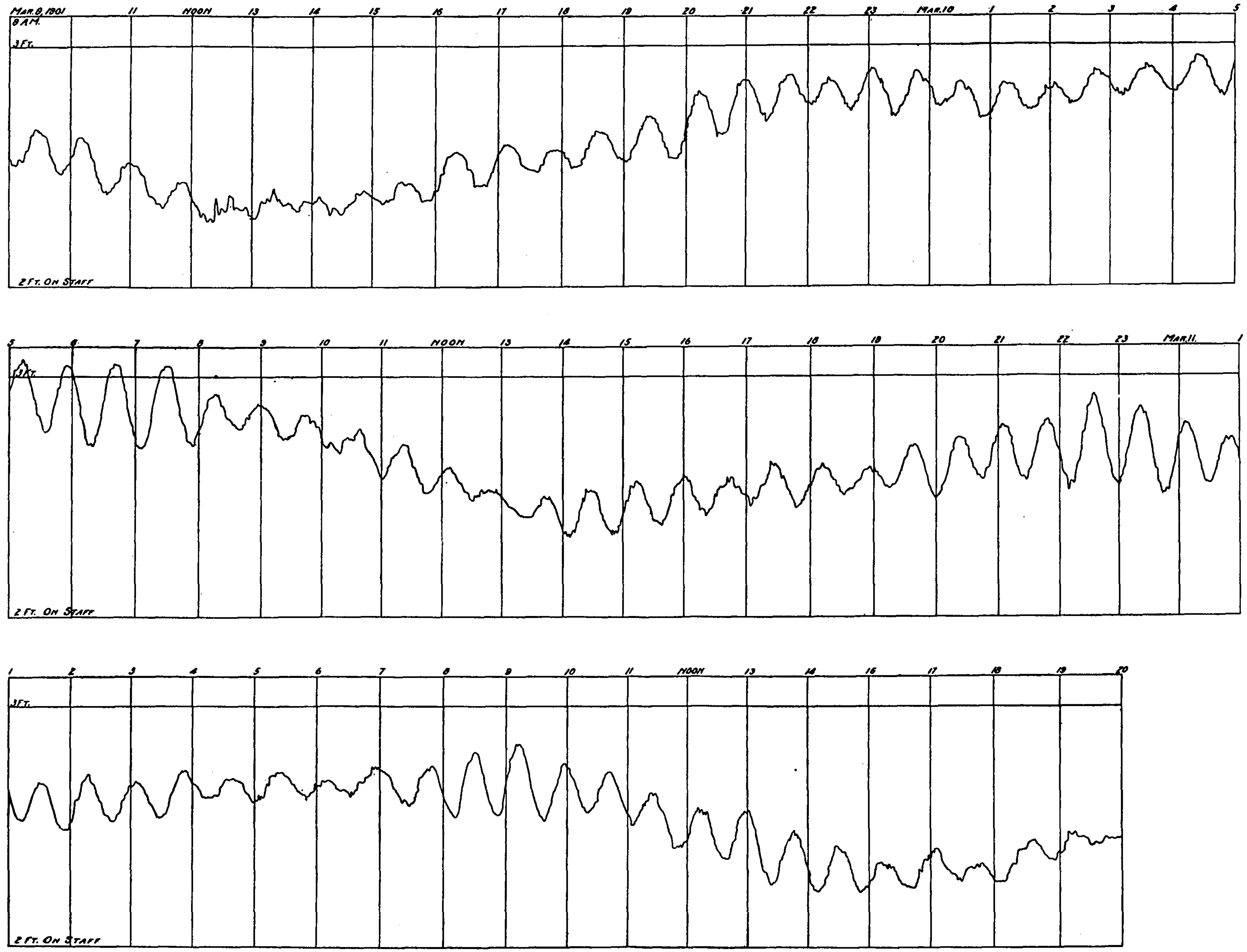
* Vol. 169 (1878), pp 136–138.

† Cf. Krümmel: Handbuch der Ozeanographie, Vol. II, p. 148.

‡ Transactions of the Royal Society of Canada, Meeting of May, 1895, Section III, pp. 25–27.

§ Amer. Jour. Sci., Vol. 153 (1897), pp. 406–412.

No. 30.



SEICHES AT GUANICA, PORTO RICO.

and the period of the binodal 0.62 hour. Now it seems in this case to be highly improbable that a binodal seiche should occur across the bay and not one of the uninodal type; for surely the winds sweeping over the surface of the bay would act most favorably across its axis and so incite uninodal motion. Again, Dawson says: "These minor undulations often continue for a week at a time; or even longer." This accords well with the facts witnessed at Guanica and described in the next paragraph. The harbor at St. John is 3.3 miles long from its head just south of the narrows to its mouth east of the northern part of Partridge Island. The average depth at half-tide level may be taken as 8 fathoms. These dimensions give as the period $4 \times .1417 = 0.567$ hour, or 34 minutes. At the bend in this arm depths of more than 20 fathoms occur, while near Partridge Island the depth of the channel is only 5 fathoms at half-tide level. These circumstances must increase the length of the period.

Remarkably regular seiches occur in Guanica Harbor. The observed period is 45 minutes, and the range varies from 1 to 4 inches. So persistent is this phenomenon that as many as 60 consecutive oscillations have been noted. (See Figure 30.)

That the phenomenon at Guanica does not depend upon a trinodal seiche across the Caribbean Sea is proved by the fact that no indication of a seiche having a period of 45 minutes occurs at Ponce or at Guayanilla.

The length of this harbor is 2 miles and the average depth 3 fathoms. The period of a rectangular dependent arm of these dimensions is, by Table 50, $4 \times .1375 = 0.55$ hour. This period must be increased by one-third part of itself in order to agree with the observed value. The average width of the harbor is at least one and one-half times its width at the narrowest part near the mouth. This fact increases the period somewhat, but it is partially offset by the increase in depth at the narrows. It seems probable that the oscillating arm of water extends some distance outside of the harbor proper, thus increasing the size and period of the body.

Port Real is a body of water 0.8 mile long and $1\frac{1}{2}$ fathoms deep. Here a fairly regular seiche occurs, having a period of 0.62 hour and a maximum range of generally 0.2 feet. A rectangular tongue of water would have for its critical period $4 \times .0800 = 0.32$ hour.

Near the entrance to this harbor the distance across the channel, counting from the 1-fathom line, is only one-twelfth of a mile, while the breadth within the capes, counting from this same contour, is two-thirds of a mile. It seems probable that the period for the actual body should be perhaps double that of the rectangular body just alluded to.

The oscillation does not persist as long as the one at Guanica; still as many as sixteen consecutive periods may at times be observed.

Edgartown Light-House, Massachusetts, is situated near the head of a bay bounded by land on one side and land and shoals on the other. This arm of water is 3 miles long and 4 fathoms deep on the average. These dimensions give for the critical period $4 \times .1825 = 0.73$ hour. Observation shows that when a strong northwest wind is blowing, a seiche may arise having a period of three-fourths of an hour and continuing for several hours.

The undulations in the tide curve at Colon on August 27–28, 1883, do not seem to have been connected with the Krakatoa eruption; for, they are remarkably regular and occur too early for allowing a reasonable time for the disturbance to be propagated around South Africa. The observed period of this oscillation is 1.17 hours.

On September 6–7, 1882, the tide curve showed an earthquake disturbance. There were apparently two oscillations thus set up, the period of the first being 1.17 hours and of the second 0.40 hour; the maximum ranges being 1.3 feet and 0.5 foot, respectively.

On June 15 and again on June 17, 1883, a good oscillation, having a period of 1.17 hours and a range of 0.2 or 0.3 foot, is recorded on the tide curve.

The form of the western portion of Carribean Sea is not favorable to seiche oscillations, even if such were possible in a sea of such great depth. Turning to the harbor of Colon, we find its length to be 4 miles and its average depth $2\frac{3}{4}$ fathoms. The resulting period is therefore $4\times\frac{4}{13.64}=1.17$ hours.

At Dutch Harbor, Alaska, observations show a seiche having a period of about one-half hour. The extreme length of Iliuliuk Bay, of which Dutch Harbor is a branch, is $4\frac{1}{2}$ miles. The average depth is about 15 fathoms. These dimensions give, by Table 50, a period of $4\times\frac{4\frac{1}{2}}{31.86}=0.565$ hour $=34$ minutes.

At Honolulu, Hawaiian Islands, the period of a regular sine-like fluctuation, groups of which appear from time to time, is $0.43\frac{1}{2}$ hour or 26 minutes. The larger ones are caused by earthquake sea waves, but the smaller ones may be due to meteorological disturbances. The following are some of the earthquakes whose observed effects had very nearly the above period: Krakatoa, August 27, 1883; Northern Japan, June 15, 1896; Ecuador, January 31, 1906; and Valparaiso, Chile, August 16, 1906.

The maximum range, depending upon the intensity of the disturbance at Honolulu, varies from 0.1 foot to 0.4 foot.

Assuming that the dependent body at Honolulu Harbor is $1\frac{3}{8}$ miles long and $2\frac{1}{2}$ fathoms deep on an average, the computed period is $4\times\frac{1\frac{3}{8}}{13.01}=0.42$ hour.

Following the Krakatoa eruption, irregular oscillations, having a period of 2.6 hours and a maximum range of $2\frac{1}{2}$ feet, were observed at Lyttleton, New Zealand. The length of Port Cooper is $8\frac{1}{4}$ miles, and average depth $2\frac{1}{2}$ fathoms. The resulting period is therefore $4\times\frac{8\frac{1}{4}}{13.01}=2.54$ hours.

At Olongapo, Subic Bay, Philippine Islands, a seiche, having a period of 1.3 hours and range of about 9 inches, has been observed; also smaller undulations having a period of from one-third to one-half an hour. The former can hardly be due to an oscillation of the greater part of China Sea lying between Luzon and Siam and Hainan Island; for, although a trinodal east-and-west seiche has a computed period of about $1\frac{1}{3}$ hours, no oscillation of such period is to be found at Manila.

Now the length of Subic Bay is 10 miles and its average depth 18 fathoms. Regarding this bay as a dependent arm, the period computed by Table 50 is $4\times\frac{10}{36.8}=1.09$ hours. By supposing the line marking the mouth of the bay to be convex, the length of the bay may be increased to 11 or 12 miles. The computed period of the east-and-west oscillation of Subic Bay at Olongapo is 0.3 hour and in a southeast-and-northwest direction 0.4 hour.

A seiche was observed at Aden, Arabia, as a result of the Krakatoa eruption, the period being 1.02 hours and the maximum range of about 0.8 foot. Small undulations of this period may sometimes be seen on the tide curve for this station.*

Aden Harbor is about 1.8 miles long, measuring from the mouth to the low-water line at the head. It is 0.4 mile broad at the mouth and $2\frac{1}{2}$ miles at its broadest part. The average depth is $1\frac{1}{2}$ fathoms. A rectangular arm 1.8 miles long and $1\frac{1}{2}$ fathoms deep has as its period $4 \times \frac{1.8}{10.08} = 0.71$ hour. For the actual harbor the period must be considerably greater than 0.71 hour and may approach the observed value.†

134. *Examples of shelving seiches.*

The larger earthquake oscillations at San Francisco must be due to the shelving shore outside and not to any oscillation of the bay, for, the disturbance resulting from the earthquake at Arica, Chile (May 9, 1877), and which reached California early on the following day, arrived at Fort Point about 7 minutes earlier than at Sausalito. This is about the difference which the depths between these two stations might imply. There is a tolerably close resemblance between the records upon the tide gauges at the two places. The maximum range of this disturbance is about 1 foot, and the irregular periods vary from 0.3 hour to an hour or more.

The saw-teeth-like disturbance having an average period of three or four minutes and which frequently occur during and after heavy westerly winds are, as already stated, due to irregular reflections across the Golden Gate and so belong to another class of seiches.

The disturbance caused by the Krakatoa eruption was well marked at Negapatam, Madras, False Point, Beypore, Port Elizabeth, and Table Bay. The resulting oscillations, although very irregular, may be said to have the following respective periods and maximum ranges:

1.5, 1.4, 2.8, 1.1, 1.1, 1.0 hours, and
1.5, 0.5, 1.6, 1.2, 4.5, 1.5 feet.

These periods are too short for permitting the assumption that all of the shallow water along the continental shelf forms a stationary wave $\frac{1}{4}\lambda$ in length. It seems probable that more or less of the water will partake of such motion at a given station according as the intensity of the disturbing force varies. The very uniformity of the slope of the bottom in these regions of shallow water must militate against the existence of definite oscillating arms of water; hence, the great variety of periods and amplitudes at a given place of observation.

Shelving seiches are by far the most common of all. Every considerable earthquake disturbance of the water of the ocean produces them in nearly all parts of a shelving coast. When caused by winds, their appearance is less striking, in that their

* Great Trigonometrical Survey of India, Vol. XVI, Details of the Tidal Observations, Part II, opposite p. 4.

[† After the MS. of Part V had gone to the printer, I learned that Messrs. K. Honda, T. Terada, and D. Isitana, had anticipated me in applying $\tau = 4\ L/\sqrt{g\,h}$ to such seiches as are described in sections 133 and 134. This oversight was due to the fact that while the MS. was being prepared, only three numbers of the Proceedings of the Tôkyô Mathematico-Physical Society were accessible to me.—R. A. H., Dec. 24, 1907.]

amplitude is generally less and the tendency to periodicity less evident. The record of these may then be likened to irregular saw-teeth.

In regular broad and open bays their size and regularity are increased, e. g., the Krakatoa disturbance is much greater and more seiche-like at Port Elizabeth than at Table Bay. At Galle, Ceylon, the tide curves contain at times minute oscillations less regular than a cul-de-sac seiche, but more regular than a shelving seiche.* The period is about 0.4 hour and the range about 0.1 foot. The bay or harbor is broad and open, but does not extend far inland. Hence, it is natural to expect a case lying between the two kinds just mentioned. The harbor helps in making the seiche definite, but because of its openness the outside water forms a large part of the fractional oscillating area.

135. *References to papers relating to the Causes of Seiches.*

Nature, Vol. 17 (1878), p. 234; Nature, Vol. 18 (1878), pp. 100, 101.

F. A. Forel: Seiches and earthquakes, Nature, Vol. 17 (1878), p. 281; Les seiches des lacs; leurs causes, Comptes Rendus, Vol. 86 (1878), pp. 1500–1503.

E. A. Perkins: The seiche in America, The American Meteorological Journal, Vol. 10 (1893), pp. 251–263.

J. R. H. MacFarlane: Occurrence of seiches in Lake Derravaragh, Co. Westmeath, 1893, 1894, Scientific Proceedings of the Royal Dublin Society, Vol. 8 (1895), pp. 288–296.

W. H. Wheeler: Undulations in lakes and inland seas due to wind and atmospheric pressure, Nature, Vol. 57 (1898), pp. 321, 322.

F. Napier Denison: The Great Lakes as a sensitive barometer, B. A. A. S. (1897), pp. 567, 568.

References to descriptions of Limnimeters or Limnographs.

G. Grablovitz: Descrizione d'un maregràfo portatile, Rendiconti delle sedute della R. Accademia dei Lincei, Vol. 6 (1890), pp. 359–362.

Dr. H. Ebert: Sarasin's neues selbstregistrirendes Limnimeter, Zeitschrift für Instrumenkunde, Vol. 21 (1901), pp. 193–201.

A. Endrös: Seichesforschungen am Chiemsee, Zeitschrift für Instrumenkunde, Vol. 24 (1904), pp. 180, 181.

* Details of Tidal Observations, *l. c.*, II, opp. p. 64.

CHAPTER X.

TIDES IN LAKES AND WELLS.

136. *Tides in lakes or inland seas.*

Passing over the tides of the eastern portion of the Mediterranean Sea which were familiar to the ancients and which have been already considered in this manual, it may be noted here that Daniel Bernoulli in Chapter XI of his "Traité sur le Flux et Reflux de la Mer" was the first to attempt to compute the tides on inland seas. (See sec. 94, Part I.)

E. B. Barlow in his book entitled "An Exact Survey of the Tide" (1717) mentions the existence of semidaily tides in Lake Huron, and thus speaks of the tides of Lake Superior:

> Moreover, the French report of the *Upper Lake*, which lies to the *N. West* of this, and falls into the same River; that notwithstanding it is situated *five hundred Fathoms above* the Superficies of the Sea, and lies at *two hundred and seventy leagues* distant from it; yet it Floods to *two*, *three*, and *four Foot* in Height; which plainly shews, that these Tumours proceed absolutely from the *Moon's Pressure*, without the Intermediation of the *Ocean* to raise 'em by way of *Libration*, at so great a Distance from the Sea, and exalted so many Fathoms above it.

Early letters and discussions relating to the tides in the Great Lakes of North America are given by Gen. H. A. S. Dearborn upon pages 78 et seq., Volume XVI (1829), American Journal of Sciences and Arts. Dearborn says:

> The phenomenon appears to have attracted the attention of Fra Marquette in 1673, of Baron Hontan in 1689, of Charlevoix in 1721.

Maj. Samuel A. Storrow observed in Green Bay in the year 1817 a fluctuation of the water surface having a range of from 5 to 8 inches and a half period of 11 or 12 hours. Schoolcraft (about 1820) concludes that there are no regular tides in the lakes, but that the observed fluctuations are meteorological in character. Dr. Joseph Lovell in 1827 expresses a similar view. Capt. Henry Whiting, U. S. A., observed the tides upon a graduated staff in Green Bay from June 1 to 6, 1819. He says:

> The height of the rise and fall, was from twelve to eighteen inches. Both the ebb and flow were very sudden, and in that respect deviate from the general character of the tides. It was seldom more than an hour, in attaining its height, and was generally as rapid in making the descent, though several hours would often intervene between the changes.

In his letter dated September 11, 1827, he expresses his conviction that the Green Bay tides are due to the winds.

Capt. Greenleaf Dearborn, U. S. A., mentions that while stationed at the outlet of Lake Superior, tides having a range of about 18 inches and a time of rising or falling of $2\frac{1}{3}$ to $2\frac{1}{2}$ hours were observed.

In a paper entitled "Remarks on the supposed tides, and periodical rise and fall of the North America Lakes," * Maj. Henry Whiting expresses (p. 212) a belief that an astronomical tide must exist, but that it must be very small. He gives Governor Cass's observations made in 1828 (July 15 to August 29, generally 4 times daily) on Fox River, Green Bay. Governor L. Cass thus comments upon his observations:

> The slightest inspection will satisfy you, that the changes in the elevation of the water are entirely too variable to be traced to any regular permanent cause; and that consequently there is no perceptible tide at Green Bay, which is the result of observation.

Lieut. D. Ruggles, in an article entitled "Tides in the North American Lakes," † gives some history of the subject and expresses the belief that the tide can not well be detected from observations made, say, four times daily (as was the case with those made in 1828), and so he causes hourly observations to be made for one week at Green Bay in 1836. It seems doubtful whether or not he really detected any tide, for his observations indicate oscillations of a foot or two.

Upon page 130 of his book entitled "Wisconsin: Its geography and topography, history, geology, and mineralogy" (2d ed. Milwaukee, 1846), Mr. Increase A. Lapham says:

> The question whether there is a regular tide on the lakes, still remains undecided. That there are strong and variable currents in Lake Michigan has been known ever since the days of Hennepin.

In 1849 Lapham kept a meteorological journal, in which he gives the height of Lake Michigan five times daily and referred his readings to the city datum. Whether or not he really detected an astronomical tide from these observations is uncertain. He, however, believed that he did, as can be seen from his statements in an appendix to Charles Whittlesey's paper, page 447, American Journal of Sciences and Arts, Volume XXVII (1859). However this may be, he subsequently obtained hourly readings day and night from September 14 to November 14, 1852. This record is in the office of the Coast and Geodetic Survey. From these it is possible to determine the tide, as has been done in section 137; but no work of Lapham's appears to be extant which might prove that he detected the true tide. A plotting of the hourly readings clearly shows the transverse seiche at Milwaukee, with a period of almost exactly two hours—which is the theoretical time of such oscillation—and a range of 0.2 foot.

A paper by Major Lachlan entitled "On the periodical rise and fall of the lakes" appears in the American Journal of Sciences and Arts, Volume XIX (1855), pages 60–71, 164–175, and Volume XX (1855), pages 45–53. On pages 63 et seq., Volume XIX, is an historical account of the subject. On page 168 he quotes an extract from a report by Colonel Whittlesey for 1838–39, in which Whittlesey strongly contends that observations fail to show any astronomical tide in Lake Erie. Lachlan comes to the conclusion (Vol. XX., p. 51) that "a long, regular course of minute observations" is necessary to settle the question of tides in lakes. At the close of the paper (Vol. XX, p. 53) the editors refer to an important paper by Whittlesey (1851), which goes to show that the fluctuations are not periodical.

Major Lachlan also discusses the annual and other variations in lake level.

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* Am. Jour. Sci. & Arts, Vol. XX (1831), pp. 205–219.
† Am. Jour. Sci. & Arts, Vol. XLV (1843), pp. 18–27.

Col. J. D. Graham, in an article entitled "Investigation of the problem regarding the existence of a lunar tidal wave on the great fresh-water lakes of North America," * finds from six months of half hourly readings, the spring range on Lake Michigan at Chicago, to be 0.25 foot, the mean range 0.15 foot, and the mean lunitidal interval to be 30 minutes. He says:

This result was announced in my annual report to the Topographical Bureau of the War Department on the 15th of November, 1858, and also before the Chicago Historical Society at its annual meeting on the 30th of that month.

This discovery is referred to on page 127, Volume 37 (1859), Journal Franklin Institute.

The later work of Colonel Graham is discussed by Ferrel, "Tidal researches," pages 250–255, who finds for the values of approximately the same quantities—0.21 foot, 0.14 foot, and 32 minutes, respectively.

In the American Journal of Sciences and Arts, Volume XXVII (1859), pages 305–310, Charles Whittlesey reviews observations made by Mr. Underwood in 1858 at Green Bay, but he does not believe the tide on Lake Michigan yet discovered. On page 447 of the same volume is a note or appendix to Mr. Whittlesey's paper in which I. A. Lapham states that he detected (and announced in 1849) a tide from observations made every three hours during the month of August, 1849. Also, that subsequent hourly observations made day and night for two months fully confirmed this conclusion. In this note Whittlesey mentions Colonel Graham's discovery of the tide in 1858, as chronicled in the proceedings of the Chicago Historical Society for the meeting of November 30, 1858.

It will be noticed that the earlier attempt at finding a lake tide failed because fluctuations many times greater than the astronomical tide were invariably mistaken for it, and also because continuous hourly readings were seldom undertaken. The justice of Lapham's claim to the discovery of a lake tide must depend upon what values he may have obtained for its range and interval.

In the Annual Report of the Survey of the Northern and Northwestern Lakes for 1872, by Maj. C. B. Comstock, is given on pages 9–14 a discussion of the tides at Milwaukee. A self-registering gauge was there maintained for several years, and portions of the record from 1867 to 1871 are discussed. Judging from the diagrams, Plates I–III, $M_2 = 0.0395$, $S_2 = 0.018$, and $S_2 + M_2 = 0.045$ foot, and the lunitidal interval, 30 minutes. The tabular values on page 12 of this report, when harmonically analyzed give $M_2 = 0.0340$ ft., $M_2{}^0 = 19^\circ.46$; $S_2 = 0.0154$ ft., $S_2{}^0 = 26^\circ.43$. In discussing these tides, the writer ascertains the theoretical equilibrium tide at Chicago and Milwaukee. These applications of the equilibrium theory, especially to the results obtained from observations by Colonel Graham at Chicago, constitute the first instance in the history of tides where the forces and tides have been rationally connected. But in this case the writer obtains a result twice as great as the equilibrium value, from an erroneous assumption concerning the kinetic energy in the tides of the lake.

In the next year's report of the Lake Survey, pages 28 and 30, and Plates I and II, are given similar results from observations at Duluth; but no theoretical considerations are introduced. An analysis of the tabular values on page 30, gives $M_2 = 0.0643$ ft., $M_2{}^0 = 64^\circ.45$; $S_2 = 0.0360$ ft.; $S_2{}^0 = 85^\circ.75$.

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* Report A. A. A. S., 1860, pp. 52–60.

137. *Harmonic constants for the Great Lakes.*

Components	Milwaukee, Lake Michigan, lat. 43° 02′ N., long. 87° 54′ W.				Marquette, Lake Superior, lat. 46° 32′ N., long. 87° 23′ W.		Duluth, Lake Superior, lat. 46° 47′ N., long. 92° 05′ W.			
	Sept. 15, 1852–Oct. 13, 1852		Oct. 13, 1852–Nov. 10, 1852		Jan. 1, 1904–Jan. 3, 1905		Oct. 11, 1901–Oct. 14, 1902		May 9, 1902–May 12, 1903	
	H Ft.	κ °	H Ft.	κ °	H Ft.	κ °	H Ft.	κ °	H Ft.	κ °
K_1					0.0066	263.03	0.0297	85.04	0.0345	99.37
K_2					0.0030	333.62	0.0101	84.32	0.0079	77.04
M_1					0.0019	213.27	0.0054	177.28	0.0052	170.68
M_2	0.0247	37.4	0.0228	40.12	0.0130	298.84	0.0631	71.05	0.0658	72.22
O_1					0.0040	233.42	0.0249	89.36	0.0213	92.54
P_1					0.0026	261.28	0.0155	85.36	0.0168	59.50
S_1							0.0159	80.93	0.0092	98.05
S_2	0.0103	48.3	0.0208	70.55	0.0086	349.33	0.0336	87.91	0.0337	87.70

The no-tide point of Lake Superior (center of gravity of the surface, section 49, Part II), is 9 statute miles north of Keweenaw Point. The latitude and longitude of the no-tide point are about 47° 32′ N., 87° 43′ W. By means of this section, or preferably by means of sections 1–4, Part IV A, it is readily seen that the values in this table agree well, as a rule, with the corrected equilibrium theory; but see section 21.

The observations at Milwaukee are hourly readings made by I. A. Laphan; those at Marquette and Duluth are taken from records of self-registering gauges maintained by the United States Army Engineers.

The large size of the tide at Chicago and Milwaukee indicates the stationary-wave motion of sec. 21.

The values of Mf and Mf° given in section 124 agree tolerably well with the theoretical values given in Table 37. . . . So far as semidaily, daily, or fortnightly forces are concerned the earth behaves nearly as a rigid body.

But according to a publication of the Royal Prussian Geodetic Institute, New Series, No. 30, 1907, O. Hecker finds from observations upon a horizontal pendulum some yielding of the earth to the tidal forces.

138. *Tides in wells or springs.*

Pliny the Elder calls attention to wells in Spain that rise and fall with the tide of the ocean and to those which rise and fall contrary to it. (Sec. 69, Part I, this manual).

Barlow on pages 30–32, First Treatise, of his "Exact Survey of the Tides," places little or no credence in the possibility of intermittent springs being influenced by the rise and fall of the ocean tide.

On pages 308 and 309 of Volume IV of his Astronomie, Lalande makes mention of wells or springs which have periodic fluctuations. Some of these are simply intermittent springs; e. g., those described in Philosophical Transactions 1665, No. 7, and 1693, No. 204.

According to the Admiralty Sailing Directions for the Pacific Islands, Volume III, wells of fresh water in Fanning Island rise and fall with the tide.

A detailed account of a considerable number of tidal wells, is given by A. C. Veatch in Water-Supply and Irrigation Paper, No. 155, U. S. Geological Survey, 1906, entitled "Fluctuations of the Water Level in Wells, with Special Reference to Long Island, New York." He finds the tide in the wells of the locality considered to be due to the periodic deformation of a clay layer immediately above the water-bearing stratum, the deformation being caused by the varying weight of the ocean tide above. The effect is a maximum at the low-water line and decreases with the distance from the shore. The lag of the tide in the well upon the ocean tide varies from a few minutes at the shore to more than an hour at a few hundred feet inland. At the shore the range of the fluctuation may be a considerable fraction of the range of the ocean tide.

The tidal oscillations in shallow wells along the sea shore he concludes to be generally due to the action of sea water upon the outflowing fresh water in the porous material into which the well is dug. The tides of the well may be behind those upon the outside by an interval of several hours.

Upon page 67 is a bibliography of the subject.

CHAPTER XI.

MISCELLANEOUS REMARKS ON TIDES AND MODES OF REDUCTION.

On the lengths of series.

139. *Effect of one or more components on observed mean sea level.*

A component produces no disturbance in mean sea level if the series of ordinates extend over exactly a whole number of its periods. Let τ denote the length of series actually used; let $\nu_1 \frac{360°}{a}$ denote the positive integral number of periods of the component A which falls nearest the length τ; and put

$$\tau = \nu_1 \frac{360°}{a} + \varepsilon_1$$

or

$$\varepsilon_1 = \tau - \nu_1 \frac{360°}{a}.$$

The displacement or disturbance of mean sea level is

$$\frac{A}{\tau}\int_0^{\tau} \cos\,(at+\alpha)\,dt = \frac{A}{\tau}\int_{t=0}^{t=\varepsilon_1} \cos\,(at+\alpha)\,dt$$

$$= \frac{A}{a\tau}\Big[\sin\,(a\varepsilon_1+\alpha) - \sin\,\alpha\Big]. \qquad (340)$$

Thus we see that the amount of disturbance of mean sea level due to a component, depends in general upon its initial phase, as well as upon its speed and amplitude. Consequently, if we have several components A, B, C, . . ., a length τ such that the disturbance shall be zero for assumed values of the initial phases α, β, γ, . . ., this length will not give a zero disturbance for other assumed values of α, β, γ, ...

Special case $\alpha=0$, assuming τ nearly equal to a multiple of periods of A.—Since ε_1 is assumed to be small, the disturbance due to A becomes $A\frac{\varepsilon_1}{\tau}$. This becomes $-A\frac{\varepsilon_1}{\tau}$ if α be taken as 180°. Hence

The disturbance of mean sea level under such assumed conditions that an improper length has the greatest possible effect, is independent of the speed of the component and is directly proportional to the error in length.

If there are several components the expression for the disturbance is

$$\frac{A\varepsilon_1}{\tau} + \frac{B\varepsilon_2}{\tau} + \frac{C\varepsilon_3}{\tau} + \ldots.$$

This becomes zero if

$$A\varepsilon_1+B\varepsilon_2+C\varepsilon_3+\ldots=0.$$

Now

$$\varepsilon_1=\tau-\nu_1\frac{360}{a},\quad \varepsilon_2=\tau-\nu_2\frac{360}{b},\quad \varepsilon_3=\tau-\nu_3\frac{360}{c},\ldots$$

and so the value of τ satisfying the last equation is

$$\tau'=\frac{A\nu_1\frac{360}{a}+B\nu_2\frac{360}{b}+C\nu_3\frac{360}{c}+\ldots}{A+B+C+\ldots} \tag{341}$$

Hence

The length of series giving the best value of sea level may be found by weighing the integral numbers of component periods (each multiple period being nearly equal to τ) according to the respective amplitudes.

Because ε_1 is supposed to be a small quantity, we may write the general expression for the disturbance in the form

$$\frac{A}{a\tau}\left[a\varepsilon_1\cos\alpha-\frac{a^2\varepsilon_1^2}{2}\sin\alpha\right]$$

If $\alpha=\mp 90°$, this becomes $\pm\frac{Aa\varepsilon_1^2}{\tau}$. In assigning limits to the integration it was assumed that ε_1 might have either a positive or a negative value. If we had supposed ε_1 to be an essentially positive quantity, the expression for the disturbance would have been either

$$\frac{A}{a\tau}\left[\sin\,(a\varepsilon_1+\alpha)-\sin\,\alpha\right]\text{ or }\frac{A}{a\tau}\left[\sin\,\alpha-\sin\,(a\varepsilon_1+\alpha)\right]$$

according as ε_1 is placed at the upper or lower limit of the integration. Hence we shall have as the required disturbance of sea level when $\alpha=-90°$ the very small quantities,

$$\frac{Aa\varepsilon_1^2}{\tau}\text{ or }-\frac{Aa\varepsilon_1^2}{\tau} \tag{342}$$

according as ε_1, is positive or negative. Hence

The disturbance of mean sea level under such assumed conditions that an improper length has the least possible effect is proportional to the speed of the component and to the square of the error in length.

For several components the disturbance is

$$\pm\frac{Aa\varepsilon_1^2}{\tau}\pm\frac{Bb\varepsilon_2^2}{\tau}\pm\frac{Cc\varepsilon_3^2}{\tau}\pm\cdots \tag{343}$$

This equated to zero would give a time τ' slightly different from the τ' already found.

We shall suppose τ' to be determined by the foregoing rule, which weights the components according to their amplitudes.

The periods of the several components expressed in mean solar days are given in the column headed $\frac{s_1}{c}$, Table 1. Let such multiples of these periods be taken as shall give in each case very nearly 29 solar days. The exact times thus determined are to be multiplied by the respective amplitudes of the components. If we use the theoretical amplitudes as given in Table 1, the above rule gives when M_2, S_2, N_2, ν_2, L_2, T_2, $2N$, μ_2 and K_1, O_1, P_1, Q_1, are substituted in the formula,

$$\tau' = 28.99 \text{ days.}$$

The result remains sensibly the same when we use semidiurnals alone or diurnals alone.

Thus we see that 29 days is almost an ideal period for the determination of mean sea level, so far as a period can be decided irrespective of the time and locality.

It may be remarked that although the above rule applies and gives $\tau' = 29$ days, it does not follow that multiples of 29 days are the most accurate lengths which can be selected. And this is so because the rule presupposes that, for any assumed length, the fractional portions of the component periods are very small, at least this should be the case with the larger components.

In attempting to find suitable lengths of series, it is to be noted that, since S_2 is a comparatively large component, such lengths should not fall from a whole number of days or of half days. This consideration, taken in connection with some of the uncertainties attending the determination of τ', seems to justify one in always cutting the series off at a whole number of days or of half days.

Before attempting to actually find the lengths suitable for determining mean sea level, it is best to prepare a table showing the value, in mean solar days, of multiples of various component days (and half days in case of semidiurnals), covering a period of a little more than one year. This having been done, the approximate lengths can be seen at once; for, the multiple periods of any component of considerable size must fall not far from the required times.

Having found the approximate lengths, the formula for τ' will be of assistance in determining the more exact values, or in discriminating between two nearly equal assumed values.

The following are fairly satisfactory lengths expressed in solar days:

29, 58, 87; 104.5, 133.5, 162.5, 191.5, 220.5, 249.5, 278.5; 297, 326, 355, 384 or 282, 311, 340, 369.

Lengths approximately equal to 3 or 9 months are the most uncertain.

140. *Effect of one or more inequalities on the observed range of tide.*

An inequality in the tide can be represented by a curve resembling somewhat a curve of sines. The effect of the inequality will disappear if τ be an exact multiple of its period. When this is not the case, the disturbance in the mean quantity due to the error in the length of series used depends upon the initial phase of the inequality. A given error in length will have the greatest effect when the initial phase is 0° or 180°.

The inequality in height (range) and that in time (interval) should be separately considered. For, if the initial phase of the height inequality in a particular series were zero, the initial phase of the corresponding time inequality would be $\pm 90°$. But for determining a suitable length of a series we can assume in our calculations that the initial phase of the time inequality is also zero; in other words, that the disturbance due to error in length is the greatest possible.

Now each subordinate component B, C, . . . can be connected with an inequality whose period is its synodic period with A. Hence we have as a suitable length of series for determining the mean range of tide or the mean lunitidal interval

$$\tau' = \frac{B\nu_1 \frac{360}{b \sim a} + C\nu_2 \frac{360}{c \sim a} + \cdots}{B + C + \ldots} \tag{344}$$

141. *Effect of one or more components on the observed values of another component.*

A series is cut off at a certain length τ. The A-summation gives the A-wave uncorrected for the effects of B, C, . . These effects are the same upon the component A as would be the direct superposition upon A of the small-waves B', C', ... These latter denote, for the moment, waves of speed a whose amplitudes and phases depend upon the value of τ . The amplitudes and phases must have such values that the wave compounded of B', C', . . . shall have its amplitude zero.

To simplify matters, assume the phases of B', C', . . . relative to A to be zero. The correction to the amplitude of A becomes, section 59, Part II.

$$\delta A = |-\delta \bar{A}| = \left| \frac{\sin \frac{1}{2}(b-a)\tau}{\frac{1}{2}(b-a)\tau} B + \frac{\sin \frac{1}{2}(c-a)\tau}{\frac{1}{2}(c-a)\tau} C + \cdots \right|. \tag{345}$$

Since τ is assumed to be near the synodic periods of A and B, A and C, etc., we have

$$\sin \tfrac{1}{2}(b-a)\ \tau = \tfrac{1}{2}(b-a)\left(\tau - \nu_1 \frac{360}{b-a}\right),$$

$$\sin \tfrac{1}{2}(c-a)\ \tau = \tfrac{1}{2}(c-a)\left(\tau - \nu_2 \frac{360}{c-a}\right),$$

. . . .

The disturbance in the amplitude of A due to the components B, C, . . . will be zero if $\tau = \tau'$, where

$$\tau' = \frac{B\nu_1 \frac{360}{b \sim a} + C\nu_2 \frac{360}{a \sim c} + \ldots}{B + C + \ldots\ldots\ldots\ldots} \tag{346}$$

Hence

A suitable length of series for the determination of any component can be found from its several synodic periods with the other components, by weighting these periods according to the amplitudes of the corresponding components.

By assuming other initial phases, slightly different results would be obtained.

142. *Rules for supplying missing portions of a tidal or tidal-current record.*

Since it is advisable to assume no particular knowledge of the tide at a given locality, the rules here laid down are designed to apply reasonably well to all stations, but somewhat better to those where the number of the tides is governed by the lunar semidiurnal constituent.

Short gaps can be filled by repeating the preceding record, starting the repeated portion at the same phase of tide (higher high, lower low, etc.) as that which immediately precedes the gap. In a similar way the curve can be extended across the gap from the record which follows. A mean between the two sets of values can then be used.

In filling a gap more than a day or two in extent which may occur in a record several months long, advantage should be taken of the fact that the tidal forces, and so the tides, are after the lapse of certain intervals of time, nearly the same as before. Such intervals are 29, 191.5, 355, and 384 days. These are the times required for most of the inequalities to recur as nearly as may be; consequently, by making use of these intervals, all inequalities may be ignored and the missing tides inferred from the preceding (or following) record through the principal lunar constituent only. The length, 162.5 days, is less satisfactory.

Periods approximately equal to the above lengths, but consisting of a whole number of half lunar days, are given here:

	d	d	h	d	h	m
2 lunar half days =	1.03505010 =	1	0.8412 =	1	0	50.47
56	= 28.981403	= 28	23.5537 =	28	23	33.22
314	= 162.502866	= 162	12.0688 =	162	12	4.13
370	= 191.484268	= 191	11.6224 =	191	11	37.35
686	= 355.022184	= 355	0.5324 =	355	0	31.95
742	= 384.003587	= 384	0.0861 =	384	0	05.17

From these values there result the following rules, which apply to any form of tide or current record:

Tides 29 days after a given date are the same as those of the given date, but occur 27 minutes earlier in the day.

Tides 29 days before a given date are the same as those of the given date, but occur 27 minutes later in the day.

Tides 191.5 days after a given date are the same as those of the given date, but occur 23 minutes earlier in the half day.

Tides 191.5 days before a given date are the same as those of the given date, but occur 23 minutes later in the half day.

A. M. tides on the earlier date will generally be P. M. tides on the later, and P. M. tides on the earlier date will generally be A. M. tides on the next day following the later date.

Tides 355 days after a given date are the same as those on the given date, but occur 32 minutes later in the day.

Tides 355 days before a given date are the same as those on the given date, but occur 32 minutes earlier in the day.

Tides 384 days after a given date are the same as those on the given date, but occur 5 minutes later in the day.

Tides 384 days before a given date are the same as those on the given date, but occur 5 minutes earlier in the day.

Tides 162.5 days after a given date are the same as those of the given date, but occur 4 minutes later in the half day.

Tides 162.5 days before a given date are the same as those of the given date, but occur 4 minutes earlier in the half day.

A.M. tides on the earlier date will generally be P.M. tides on the later, and P.M. tides on the earlier date will generally be A. M. tides on the next day following the later date.

It is often convenient to take for the interpolated value the mean of the values occurring 29 days before and after the given date.

As a practical test, the first of these rules was applied to the predictions for San Francisco, Cal., as given in the Coast Survey Tide Tables for 1902. Comparison was made between the 112 tides there given for May 1–29 and those occurring 29 days later. The latter were found to occur on an average 26.62 minutes earlier in the day than the former, the individual difference ranging from 1 to 55 minutes. The greatest difference between corresponding heights is 0.6 foot.

To facilitate the application of these rules, Table 57 has been prepared showing dates upon which the tide should be almost the same in time and height.

In using these tables, care must be taken to properly allow for February 29 when this date occurs in the period considered. The table is for common years.

143. *General rule for inferring a component from larger components.*

Let A and B denote two large components, both diurnals or both semidiurnals.

The age of the inequality in the A tide due to the B wave is

$$\frac{B^0-A^0}{b-a}$$

The epoch of C, assuming the age of the C inequality is the same as of the B inequality, is

$$C^0=A^0+\frac{c-a}{b-a}(B^0-A^0). \tag{347}$$

In particular

$$\begin{aligned}M_1^0&=K_1^0+\frac{m_1-k^1}{o_1-k_1}(O_1^0-K_1^0)\\&=K_1^0+\frac{1}{2}O_1^0-\frac{1}{2}K_1^0=\frac{1}{2}(K_1^0+O_1^0).\end{aligned}$$

The amplitude may be taken as the theoretical percentage of B or of A or of A+B. In particular, (see Table 1).

$$[M_1]=0.079\ O_1 \text{ or } 0.056\ K_1 \text{ or } 0.033\ (K_1+O_1).$$

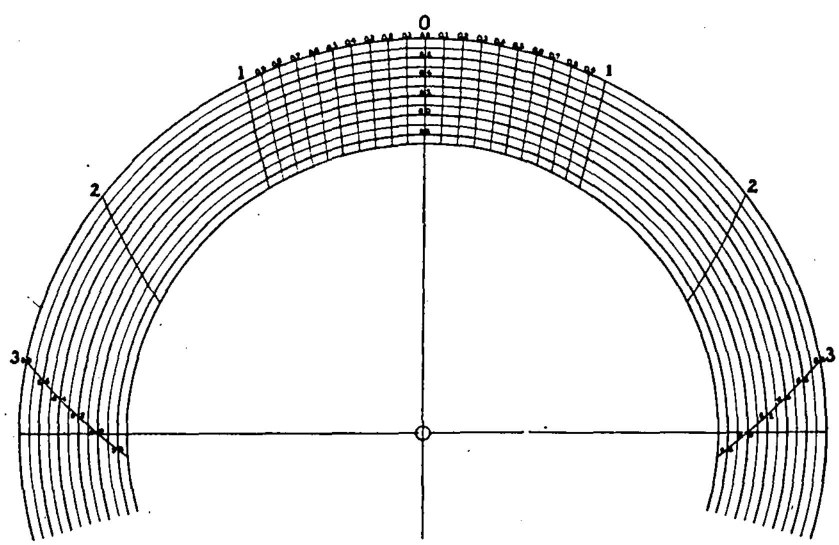
If c has very nearly the value a or b take C as the theoretical percentage of A or B (Table 1). If c has not very nearly the speed of either of these components, consider whether or not the period of the C inequality is equal to or commensurable with the period of the B inequality. If so, C can be taken as a fraction of B, even though c differs considerably from b. For example, the amplitude of L_2 can be better inferred as a fraction of the amplitude of M_2 or N_2 than of S_2, although the speed of L_2 differs comparatively little from the speed of S_2.

144. *Remarks on reductions and analyses.*

In section 74, Part II, it is explained how the harmonic components may be obtained from observed high and low waters. In the method as there laid down some error is incurred because the period of the semidaily tide is not constant and because its amplitude, as there determined, is affected by the residual effect of the diurnal tide. This means that the principal tide, M_2, can not be well determined from the interpolated ordinates, and so must be inferred from a "first reduction." The smaller components, however, are well determined, as the example given in the section just referred to goes to show.

The more correct expression for the range of the semidaily wave is (498), Part II. A few extra columns on the reduction sheet will enable one to make the correction for the effect of the daily tide.

No. 31.



For interpolating hourly ordinates, when the period of the tide varies from day to day, various schemes might be suggested, such as tables or several sets of sine curves. A convenient apparatus may be described as follows:

Upon a sheet of drawing paper (tacked to a drawing board) draw a series of, say, 12 consecutive circles 0.2 inch apart, the radius of the inner circle being 6 inches. Let 3 solar hours represent a quadrant of the 4th (which is for a tidal day of just 24 solar hours) circle, counting the inmost circle as the first. Lay off from an initial diameter 1, 2, and 3 solar hours on either side. From the same initial diameter, but upon other circles, lay off distances such that the angles at the center shall not be 0°, 30°, 90°, as before, but these angles multiplied by c_2/s_2 where c_2 is the hourly speed of the tide and s_2 that of the component S_2, or 30° per hour, c_2 can be assumed to decrease uniformly in going outward from the inner circle (see Fig. 31).

The values used for the duration of a tide, and which should be written upon the circles, may range from, say, 5.7 to 6.8 hours. Either way from the initial diameter the first hour should be divided into tenths to represent the tenths of hours in the times of occurrence of mean sea level of the semidaily tide. The hours are reckoned in either direction; they increase, say, from right to left for a rising tide and from left to right for a falling tide. Just within the circle is a disc, 12 inches in diameter, ruled with parallel lines, say, one-sixth of an inch apart, representing tenths of feet of amplitude, and numbered to make mean sea level any convenient reading. The disc bears a pointer extending across the system of circumferences, already described. After setting the pointer at the proper fraction of hour (the fraction of hour in the time of occurrence of mean sea level, column 5, p. 570, Part II) and across the proper circle (column 6), the disc is weighted down or otherwise held in position. A graduated scale revolving about the center of the circles is set with its edge upon the exact hours of this circle. The amplitude of the tide taken from this scale is then projected by means of the parallel lines upon the disc, upon a line perpendicular to them. This gives the required hourly heights.

In computing the effects of the diurnal components upon the amplitude (No. 498, Part II) it is convenient to make use of a system of parabolas whose ordinates are the ranges of the diurnal wave and whose abscissæ are twice the ranges of the semidaily wave. The diurnal components are found as described on page 571, Part II.

As a test of this process, ordinates have been inferred from high and low waters at Presidio, California, extending from January 1, 1898, over a series of 191½ days. The results as obtained from these ordinates generally compares well with results obtained from analyzing the observed ordinates for the same period. The results, not corrected for imperfect elimination, are as follows:

Component	From ordinates obtained from high and low waters		From observed hourly ordinates	
	H	κ	H	κ
	Feet	°	*Feet*	°
K_2	0.0965	313.85	0.0912	330.28
M_2	1.8165	332.27	1.7987	330.40
N_2	0.3778	307.25	0.3833	305.58
S_2	0.4100	341.47	0.4034	338.39
μ_2	0.0327	175.26	0.0328	192.56
K_1	1.1989	104.59	1.2494	105.84
O_1	0.6525	83.59	0.7646	88.64
P_1	0.4281	107.84	0.4131	105.34

145. In sections 30, 31, Part III, a plan is outlined for finding the spring and neap ranges of tide and the approximate value of S_2 from observed high and low waters. In practice it is generally best to assume that the age of the phase inequality is known from an harmonic analysis at the given station or at one not far away (see tables

under section 97, Part IV A, section 19, Part IV B). If harmonic constants are to be found, it seems best to use the method described in section 74, Part II, and slightly improved in section 144, Part V. The assuming of the age makes it possible to use comparatively short groups at springs and neaps.

In correcting for parallax it has been found best to make use of mean, rather than true, perigees and apogees. The times of the occurrence of these are given in Table 58, and the effect of the parallax wave upon the spring and neap ranges is given in Table 59.

146. In sections 36–39, Part III, a treatment of high and low waters for obtaining quantities connected with the diurnal part of the tide is given. In practice we can generally assume that the age of the diurnal wave is known from harmonic analyses at the given station or at one not very far away (see tables under section 97, Part IV A, and section 19, Part IV B). If harmonic constants are to be found, it seems best to use the method described in section 74, Part II, and slightly improved in section 144, Part V.

The object of giving the below computations is to show how the nonharmonic quantities can be obtained and how corrections for the time of year and for the longitude of the moon's node are to be applied. The results obtained from a one-month series and from one six months in length are seen to be in fair accord with each other. Before beginning these computations, it is assumed that if Greenwich transits have been used, the intervals have been so corrected as to refer to the local meridian. The effect of solar K_2 upon the interval can generally be ignored in computations relating to short series.

STATION: PRE

Declinational tides, January 6 to December 26,

(1) HWQ from reduction.
(2) LWQ from reduction.
(3) (1)×(group factor, Table 35)=HWQ corrected for group.
(4) (2)×(group factor, Table 35)=LWQ corrected for group.
(5) (Gc from reduction)+½[(3)+(4)−(1)−(2)]=Gc corrected for group.
(6) (Sc from reduction)−½[(3)+(4)−(1)−(2)]=Sc corrected for group.
(7) (Tropic LLW from reduction)−½[(4)−(2)] =Tropic LLW corrected for group.
(8) $(3)^2+(4)^2=(HWQ)^2+(LWQ^2)=(\text{approx. } 2D_1)^2$.
(9) (Mc from reduction)−(8)+[(.06)×16 Mc] $=\text{Mc}-\frac{(2D_1)^2}{16\text{Mc}}=2D_2$.
(10) $(3)+(9)=\frac{HWQ}{2D_2}=$ argument Table 19.
(11) $(4)+(9)=\frac{LWQ}{2D_2}=$ argument Table 19.
(12) $2D_1$ Table 19. $2D_2=$unity.
(13) HW phase Table 19. See Part III, p. 161.
(14) $1.02F_1$, Table 14, or $\frac{1.02(K_1+O_1)}{c_{11}K'_1+O'_1}$, when O_1/K_1 differs much from 0.7.
*(15) (9)×(12)×(14)=$2D_2$×($2D_1$ Table 19)×$1.02F_1$= corrected $2D_1$.
*(16) (3)×(14)=HWQ×$1.02F_1$= corrected HWQ.
*(17) (4)×(14)=LWQ×$1.02F_1$= corrected LWQ.
(18) $37.6^m \frac{K_2}{M_2}\sin(K_1^0-O_1^0-\overline{K_2^0-M_2^0})=$ increase in interval due to solar K_2.
(19) (9)×[F(Mn), Table 14, $K_1+O_1=0$]=$2D_2$ corrected for moon's node.
(20) (14)+F(Mn)=[(D_2 uncorr.)×(D_1 corr.)]+[(D_2 corr.)×(D_1 uncorr.)] = factor for time inequalities.
(21) HWI+(18)= Mean tropic HWI.
(22) LWI+(18)= Mean tropic LWI.
*(23) [HHWI−(21)]×(20)+(21) = corrected HHWI.
*(24) [LHWI−(21)]×(20)+(21) = corrected LHWI.
*(25) [HLWI−(22)]×(20)+(22) = corrected HLWI.
*(26) [LLWI−(22)]×(20)+(22) = corrected LLWI.
*(27) [(5)−9)]×(14)+(19) = corrected Gc.
*(28) [(6)−(9)]×(14)+(19) = corrected Sc.
*(29) [Gt−Mn']×(14)+Mn = corrected Gt.
*(30) 2Mn−Gt = corrected Sl.
*(31) [(7) (HTL − ½(9)]×(14) + HTL − ½(19) = [Tropic LLW−uncorr. D_2LW]×$1.02F_1$ + corr. D_2LW = corrected Tropic LLW.
*(32) [Mean LLW−LW]×(14)+LW= corrected mean LLW.
*(33) ½[HWI+LWI±$6^h\,12^m.6$]+(18)−$0^h.069$×(13)=(M_2^0 accel. by solar K_2−HW phase)+m_1=D_1HWI.

An asterisk (*) indicates one of the quantities sought.

SIDIO, CAL., 1898.

(*length of series a multiple of six months*).

(1) 1.670.
(2) 3.714
(3) $1.670 \times 1.012 = 1.690$
(4) $3.714 \times 1.012 = 3.759$
(5) $6.451 + \frac{1}{2}[0.065] = 6.483$.
(6) $1.167 - \frac{1}{2}[0.065] = 1.135$.
(7) $4.688 - \frac{1}{2}[0.045] = 4.666$.
(8) $(1.690)^2 + (3.759)^2 = 2.856 + 14.130 = 16.986$.
(9) $3.809 - 16.986 + (16 \times 3.809) = 3.809 - 0.279 = 3.530$.
(10) $1.690 + 3.530 = 0.479$.
(11) $3.759 + 3.530 = 1.065$.
(12) 1.178.
(13) 65^0.
(14) 1.02×0.944. [Table 14] $= 0.963$.
*(15) $3.530 \times 1.178 \times 0.963 = 4.004 =$ corrected $2D_1$.
*(16] $1.690 \times 0.963 = 1.627 =$ corrected HWQ.
*(17) 3.759×0.963 $3.620 =$ corrected LWQ.
(18) $37^m.6 \times \frac{0.116}{1.696} \sin 21.^\circ 5 = 1^m.0$.
(19) $3.530 \times 1.009 = 3.562$.
(20) $0.963 + 1.009 = 0.954$.
(21) $11^h 43^m.3 + 1^m.0 = 11^h\ 44^m.3$.
(22) $5\ 05.8 + 1.0 = 5\ 06.8$.
*(23) $(10^h\ 39^m.4 - 11\ 44.3) \times 0.954 + 11^h\ 44^m.3 = 10^h\ 40^m.5 =$ HHWI.
*(24) $(13\ 08.3 - 11\ 44.3) \times 0.954 + 11\ 44.3 = 13\ 02.5 =$ LHWI.
*(25) $(4\ 42.0 - 5\ 06.8) \times 0.954 + 5\ 06.8 = 4\ 41.2 =$ HLWI.
*(26) $(5\ 32.5 - 5\ 06.8) \times 0.954 + 5\ 06.8 = 5\ 29.4 =$ LLWI.
*(27) $[6.483 - 3.530] \times 0.963 + 3.562 = 6.408 =$ Gc.
*(28) $[1.135 - 3.530] \times 0.963 + 3.562 = 1.256 =$ Sc.
*(29) $[5.696 - 3.897] \times 0.963 + 3.920 = 5.652 =$ Gt.
*(30) $2 \times 3.920 - 5.652$ $= 2.188 =$ Sl.
*(31) $[4.666 - 8.366 + 1.765] \times 0.963 + 8.366 - 1.781 = 4.722 =$ corrected Tropic LLW.
*(32) $[5.191 - 6.416] \times 0.963 + 6.416 = 5.236 =$ corrected mean LLW.
*(33) $\frac{1}{3}[11^h\ 43^m.3 + 5^h\ 05^m.8 + 6^h\ 12^m.6] + 1^m.0 - 4^h.485 = 7^h\ 02.^m7$.

Declinational tides, March 1 to April 16,

(1) HWQ from reduction.
(2) LWQ from reduction.
(3) (1)×(group factor, Table 35) = HWQ corrected for group.
(4) (2)×(group factor, Table 35) = LWQ corrected for group.
(5) $\sqrt{(3)^2+(4)^2} = \sqrt{(HWQ)^2+(LWQ)^2}$ = approx. $2D_1$.
(6) Mc from reduction or 0.88 Mn or Mn − 0.54 S_2.
(7) $(6) - (5)^2 \div 16 \times (6) = Mc - \frac{(2D_1)^2}{16 Mc} = 2D_2$.
(8) $(3) \div (7) = \frac{HWQ}{2D_2}$ = Arg. Table 19.
(9) $(4) \div (7) = \frac{LWQ}{2D_2}$ = Arg. Table 19.
(10) 2 D_1 from Table 19. $2D_2$ = unity.
(11) HW phase from Table 19. See Part III, p. 161.
(12) 1.02 F_1, Table 32, or $\frac{102}{c_{11}} \frac{(K_1+O_1)}{K'_1+O'_1}$ Table 31, if O_1/K_1 differs much from 0.7.
(13) 0.606×(Table 31, col. 2)+(12) = accel. of dirunal wave due to P_1.
(14) $37^m.6 \frac{K_2}{M_2} \sin (K^\circ_1+O^\circ_1-K^\circ_2-M^\circ_2)$ = Increase in interval at tropic tides.
(15) ½[2(HWI+LWI)+2(14)]−(HHWI+LHWI+HLWI+LLWI)] = accel. of D_2 due to solar effect in minutes and mulplied by 0.483 in M°_2 degrees.
(16) [(7)−$2S_2$ (average phase corr. Table 24)×(col. 9 Table 31)] [F(Mn)−Table 14 (K_1+O_1)=O] = $2D_2$ corrected for solar effect and moon's node.
*(17) (7)×(10)×(12) = $2D_1$ corrected.
(18) ½(15)−(13)+(11) = corrected HW phase. Arg. Tables 17 and 18.
(19) $= \frac{(17)}{(16)} = \frac{D_1}{D_2}$ arg. Tables 17 and 18.
(20) Table 17, arg. (18) and (19). Accelerations.
 (i) HHW.
 (ii) LHW.
 (iii) HLW.
 (iv) LLW.
(21) Table 17, arg. (10) and (11). Accelerations.
 (i) HHW.
 (ii) LHW.
 (iii) HLW.
 (iv) LLW.
*(22) (i) HHWI from reduction+[(21i) −(20i)] × 2^m.07+(15) = corrected HHWI.
 (ii) LHWI from reduction+[(21ii) −(20ii)] × 2.07+(15) = corrected LHWI.
 (iii) HLWI from reduction+[(21iii)−(20iii)] × 2.07+(15) = corrected HLWI.
 (iv) LLWI from reduction +[(21iv) −(20iv)] × 2.07+(15) = corrected LLWI.
(23) Table (18) arg. 18 and 19.
 (i) HHW.
 (ii) LHW.
 (iii) HLW.
 (iv) LLW.
*(24) $\left.\begin{array}{r}(23i)\\(23ii)\\(23iii)\\(23iv)\end{array}\right\} \times \tfrac{1}{2}(16) \left.\begin{array}{l}=HHW\\=LHW\\=HLW\\=LLW\end{array}\right\}$ from HTL
*(25) (23i) − (23ii) = HWQ.
*(26) (23iii) − (23iv) = LWQ.
*(27) (23i) − (23iv) = Gc.
*(28) (23ii) − (23iii) = Sc.
*(29) (Gt−Mn′)×(12)+Mn = corrected Gt.
*(30) HTL−(23i) = corrected Tropic LLW on staff.
*(31) (Mean LLW−LW^1)×(12)+L W = corrected mean LLW.
*(32) ½[HWI+LWI±6^h12^m6]+(14)−0^h.069×(18) = [$M_2\rho$ accel. by solar K_2−HW phase]÷m_1 = D_1 HWI.

An asterisk (*) indicates one of the quantities sought.

(*length of series not a multiple of six months*).

(1) 1.42.

(2) 3.38.

(3) $1.42 \times 1.012 = 1437.$

(4) $3.38 \times 1.012 = 3.421.$

(5) $\sqrt{(1.437)^2 + (3.421)^2} = \sqrt{2.065 + 11.703} = 3.711.$

(6) 3.12.

(7) $312 - \dfrac{13.768}{16 \times 3.12} = 2.844.$

(8) $\dfrac{1.437}{2.844} = 0.505.$

(9) $\dfrac{3.421}{2.844} = 1.203.$

(10) 1.330.

(11) 66.5.

(12) $1.02 \times 1.081 = 1.103.$

(13) $0.606 \times (13^\circ.3 \times 0.946) + 1.103 = 7^\circ.0.$

(14) $37^m.6 \times \dfrac{0.116}{1.696} \sin 21^\circ.5 = 1^m.0$

(15) $\frac{1}{4}[2(11^h\,40^m.5 + 5^h\,01^m.9 + 2^m.0) - (10^h\,14^m.1 + 12^h\,56^m.6 + 4^h\,21^m.5 + 4^h\,58^m.3)] = 14^m.6 = 7^\circ.0.$

(16) $2.844 - 0.80 \times \dfrac{-0.68 - 0.94}{2} = 3.492. \quad 3.492 \times 1.011 = 3.530.$

(17) $2.844 \times 1.330 \times 1.103 = 4.172.$

(18) $3^\circ.5 - 7^\circ.0 + 66^\circ.5 = 63^\circ.0.$

(19) $\dfrac{4.172}{3.530} = 1.182.$

(20) **Accel. of HW and LW. Arg. 63°.0 and 1.182.**

(i) **HHW** +26°.8.

(ii) **LHW** −35.5.

(iii) **HLW** +21.0.

(iv) **LLW** −12.2.

(21) **Accel. of HW and LW. Agr. 66°.5 and 1.330.**

(i) **HHW** $+31^m.0.$

(ii) **LHW** −41.7

(iii) **HLW** +22.1.

(iv) **LLW** −11.7.

*(22) (i) $10^h\,14^m.1 + 8^m.7 + 14^m.6 = 10^h\,37^m.4$ = **HHWI**

(ii) $12\ \ 56\ .6 - 13\ .2 + 14\ .6 = 12\ \ 58\ .4$ = **LHWI.**

(iii) $4\ \ 21\ .5 + 2\ .3 + 14\ .6 = 4\ \ 38\ .4$ = **HLWI.**

(iv) $4\ \ 58\ .3 + 1\ .0 + 14\ .6 = 5\ \ 13\ .9$ = **LLWI.**

(23) **Arg. 63°.0 and 1.182.**

(i) +1.655.

(ii) +0.620.

(iii) 0.000.

(iv) −2.080.

*(24) $\left.\begin{array}{lr} \text{(i)} & 1.655 \\ \text{(ii)} & 0.620 \\ \text{(iii)} & 0.000 \\ \text{(iv)} & -2.080 \end{array}\right\} \times 1.765 = \left.\begin{array}{r} 2.921 = \mathbf{HHW} \\ 1.094 = \mathbf{LHW} \\ 0.000 = \mathbf{LHW} \\ -3.671 = \mathbf{LLW} \end{array}\right\}$ **from HTL.**

*(25) $2.921 - 1.094 = 1.827$ = **HWQ.**

*(26) $0.000 + 3.671 = 3.671$ = **LQW.**

*(27) $2.921 + 3.671 = 6.592$ = **Gc.**

*(28) $1.094 + 0.000 = 1.094$ = **Sc.**

*(29) $(5.356 - 3.884) \times 1.103 + 3.911 = 5.535$ = **Gt.**

(30) $2 \times 3.911 - 5.535 + 2.287$ = **Sl.**

(31) $(5.056 - 6.104) \times 1.103 + 6.090 = 4.933$ = mean **LLW.**

(32) $\frac{1}{2}(11^h\,40^m.5 + 5^h\,01^m.9 + 6^h\,12^m.6) + 1^m.0 - 0.069 \times 63.0 = 11^h\,28^m.5 - 4^h\,20^m.8 = 7^h\,07^m.7.$

147. Where the tides are chiefly diurnal, it becomes necessary to make reduction of the equatorial tides in order to ascertain the semidaily wave. The semidaily wave being thus known, the diurnal can be ascertained at the time of the tropic tides by means of the great tropic range of tide and the times of occurrence of the tropic high and low waters. This procedure is preferable to that proposed in Part III, which makes use of Table 20, because mean sea level is subject to considerable variation. Given the displacements (accelerations) v and w of the semidaily wave due to the diurnal wave, then the HW-phase, β, can be found either by means of a table, like Table 17 extended, or by means of the formula:

$$\tan(\text{HW-phase}) = -\tan\frac{1}{2}v\cot\frac{1}{2}w\tan\left(45^\circ - \frac{v+w}{4}\right). \qquad (348)$$

This equation is found by successively substituting for $b\,t$ in the derivative of (27), Part III, equated to zero, $-\frac{1}{2}v$ and $90°-\frac{1}{2}w$, and eliminating $B \mid A$.

A reduction of the tides for one year at Manila shows that, not only can the ranges and intervals be determined from observed high and low waters, but also that the principal harmonic constants determined by this means agree well with the constants obtained by analyzing hourly ordinates.

148. *Miscellaneous remarks and corrections.*

In section 24, Part I, the wave profile is shown to be trochoidal; but the approximation there used for y requires a correction when the amplitude of the wave is a considerable fraction of its length. The necessity for this correction is apparent in Fig. 12, Part IV A. Using the value of x given in (51) Part I and increasing the right-hand member of (52) by a quantity ε, the value of $\int_{\theta=0}^{\theta=2\pi} y'dx$, where $y'=y-h$, equated to zero gives

$$\varepsilon=\frac{\lambda m^2}{4\pi}. \qquad (349)$$

In other words, the condition of continuity where a whole wave length is considered prevents $y'=y-h$ from having the form (52).

In equation (1), Part I, for 50, substitute 48.8. The same substitution should be made in second footnote, section 93. Here also substitute for "daily retardation," "retardation per solar day," and for 36, 88, 51, and 49; 35, 87, 50, and 48, respectively.

In section 5, Part III, a graphic process is outlined for determining the times of maxima and minima of a wave composed of two simple waves, the period of one being twice that of the other. In construction of Tables 4 and 44 the following process of further approximation was used:

Let v' denote the approximate values of v, either directly from construction or from a second or higher approximation.

Then

$$\frac{1}{2}v=\frac{1}{2}v'+57.3y \qquad (350)$$

where

$$y=\frac{B\sin\beta}{4\cos\frac{1}{2}v'+B\cos\beta}-\tan\frac{1}{2}v'. \qquad (351)$$

If this value of v does not satisfy equation (28), Part III, where $A=1$, a second approximation should be made in the same manner.

If we write

$$z=\cos^2\beta, \tag{352}$$

then, in the limiting or discriminating case, B and β are connected by the relation

$$z^2-z=\frac{1}{2B^4}\left(\frac{B^2-16}{6}\right)^3. \tag{353}$$

This equation, equated to zero, represents the discriminant of eq. (28), Part III, wherein x is written for

$$\cos\frac{1}{2}vt.$$

In section 20, Part III, for 1.006, put 1.012.

An harmonic analysis of the tide at Tamatave, made by the French, show that more of the cotidal lines should meet the eastern coast of Madagascar than are represented as doing so in Figs. 6, 7, Part IV B. In fact, under this station, page 350, Part IV B, the M_2-cotidal hour is given as X.33, indicating that at least lines X½—XII½ meet the coast. The values used in the construction of the cotidal lines for this region were taken chiefly from the Admiralty Tide Tables; the French values for Tamatave did not come to my notice until after the chart had been constructed.

Recent observations at Kiska Harbor, Aleutian Islands, show that the crowding up of the cotidal lines should occur in this vicinity instead of a little farther east, as shown in Figs. 34, 35, Part IV B. Observations give for mean high and low water intervals $2^h\,07^m$ and $8^h\,17^m$, and for mean range of tide 1.9 feet. This fact, together with the small range of tide found at Kiska, go to confirm the existence of the nodal line shown in Fig. 23, Part IV A.

In third line from bottom of page 545, Part IV A, for *e* read *c*.

A few corrections of errata are indicated in section 76, Part II; others have been indicated on errata sheets accompanying the Reports in which the parts of this manual have appeared.

For want of time, several matters whose treatment was contemplated must be omitted here. For example, the determination of the moon's mass from the ratio P_1/K_1 for ocean stations where the diurnal wave is large. That the assumed mass of the moon approximately agrees with the value inferred from the tides can be seen upon comparing the ratios P_1/K_1 for such stations in section 97, Part IV A, and section 19, Part IV B, with the assumed theoretical ratio. Other astronomical quantities can be estimated from the tides.

The slow rate of propagation in rivers, or other arms of the sea, having broad marginal strips of shallow water, or inequalities in shoreline like those possessed by Chesapeake Bay, is another matter passed over for want of time.

A few other matters are: The course of the diurnal wave, the K_1-wave, for instance; the analysis and discussion of long-period gravitational tides; the latitude-variational tide; improvements in the methods of making and reducing observations; and the construction of additional auxiliary tables.

ADDITIONAL ERRATA, PARTS I TO IV B.

Part I. Fig. 19, opposite page 384, all numerals denoting heights should be multiplied by two.

Page 421, strike out lines 16–19.

Part II. Page 479, line 15, for "*bench mark*" read "*water;*" for "*water*" read "*bench mark;*" for "difference between" read "sum of."

Transfer "††" at end of line 35 to end of line 37.

Page 514, 10th line from bottom, delete "a small displacement of."

Page 517, 14th line from bottom, for "1" write "$1+\frac{3}{2}e^2$."

Page 535, line 15, for "87°" write "87° 43′."

Page 553, 11th line from bottom, for "in local time" read "in standard time."

Page 556, 1st table, for "$\zeta\,(A)$" write "$\zeta_c\,(A)$"; for "$\zeta_c\,(B)$" write "$\zeta\,(B)$"; for "$\kappa'=+V_0+u$" write "$\kappa'=\zeta+V_0+u$."

Page 573, 9th line from bottom, for "all multiplied by the same constant" read "each divided by a constant proportional to its speed;" 7th line from bottom, for "This shows that" read "In certain straits, see section 34, Part I."

Page 583, Table, after "All" add "except S."

Part IV A. Page 564, 5th line, for "t" read "x;" 6th line after "have" add "for the flood stream;" 12th line, for "$+$" read "$\pm$;" 13th line, for "$+$" read "$-$;" in eq. (74) and following expressions on page 564, for "α" read "$-\alpha$."

Page 579, in 2d, 4th, and 6th lines from bottom of page, for "Z" read "z."

Page 616, near middle of page, for "three" read "these."

Page 620, annex "$\cos\alpha_{\nu\mu}$" to each parenthesis of eq. (314).

Page 623, 4th line from bottom of page, for "(321)" read "(318)."

Part IV B. Page 332, 1st line before eq. (24), for "x" write "χ."

Page 351, 3d column from right-hand side, for "5.87" read "11.87."

Page 351, 5th, 4th, and 2d columns from right-hand side for "224.5" read "324.5;" for "14.97," read "21.63;" for "6.27" read "12.93."

Page 371, 9th line from bottom, before "occur," insert "not."

Page 375, 13th line from bottom, delete "approach."

Page 386, 2d line from bottom, delete "scarcely."

Page 388, near middle of page, for "III" write "III½."

AUXILIARY TABLES FOR THE REDUCTION AND PREDICTION OF TIDES

[Tables 1 to 54 are appended to Part III, Appendix No. 7, Report for 1894, to Part II, Appendix No. 8, Report for 1897, and to Part IV, Appendix No. 7, 1900]

TABLE 55.—*For clearing one component of the effects of the others.**

[Length of series, 14 days.]

Component sought (A)	Disturbing components (B, C, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	0.6263	0.020	0.2065	0.615	0.525	0.020	0.123	0.576	0.014
	....	269	356	264	93	255	353	261	262	185
K_1	0.626	....	0.621	0.0242	0.024	0.990	0.207	0.020	0.998	0.216
	91	....	268	356	4	346	264	353	353	276
M_1	0.020	0.6208	....	0.6208	0.206	0.716	0.020	0.207	0.669	0.050
	4	92	....	268	97	78	356	265	85	189
O_1	0.207	0.0242	0.621	....	0.024	0.054	0.626	0.016	0.014	0.710
	96	4	92	....	9	171	269	357	178	281
OO	0.615	0.0242	0.206	0.0241	....	0.091	0.122	0.021	0.059	0.128
	267	356	263	351	....	342	260	348	349	272
P_1	0.525	0.9904	0.716	0.0544	0.091	....	0.217	0.018	0.998	0.215
	105	14	282	189	18	....	278	186	7	290
Q_1	0.020	0.2065	0.020	0.6263	0.122	0.217	....	0.626	0.213	0.992
	7	96	4	91	100	82	....	269	89	12
2Q	0.123	0.0200	0.207	0.0159	0.021	0.018	0.626	....	0.001	0.537
	99	7	95	3	12	174	91	....	0	104
S_1	0.576	0.9976	0.669	0.0137	0.059	0.998	0.213	0.001	....	0.217
	98	7	275	182	11	353	271	360	....	283
ρ_1	0.014	0.2160	0.050	0.7105	0.128	0.215	0.992	0.537	0.217	....
	175	84	171	79	88	70	348	256	77	....

* This is a continuation of Table 41.

TABLE 55.—*For clearing one component of the effects of the others**—Continued.

[Length of series, 15 days.]

Component sought (A)	Disturbing components (B, C, etc.)											
	K_2	L_2	M_2	N_2	2N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM
K_2	....	0.567 260	0.0879 342	0.175 244	0.081 326	0.997 353	0.9889 345	0.975 338	0.468 247	0.053 339	0.198 257	0.070 168
L_2	0.567 100	....	0.5790 262	0.080 344	0.178 246	0.620 92	0.6724 85	0.722 77	0.991 347	0.200 259	0.016 357	0.214 88
M_2	0.088 18	0.579 98	....	0.579 262	0.080 344	0.054 10	0.0156 3	0.026 175	0.672 85	0.016 357	0.672 275	0.016 6
N_2	0.175 116	0.080 16	0.5790 98	....	0.579 262	0.189 108	0.2004 101	0.209 93	0.016 3	0.672 275	0.991 13	0.120 104
2N	0.081 34	0.178 114	0.0804 16	0.579 98	....	0.066 26	0.0488 19	0.031 11	0.200 101	0.991 13	0.481 111	0.038 22
R_2	0.997 7	0.620 268	0.0536 350	0.189 252	0.066 334	....	0.9972 353	0.989 345	0.524 255	0.035 347	0.207 265	0.026 175
S_2	0.989 15	0.672 275	0.0156 357	0.200 259	0.049 341	0.997 7	....	0.997 353	0.579 262	0.016 354	0.214 272	0.016 3
T_2	0.975 22	0.722 283	0.0258 185	0.209 267	0.031 349	0.989 15	0.9972 7	....	0.632 269	0.005 182	0.217 280	0.054 10
λ_2	0.468 113	0.991 13	0.6724 275	0.016 357	0.200 259	0.524 105	0.5790 98	0.632 91	....	0.214 272	0.060 190	0.200 101
μ_2	0.053 21	0.200 101	0.0156 3	0.672 85	0.991 347	0.035 13	0.0156 6	0.005 178	0.214 88	....	0.579 98	0.016 9
ν_2	0.198 103	0.016 3	0.6724 85	0.991 347	0.481 249	0.207 95	0.2138 88	0.217 80	0.060 170	0.579 262	....	0.127 91
2SM	0.070 192	0.214 272	0.0156 354	0.120 256	0.038 338	0.026 185	0.0156 357	0.054 350	0.200 259	0.016 351	0.127 269	....

*This is a continuation of Table 41.

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 58 days.]

Component sought (A)	Disturbing components (B, C, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	.0489	.049	.0447	.064	.128	.037	.030	.104	.020
	....	341	319	297	25	284	278	259	313	329
K_1	.049	....	.056	.0523	.052	.842	.045	.037	.959	.011
	19	....	338	316	44	303	297	278	331	348
M_1	.049	.0565	....	.0565	.046	.101	.049	.043	.018	.014
	41	22	....	338	66	145	319	300	174	190
O_1	.045	.0523	.056	....	.037	.018	.049	.046	.021	.092
	63	44	22	....	88	167	341	322	16	212
OO	.064	.0523	.046	.0375	....	.068	.029	.020	.069	.026
	335	316	294	272	....	259	253	234	287	303
P_1	.128	.8421	.101	.0181	.068	....	005	.016	.959	.039
	76	57	215	193	101	....	354	335	29	225
Q_1	.037	.0447	.049	.0489	.029	.005	....	.049	.029	.875
	82	63	41	19	107	6	....	341	35	51
2Q	.030	.0373	.043	.0463	.020	.016	049	....	.031	.125
	101	82	60	38	126	25	19	....	53	70
S_1	.104	.9591	.018	.0210	.069	959	.029	.031	....	.015
	47	29	186	344	73	331	325	307	....	196
ρ_1	.020	.0113	.014	.0920	.026	.039	.875	.125	.015	....
	31	12	170	148	57	135	309	290	164	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 58 days.]

Component sought (A)	Disturbing components (B, C, etc.)											
	K_2	L_2	M_2	N_2	2N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM
K_2	....	.064	.0523	.045	.037	.959	.8421	.666	.128	020	.011	.083
	....	335	316	297	278	331	303	274	284	329	348	110
L_2	.064	....	.0489	.046	.042	.009	.0920	.166	.875−	.005	.018	.039
	25	....	341	322	303	177	148	120	309	354	193	135
M_2	.052	.049	....	.049	.046	.021	.0181	.056	.092	.018	.092	.018
	44	19	....	341	322	16	167	138	148	193	212	154
N_2	.045	.046	.0489	....	.049	.029	.0055−	.021	.018	.092	.875	.004
	63	38	19	....	341	35	6	157	167	212	51	173
2N	.037	.042	.0463	.049	....	.031	.0164	.003	.005	.875	.125	.005
	82	57	38	19	....	53	25	176	6	51	70	12
R_2	.959	.009	.0210	.029	.031	....	.9591	842	.104	.002	.015	.056
	29	183	344	325	307	....	331	303	313	357	196	138
S_2	.842	.092	.0181	.005	.016	959	....	959	.049	.018	.039	.018
	57	212	193	354	335	29	....	331	341	206	225	167
T_2	.666	.166	.0560	.021	.003	.842	.9591	....	.028	.034	.055	.021
	86	240	222	203	184	57	29	....	190	234	253	16
λ_2	.128	.875−	.0920	.018	.005	.104	.0489	.028	....	.039	.078	.005
	76	51	212	193	354	47	19	170	....	225	244	6
μ_2	.020	.005	.0181	.092	.875	.002	.0177	.034	.039	....	.049	.017
	31	6	167	148	309	3	154	126	135	....	19	141
ν_2	.011	.018	.0920	.875	.125	.015	.0390	.055	.078	.049	....	.028
	12	167	148	309	290	164	135	107	116	341	....	122
2SM	.083	.039	.0177	.004	.005	.056	.0181	.021	.005	.017	.028	....
	250	225	206	187	348	222	193	344	354	219	238	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 87 days.]

Component sought (*A*)	Disturbing components (*B*, *C*, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	.0478	.044	.0333	.061	.080	.021	.010	.089	.019
	....	332	298	265	38	246	237	209	289	313
K_1	.048	....	.055	.0458	.046	.666	.033	.021	.909	.011
	28	....	327	294	66	274	265	237	317	341
M_1	.044	.0547	....	.0547	.033	.093	.044	.034	.018	.014
	62	33	....	327	100	127	298	270	170	195
O_1	.033	.0458	.055	....	.018	.018	.048	.042	.021	.086
	95	66	33	....	133	161	332	303	23	228
OO	.061	.0458	.033	.0184	....	.022	.007	.003	.045	.020
	322	294	260	227	....	208	199	351	251	275
P_1	.080	.6663	.093	.0180	.022	....	.005	.016	.909	.034
	114	86	233	199	152	....	351	323	43	247
Q_1	.021	.0333	.044	.0478	.007	.005	....	.048	.027	.731
	123	95	62	28	161	9	....	332	52	76
2Q	.010	.0210	.034	.0421	.003	.016	048	....	.025	.086
	151	123	90	57	9	37	28	....	80	104
S_1	.089	.9092	.018	.0207	.045	909	.027	.025	....	.015
	71	43	190	337	109	317	308	280	....	204
ρ_1	.019	.0112	. 4	.0861	.020	.034	.731	.086	.015	....
	47	19	165	132	85	113	284	256	156	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series 87 days.]

Component sought (A)	Disturbing components (B, C, etc.).											
	K_2	L_2	M_2	N_2	2N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM.
K_2	....	.061	.0458	.033	.021	.909	.6663	.348	.080	.019	.011	.057
	....	322	.294	265	237	317	274	231	246	313	341	75
L_2	.061	....	.0478	.042	.033	.009	.0861	.127	.731	.005	.018	.034
	38	....	332	303	275	175	132	89	284	351	199	113
M_2	.046	.048	....	.048	.042	.021	.0180	.050	.086	.018	.086	.017
	66	28	....	322	303	23	161	118	132	199	228	141
N_2	.033	.042	.0478	....	.048	.027	.0055	.020	.018	.086	.731	.004
	95	57	28	....	332	52	9	146	161	228	76	170
2N	.021	.033	.0421	.048	....	.025	.0158	.003	.005	.731	.086	.005
	123	85	57	28	....	80	37	174	9	76	104	18
R_2	.909	.009	.0207	.027	.025	....	.9092	.666	.089	.002	.015	.050
	43	185	337	308	280	....	317	274	289	356	204	118
S_2	.666	.086	.0180	.005	.016	.909	....	.909	.048	.017	.034	.018
	86	228	199	351	323	43	....	317	332	219	247	161
T_2	.348	.127	.0498	.020	.003	.666	.9092	....	.027	.027	.036	.021
	129	271	242	214	186	86	43	....	195	262	290	23
λ_2	.080	.731	.0861	.018	.005	.089	.0478	.027	....	.034	.058	.005
	114	76	228	199	351	71	28	165	....	247	275	9
μ_2	.019	.005	.0180	.086	.731	.002	.0169	.027	.034	....	.048	.015
	47	9	161	132	284	4	141	98	113	....	28	122
ν_2	.011	.018	.0861	.731	.086	.015	.0340	.036	.058	.048	....	.022
	19	161	132	284	256	156	113	70	85	332	....	93
2SM	.057	.034	.0169	.004	.005	.050	.0180	.021	.005	.015	.022	....
	285	247	219	190	342	242	199	337	351	238	267	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series 104½ days.]

Component sought (A)	Disturbing components (*B*, *C*, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S.	ρ_1
J_1	....	.0509	.039	.0274	.036	.066	.014	.001	.019	.016
	....	217	249	280	154	294	318	355	346	229
K_1	.051	....	.044	.0371	.037	.542	.027	.014	.871	.006
	143	....	212	243	117	257	280	318	308	192
M_1	.039	.0435	....	.0435	.028	.070	.039	.027	.089	.015
	111	148	....	212	85	45	249	286	97	340
O_1	.027	.0371	.044	....	.017	.011	.051	.040	.039	.076
	80	117	148	....	54	14	217	255	65	309
OO	.036	.0371	.028	.0168	....	.025	.005	.005	.008	.017
	206	243	275	306	....	320	343	.201	192	255
P_1	.066	.5420	.070	.0108	.025−	....	.012	.019	.871	.028
	66	103	315	346	40	....	203	241	52	295
Q_1	.014	.0274	.039	.0509	.005−	.012	....	.051	.013	.627
	42	80	111	143	17	157	....	217	28	91
2Q	.001	.0140	.027	.0405−	.005−	.019	.051	....	.003	.060
	5	42	74	105	159	119	143	....	171	54
S_1	.019	.8707	.089	.0393	.008	.871	.013	.003	....	.027
	14	52	263	295	168	308	332	189	....	243
ρ_1	.016	.0059	.015	.0756	.017	.028	.627	.060	.027	....
	131	168	20	51	105	65	269	306	117	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 104½ days.]

Component sought (A)	Disturbing components (*B*, *C*, etc.)											
	K_2	L_2	M_2	N_2	2N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM
K_2	....	.036	.0371	.027	.014	.871	.5420	.160	.066	.016	.006	.049
	....	206	243	280	318	308	257	205	294	229	192	91
L_2	.036	....	.0509	.040	.026	.087	.0756	.000	.627	.012	.011	.028
	154	....	217	255	292	103	51	180	269	203	346	65
M_2	.037	.051	....	.051	.040	.039	.0108	.029	.076	.011	.076	.011
	117	143	....	217	255	65	14	142	51	346	309	28
N_2	.027	.040	.0509	....	.051	.013	.0116	.029	.011	.076	.627	.003
	80	105	143	....	217	28	157	105	14	309	91	171
2N	.014	.026	.0405	.051	....	.003	.0189	.020	.012	.627	.060	.011
	42	68	105	143	....	171	119	68	157	91	54	133
R_2	.871	.087	.0393	.013	.003	....	.8707	.542	.019	.022	.027	.029
	52	257	295	332	189	....	308	257	346	281	243	142
S_2	.542	.076	.0108	.012	.019	.871	....	.871	.051	.011	.028	.011
	103	309	346	203	241	52	....	308	217	332	295	14
T_2	.160	.000	.0286	.029	.020	.542	.8707	....	.091	.009	.007	.039
	155	180	218	255	292	103	52	....	269	204	346	65
λ_2	.066	.627	.0756	.011	.012	.019	.0509	.091	....	.028	.047	.012
	66	91	309	346	203	14	143	91	....	295	257	157
μ_2	.016	.012	.0108	.076	.627	.022	.0105	.009	.028	....	.051	.010
	131	157	14	51	269	79	28	156	65	....	143	42
ν_2	.006	.011	.0756	.627	.060	.027	.0279	.007	.047	.051	....	.018
	168	14	51	269	.306	117	65	14	103	217	....	79
2SM	0.49	.028	.0105	.003	.011	.029	.0108	.039	.012	.010	.018	....
	269	295	332	189	227	218	346	295	203	318	281	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 134 days.]

Component sought (A)	Disturbing component (*B*, *C*, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	.0273	.022	.0186	.011	.054	.016	.012	.040	.006
	....	205	222	239	170	253	264	288	319	201
K_1	.027	....	.019	.0183	.018	.322	.019	.016	.793	.002
	155	....	197	214	146	228	239	264	294	356
M_1	.022	.0192	....	.0192	.017	.039	.022	.020	.070	.013
	138	163	....	197	128	31	222	246	97	339
O_1	.019	.0183	.019	....	.015	.008	.027	.025	.033	.047
	121	146	163	....	111	14	205	229	80	322
OO	.011	.0183	.017	.0151	....	.030	.013	.010	.016	.007
	190	214	232	249	....	262	273	298	328	211
P_1	.054	.3219	.039	.0082	.030	....	.004	.010	.793	.019
	107	132	329	346	98	....	191	216	66	308
Q_1	.016	.0186	.022	.0273	.013	.004	....	.027	.018	.435
	96	121	138	155	87	169	....	205	55	117
2Q	.012	.0162	.020	.0248	.010	.010	.027	....	.008	.058
	72	96	114	131	62	144	155	....	30	92
S_1	.040	.7928	.070	.0331	.016	.793	018	.008	....	.021
	41	66	263	280	32	294	305	330	....	242
ρ_1	.006	.0015	.013	.0467	.007	.019	.435	.058	.021	....
	159	4	21	38	149	52	243	268	118	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 134 days.]

Component sought (A)	Disturbing component (*B*, *C*, etc.)											
	K_2	L_2	M_2	N_2	2N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM
K_2	....	.011	.0183	.019	.016	.793	.3219	.090	.054	.006	.002	.034
	....	190	214	239	264	294	228	342	253	0201	356	61
L_2	.011	....	.0273	.025	.021	.067	.0467	.039	.435	.004	.008	.019
	170	....	205	229	254	104	38	152	243	191	346	52
M_2	.018	.027	....	.027	.025	.033	.0082	.029	.047	.008	.047	.008
	146	155	....	205	229	80	14	128	38	346	322	27
N_2	.019	.025	.0273	....	.027	.018	.0044	.023	.008	.047	.435	.001
	121	131	155	....	205	55	169	103	14	322	117	2
2N	.016	.021	.0248	.027	....	.008	.0099	.017	.004	.435	.058	.004
	96	106	131	155	....	30	144	78	169	117	92	158
R_2	.793	.067	.0331	.018	.008	....	.7928	.322	.040	.017	.021	.029
	66	256	280	305	330	....	294	228	319	267	242	128
S_2	.322	.047	.0082	.004	.010	.793	....	.793	.027	.008	.019	.008
	132	322	346	191	216	66	....	294	205	333	308	14
T_2	.090	.039	.0290	.023	.017	.322	.7928	....	.071	.011	.006	.033
	18	208	232	257	282	132	66	....	271	219	194	80
λ_2	.054	.435	.0467	.008	.004	.040	.0273	.071	....	.019	.037	.004
	107	117	322	346	191	41	155	89	....	308	284	169
μ_2	.006	.004	.0082	.047	.435	.017	.0080	.011	.019	....	.027	.008
	159	169	14	38	243	93	27	141	52	....	155	41
ν_2	.002	.008	.0467	.435	.058	.021	.0188	.006	.037	.027	....	.013
	4	14	38	243	268	118	52	166	76	205	....	65
2SM	.034	.019	.0080	.001	.004	.029	.0082	.033	.004	.008	.013	....
	299	308	333	358	202	232	346	280	191	319	295	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 162½ days.]

Component sought (*A*)	Disturbing components (*B*, *C*, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	.0171	.013	.0108	.000	.029	.011	.010	.044	.004
	....	198	208	217	180	218	236	254	298	198
K_1	.017	....	.009	.0086	.009	.121	.011	.011	.705	.000
	162	....	189	199	161	200	217	236	280	359
M_1	.013	.0088	....	.0088	.008	.011	.013	.013	.058	.005
	152	171	....	189	152	10	208	226	90	350
O_1	.011	.0086	.009	....	.008	.001	.017	.016	.027	.021
	143	161	171	....	142	1	198	217	81	341
OO	.000	.0086	.008	.0082	....	.016	.009	.009	.023	.003
	180	199	208	218	....	219	236	255	299	198
P_1	.029	.1213	.011	.0005	.016	....	.006	.008	.705	.007
	142	160	350	359	141	....	197	216	80	340
Q_1	.011	.0108	.013	.0171	.009	.006	....	.017	.016	.248
	124	143	152	162	124	163	....	198	63	142
2Q	.010	.0111	.013	.0162	.009	.008	.017	....	.010	.040
	106	124	134	143	105	144	162	....	44	124
S_1	.044	.7048	.058	.0275	.023	.705	.016	.010	....	.019
	62	80	270	279	61	280	297	316	....	259
ρ_1	.004	.0002	.005	.0208	.003	.007	.248	.040	.019	....
	162	1	10	19	162	20	218	236	101	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 162½ days.]

Component sought (A)	Disturbing components (B, C, etc.)											
	K_2	L_2	M_2	N_2	2 N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2 SM
K_2	....	.000	.0086	.011	.011	.705	.1213	.207	.029	.004	.000	.011
	....	180	199	217	236	280	200	300	218	198	359	21
L_2	.000	....	.0171	.016	.015	.057	.0208	.059	.248	.006	.001	.007
	180	....	198	217	235	100	19	119	218	197	359	20
M_2	.009	.017	....	.017	.016	.027	.0005	.030	.021	.001	.021	.001
	161	162	....	198	217	81	1	101	19	359	341	2
N_2	.011	.016	.0171	....	.017	.016	.0057	.019	.001	.021	.248	.003
	143	143	162	....	198	63	163	82	1	341	142	164
2N	.011	.015	.0162	.017	....	.010	.0082	.013	.006	.248	.040	.005
	124	125	143	162	....	44	144	64	163	142	124	145
R_2	.705	.057	.0275	.016	.010	....	.7048	.121	.044	.014	.019	.030
	80	260	279	297	316	....	280	200	298	278	259	101
S_2	.121	.021	.0005	.006	.008	.705	....	.705	.017	.001	.007	.001
	160	341	359	197	216	80	....	280	198	358	340	1
T_2	.207	.059	.0296	.019	.013	.121	.7048	....	.058	.014	.018	.027
	60	241	259	278	296	160	80	....	279	258	240	81
λ_2	.029	.248	.0208	.001	.006	.044	.0171	.058	....	.007	.020	.006
	142	142	341	359	197	62	162	81	....	340	321	163
μ_2	.004	.006	.0005	.021	.248	.014	.0005	.014	.007	....	.017	.001
	162	163	1	19	218	82	2	102	20	....	162	3
ν_2	.000	.001	.0208	.248	.040	.019	.0069	.018	.020	.017	....	.004
	1	1	19	218	236	101	20	120	39	198	....	21
2SM	.011	.007	.0005	.003	.005	.030	.0005	.027	.006	.001	.004	....
	339	340	358	196	215	259	359	279	197	357	339	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 191½ days.]

Component sought (A)	Disturbing Components (B, C, etc.)									
	J_1	K_1	M_1	O_1	OO	P_1	Q_1	2Q	S_1	ρ_1
J_1	....	.0072	.003	.0015	.010	.000	.003	.004	.042	.000
	....	189	187	186	12	180	195	204	275	182
K_1	.007	....	.001	.0013	.001	.046	.002	.003	.605	.002
	171	....	358	357	3	351	186	195	266	353
M_1	.003	.0013	....	.0013	.001	.007	.003	.004	.049	.002
	173	2	....	358	5	173	187	196	87	355
O_1	.002	.0013	.001	....	.001	.002	.007	.007	.024	.003
	174	3	2	....	7	175	189	198	89	356
OO	.010	.0013	.001	.0013	....	.004	.000	.002	.022	.002
	348	357	355	353	....	348	182	191	262	350
P_1	.000	.0462	.007	.0023	.004	....	.004	.005	.605	.001
	180	9	187	185	12	....	194	204	94	182
Q_1	.003	0.015	.003	.0072	.000	.004	....	.007	.015	.075
	165	174	173	171	178	166	....	189	80	167
2Q	.004	.0029	.004	.0071	.002	.005	.007	....	.011	.015
	.156	165	164	162	169	156	171	....	71	158
S_1	.042	.6053	.049	.0236	.022	.605	.015	.011	....	.016
	85	94	273	271	98	266	280	289	....	268
ρ_1	.000	.0019	.002	.0033	.002	.001	.075	.015	.016	....
	178	7	5	4	10	178	193	202	92	....

TABLE 55.—*For clearing one component of the effects of the others*—Continued.

[Length of series, 191½ days.]

Component sought (A)	Disturbing Components (B, C, etc.)											
	K_2	L_2	M_2	N_2	2 N	R_2	S_2	T_2	λ_2	μ_2	ν_2	2SM
K_2	....	.010	.0013	.002	.003	.605	.0462	.197	.000	.000	.002	.007
	....	348	357	186	195	266	351	257	180	182	353	166
L_2	.010	....	.0072	.007	.007	.048	.0033	.058	.075	.004	.002	.001
	12	....	189	198	207	98	4	89	193	194	185	178
M_2	.001	.007	....	.007	.007	.024	.0023	.025	.003	.002	.003	.002
	3	171	....	189	198	89	175	80	4	185	356	169
N_2	.002	.007	.0072	....	.007	.015	.0040	.016	.002	.003	.075	.003
	174	162	171	....	189	80	166	71	175	356	167	160
2N	.003	.007	.0071	.007	....	.011	.0047	.011	.004	.075	.015	.004
	165	153	162	171	....	71	156	62	166	167	158	151
R_2	.605	.048	.0236	.015	.011	....	.6053	.046	.042	.012	.016	.025
	94	262	271	280	289	....	266	351	275	277	268	80
S_2	.046	.003	.0023	.004	.005	.605	....	.605	.007	.002	.001	.002
	9	356	185	194	204	94	....	266	189	191	182	175
T_2	.197	.058	.0252	.016	.011	.046	.6053	....	.048	.012	.017	.024
	103	271	280	289	298	9	94	....	283	285	276	89
λ_2	.000	.075	.0033	.002	.004	.042	.0072	.048	....	.001	.003	.004
	180	167	356	185	194	85	171	77	....	182	353	166
μ_2	.000	.004	.0023	.003	.075	.012	.0023	.012	.001	....	.007	.002
	178	166	175	4	193	83	169	75	178	....	171	164
ν_2	.002	.002	.0033	.075	.015	.016	.0006	.017	.003	.007	....	.001
	7	175	4	193	202	92	178	84	7	189	....	173
2SM	.007	.001	.0023	.003	.004	.025	.0023	.024	.004	.002	.001	....
	194	182	191	200	209	280	185	271	194	196	187	....

TABLE 56.—*For the summation of the annual tide.*

Day of series	Sa.	Day of series	Sa.	Day of series	Sa.	Day of series	Sa.	Day of series	Sa.	Day of series	Sa.	Day of series	Sa.
1	0	206	14	420	4	633	18	846	8	1 059	22	1 272	12
8	0	221	14	434	4	647	18	860	8	1 073	22	1 286	12
9	1	222	15	435	5	648	19	861	9	1 074	23	1 287	13
23	1	236	15	449	5	662	19	875	9	1 088	23	1 301	13
24	2	237	16	450	6	663	20	876	10	1 089	0	1 302	14
38	2	251	16	464	6	677	20	890	10	1 103	0	1 316	14
39	3	252	17	465	7	678	21	891	11	1 104	1	1 317	15
53	3	266	17	479	7	692	21	906	11	1 119	1	1 332	15
54	4	267	18	480	8	693	22	907	12	1 120	2	1 333	16
69	4	282	18	495	8	708	22	921	12	1 134	2	1 347	16
70	5	283	19	496	9	709	23	922	13	1 135	3	1 348	17
84	5	297	19	510	9	723	23	936	13	1 149	3	1 362	17
85	6	298	20	511	10	724	0	937	14	1 150	4	1 363	18
99	6	312	20	525	10	738	0	951	14	1 164	4	1 377	18
100	7	313	21	526	11	739	1	952	15	1 165	5	1 378	19
114	7	327	21	540	11	753	1	966	15	1 179	5	1 393	19
115	8	328	22	541	12	754	2	967	16	1 180	6	1 394	20
129	8	342	22	555	12	769	2	982	16	1 195	6	1 408	20
130	9	348	23	556	13	770	3	983	17	1 196	7	1 409	21
145	9	358	23	571	13	784	3	997	17	1 210	7	1 423	21
146	10	359	0	572	14	785	4	998	18	1 211	8	1 424	22
160	10	373	0	586	14	799	4	1 012	18	1 225	8	1 438	22
161	11	374	1	587	15	800	5	1 013	19	1 226	9	1 439	23
175	11	388	1	601	15	814	5	1 027	19	1 240	9	1 453	23
176	12	389	2	602	16	815	6	1 028	20	1 241	10	1 454	0
190	12	403	2	616	16	829	6	1 042	20	1 256	10	1 469	0
191	13	404	3	617	17	830	7	1 043	21	1 257	11	1 470	1
205	13	419	3	632	17	845	7	1 058	21	1 271	11	....	....

This table gives the nearest component "hour" (i. e., 24th of monthly or yearly period) for each day (11.30 a. m.) of the series.

The values here given replace those given in the last column of Table 43 (Part II), which were found to be slightly in error.

TABLE 57.—*Days having similar tides.**

Day of—		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
1	Jan. 1	Dec. 3	Jan. 30	July 22.5	June 12.5	June 23.5	July 11.5	Jan. 11	Dec. 22	Dec. 13	Jan. 20
2	2	4	31	23.5	13.5	24.5	12.5	12	23	14	21
3	3	5	Feb. 1	24.5	14.5	25.5	13.5	13	24	15	22
4	4	6	2	25.5	15.5	26.5	14.5	14	25	16	23
5	5	7	3	26.5	16.5	27.5	15.5	15	26	17	24
6	6	8	4	27.5	17.5	28.5	16.5	16	27	18	25
7	7	9	5	28.5	18.5	29.5	17.5	17	28	19	26
8	8	10	6	29.5	19.5	30.5	18.5	18	29	20	27
9	9	11	7	30.5	20.5	July 1.5	19.5	19	30	21	28
10	10	12	8	31.5	21.5	2.5	20.5	20	31	22	29
11	11	13	9	Aug. 1.5	22.5	3.5	21.5	21	Jan. 1	23	30
12	12	14	10	2.5	23.5	4.5	22.5	22	2	24	31
13	13	15	11	3.5	24.5	5.5	23.5	23	3	25	Feb. 1
14	14	16	12	4.5	25.5	6.5	24.5	24	4	26	2
15	15	17	13	5.5	26.5	7.5	25.5	25	5	27	3
16	16	18	14	6.5	27.5	8.5	26.5	26	6	28	4
17	17	19	15	7.5	28.5	9.5	27.5	27	7	29	5
18	18	20	16	8.5	29.5	10.5	28.5	28	8	30	6
19	19	21	17	9.5	30.5	11.5	29.5	29	9	31	7
20	20	22	18	10.5	July 1.5	12.5	30.5	30	10	Jan. 1	8
21	21	23	19	11.5	2.5	13.5	31.5	31	11	2	9
22	22	24	20	12.5	3.5	14.5	Aug. 1.5	Feb. 1	12	3	10
23	23	25	21	13.5	4.5	15.5	2.5	2	13	4	11
24	24	26	22	14.5	5.5	16.5	3.5	3	14	5	12
25	25	27	23	15.5	6.5	17.5	4.5	4	15	6	13
26	26	28	24	16.5	7.5	18.5	5.5	5	16	7	14
27	27	29	25	17.5	8.5	19.5	6.5	6	17	8	15
28	28	30	26	18.5	9.5	20.5	7.5	7	18	9	16
29	29	31	27	19.5	10.5	21.5	8.5	8	19	10	17
30	30	Jan. 1	28	20.5	11.5	22.5	9.5	9	20	11	18
31	31	2	Mar. 1	21.5	12.5	23.5	10.5	10	21	12	19
32	Feb. 1	3	2	22.5	13.5	24.5	11.5	11	22	13	20
33	2	4	3	23.5	14.5	25.5	12.5	12	23	14	21
34	3	5	4	24.5	15.5	26.5	13.5	13	24	15	22
35	4	6	5	25.5	16.5	27.5	14.5	14	25	16	23
36	5	7	6	26.5	17.5	28.5	15.5	15	26	17	24
37	6	8	7	27.5	18.5	29.5	16.5	16	27	18	25
38	7	9	8	28.5	19.5	30.5	17.5	17	28	19	26
39	8	10	9	29.5	20.5	31.5	18.5	18	29	20	27
40	9	11	10	30.5	21.5	Aug. 1.5	19.5	19	30	21	28
41	10	12	11	31.5	22.5	2.5	20.5	20	31	22	Mar. 1
42	11	13	12	Sept. 1.5	23.5	3.5	21.5	21	Feb. 1	23	2
43	12	14	13	2.5	24.5	4.5	22.5	22	2	24	3
44	13	15	14	3.5	25.5	5.5	23.5	23	3	25	4
45	14	16	15	4.5	26.5	6.5	24.5	24	4	26	5
46	15	17	16	5.5	27.5	7.5	25.5	25	5	27	6

* For explanation of this table see sec. 142.

TABLE 57.—*Days having similar tides*—Continued.

Day of—		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month.	Before	After	Before	After	Before	After	Before	After	Before	After
47	Feb. 16	Jan. 18	Mar. 17	Sept. 6.5	July 28.5	Aug. 8.5	Aug. 26.5	Feb. 26	Feb. 6	Jan. 28	Mar. 7
48	17	19	18	7.5	29.5	9.5	27.5	27	7	29	8
49	18	20	19	8.5	30.5	10.5	28.5	28	8	30	9
50	19	21	20	9.5	31.5	11.5	29.5	Mar. 1	9	31	10
51	20	22	21	10.5	Aug. 1.5	12.5	30.5	2	10	Feb. 1	11
52	21	23	22	11.5	2.5	13.5	31.5	3	11	2	12
53	22	24	23	12.5	3.5	14.5	Sept. 1.5	4	12	3	13
54	23	25	24	13.5	4.5	15.5	2.5	5	13	4	14
55	24	26	25	14.5	5.5	16.5	3.5	6	14	5	15
56	25	27	26	15.5	6.5	17.5	4.5	7	15	6	16
57	26	28	27	16.5	7.5	18.5	5.5	8	16	7	17
58	27	29	28	17.5	8.5	19.5	6.5	9	17	8	18
59	28	30	29	18.5	9.5	20.5	7.5	10	18	9	19
60	Mar. 1	31	30	19.5	10.5	21.5	8.5	11	19	10	20
61	2	Feb. 1	31	20.5	11.5	22.5	9.5	12	20	11	21
62	3	2	Apr. 1	21.5	12.5	23.5	10.5	13	21	12	22
63	4	3	2	22.5	13.5	24.5	11.5	14	22	13	23
64	5	4	3	23.5	14.5	25.5	12.5	15	23	14	24
65	6	5	4	24.5	15.5	26.5	13.5	16	24	15	25
66	7	6	5	25.5	16.5	27.5	14.5	17	25	16	26
67	8	7	6	26.5	17.5	28.5	15.5	18	26	17	27
68	9	8	7	27.5	18.5	29.5	16.5	19	27	18	28
69	10	9	8	28.5	19.5	30.5	17.5	20	28	19	29
70	11	10	9	29.5	20.5	31.5	18.5	21	Mar. 1	20	30
71	12	11	10	30.5	21.5	Sept. 1.5	19.5	22	2	21	31
72	13	12	11	Oct. 1.5	22.5	2.5	20.5	23	3	22	Apr. 1
73	14	13	12	2.5	23.5	3.5	21.5	24	4	23	2
74	15	14	13	3.5	24.5	4.5	22.5	25	5	24	3
75	16	15	14	4.5	25.5	5.5	23.5	26	6	25	4
76	17	16	15	5.5	26.5	6.5	24.5	27	7	26	5
77	18	17	16	6.5	27.5	7.5	25.5	28	8	27	6
78	19	18	17	7.5	28.5	8.5	26.5	29	9	28	7
79	20	19	18	8.5	29.5	9.5	27.5	30	10	Mar. 1	8
80	21	20	19	9.5	30.5	10.5	28.5	31	11	2	9
81	22	21	20	10.5	31.5	11.5	29.5	Apr. 1	12	3	10
82	23	22	21	11.5	Sept. 1.5	12.5	30.5	2	13	4	11
83	24	23	22	12.5	2.5	13.5	Oct. 1.5	3	14	5	12
84	25	24	23	13.5	3.5	14.5	2.5	4	15	6	13
85	26	25	24	14.5	4.5	15.5	3.5	5	16	7	14
86	27	26	25	15.5	5.5	16.5	4.5	6	17	8	15
87	28	27	26	16.5	6.5	17.5	5.5	7	18	9	16
88	29	28	27	17.5	7.5	18.5	6.5	8	19	10	17
89	30	Mar. 1	28	18.5	8.5	19.5	7.5	9	20	11	18
90	31	2	29	19.5	9.5	20.5	8.5	10	21	12	19
91	Apr. 1	3	30	20.5	10.5	21.5	9.5	11	22	13	20
92	2	4	May 1	21.5	11.5	22.5	10.5	12	23	14	21
93	3	5	2	22.5	12.5	23.5	11.5	13	24	15	22

TABLE 57.—*Days having similar tides*—Continued.

Day of—		29 days		162.5 days		101.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
94	Apr. 4	Mar. 6	May 3	Oct 23.5	Sept. 13.5	Sept. 24.5	Oct. 12.5	Apr. 14	Mar. 25	Mar. 16	Apr. 23
95	5	7	4	24.5	14.5	25.5	13.5	15	26	17	24
96	6	8	5	25.5	15.5	26.5	14.5	16	27	18	25
97	7	9	6	26.5	16.5	27.5	15.5	17	28	19	26
98	8	10	7	27.5	17.5	28.5	16.5	18	29	20	27
99	9	11	8	28.5	18.5	29.5	17.5	19	30	21	28
100	10	12	9	29.5	19.5	30.5	18.5	20	31	22	29
101	11	13	10	30.5	20.5	Oct. 1.5	19.5	21	Apr. 1	23	30
102	12	14	11	31.5	21.5	2.5	20.5	22	2	24	May 1
103	13	15	12	Nov. 1.5	22.5	3.5	21.5	23	3	25	2
104	14	16	13	2.5	23.5	4.5	22.5	24	4	26	3
105	15	17	14	3.5	24.5	5.5	23.5	25	5	27	4
106	16	18	15	4.5	25.5	6.5	24.5	26	6	28	5
107	17	19	16	5.5	26.5	7.5	25.5	27	7	29	6
108	18	20	17	6.5	27.5	8.5	26.5	28	8	30	7
109	19	21	18	7.5	28.5	9.5	27.5	29	9	31	8
110	20	22	19	8.5	29.5	10.5	28.5	30	10	Apr. 1	9
111	21	23	20	9.5	30.5	11.5	29.5	May 1	11	2	10
112	22	24	21	10.5	Oct. 1.5	12.5	30.5	2	12	3	11
113	23	25	22	11.5	2.5	13.5	31.5	3	13	4	12
114	24	26	23	12.5	3.5	14.5	Nov. 1.5	4	14	5	13
115	25	27	24	13.5	4.5	15.5	2.5	5	15	6	14
116	26	28	25	14.5	5.5	16.5	3.5	6	16	7	15
117	27	29	26	15.5	6.5	17.5	4.5	7	17	8	16
118	28	30	27	16.5	7.5	18.5	5.5	8	18	9	17
119	29	31	28	17.5	8.5	19.5	6.5	9	19	10	18
120	30	Apr. 1	29	18.5	9.5	20.5	7.5	10	20	11	19
121	May 1	2	30	19.5	10.5	21.5	8.5	11	21	12	20
122	2	3	31	20.5	11.5	22.5	9.5	12	22	13	21
123	3	4	June 1	21.5	12.5	23.5	10.5	13	23	14	22
124	4	5	2	22.5	13.5	24.5	11.5	14	24	15	23
125	5	6	3	23.5	14.5	25.5	12.5	15	25	16	24
126	6	7	4	24.5	15.5	26.5	13.5	16	26	17	25
127	7	8	5	25.5	16.5	27.5	14.5	17	27	18	26
128	8	9	6	26.5	17.5	28.5	15.5	18	28	19	27
129	9	10	7	27.5	18.5	29.5	16.5	19	29	20	28
130	10	11	8	28.5	19.5	30.5	17.5	20	30	21	29
131	11	12	9	29.5	20.5	31.5	18.5	21	May 1	22	30
132	12	13	10	30.5	21.5	Nov. 1.5	19.5	22	2	23	31
133	13	14	11	Dec. 1.5	22.5	2.5	20.5	23	3	24	June 1
134	14	15	12	2.5	23.5	3.5	21.5	24	4	25	2
135	15	16	13	3.5	24.5	4.5	22.5	25	5	26	3
136	16	17	14	4.5	25.5	5.5	23.5	26	6	27	4
137	17	18	15	5.5	26.5	6.5	24.5	27	7	28	5
138	18	19	16	6.5	27.5	7.5	25.5	28	8	29	6
139	19	20	17	7.5	28.5	8.5	26.5	29	9	30	7
140	20	21	18	8.5	29.5	9.5	27.5	30	10	May 1	8
141	21	22	19	9.5	30.5	10.5	28.5	31	11	2	9

TABLE 57.—*Days having similar tides*—Continued.

Day of—		29 days		162.5 days		101.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
142	May 22	Apr. 23	June 20	Dec. 10.5	Oct. 31.5	Nov. 11.5	Nov. 29.5	June 1	May 12	May 3	June 10
143	23	24	21	11.5	Nov. 1.5	12.5	30.5	2	13	4	11
144	24	25	22	12.5	2.5	13.5	Dec. 1.5	3	14	5	12
145	25	26	23	13.5	3.5	14.5	2.5	4	15	6	13
146	26	27	24	14.5	4.5	15.5	3.5	5	16	7	14
147	27	28	25	15.5	5.5	16.5	4.5	6	17	8	15
148	28	29	26	16.5	6.5	17.5	5.5	7	18	9	16
149	29	30	27	17.5	7.5	18.5	6.5	8	19	10	17
150	30	May 1	28	18.5	8.5	19.5	7.5	9	20	11	18
151	31	2	29	19.5	9.5	20.5	8.5	10	21	12	19
152	June 1	3	30	20.5	10.5	21.5	9.5	11	22	13	20
153	2	4	July 1	21.5	11.5	22.5	10.5	12	23	14	21
154	3	5	2	22.5	12.5	23.5	11.5	13	24	15	22
155	4	6	3	23.5	13.5	24.5	12.5	14	25	16	23
156	5	7	4	24.5	14.5	25.5	13.5	15	26	17	24
157	6	8	5	25.5	15.5	26.5	14.5	16	27	18	25
158	7	9	6	26.5	16.5	27.5	15.5	17	28	19	26
159	8	10	7	27.5	17.5	28.5	16.5	18	29	20	27
160	9	11	8	28.5	18.5	29.5	17.5	19	30	21	28
161	10	12	9	29.5	19.5	30.5	18.5	20	31	22	29
162	11	13	10	30.5	20.5	Dec. 1.5	19.5	21	June 1	23	30
163	12	14	11	31.5	21.5	2.5	20.5	22	2	24	July 1
164	13	15	12	Jan. 1.5	22.5	3.5	21.5	23	3	25	2
165	14	16	13	2.5	23.5	4.5	22.5	24	4	26	3
166	15	17	14	3.5	24.5	5.5	23.5	25	5	27	4
167	16	18	15	4.5	25.5	6.5	24.5	26	6	28	5
168	17	19	16	5.5	26.5	7.5	25.5	27	7	29	6
169	18	20	17	6.5	27.5	8.5	26.5	28	8	30	7
170	19	21	18	7.5	28.5	9.5	27.5	29	9	31	8
171	20	22	19	8.5	29.5	10.5	28.5	30	10	June 1	9
172	21	23	20	9.5	30.5	11.5	29.5	July 1	11	2	10
173	22	24	21	10.5	Dec. 1.5	12.5	30.5	2	12	3	11
174	23	25	22	11.5	2.5	13.5	31.5	3	13	4	12
175	24	26	23	12.5	3.5	14.5	Jan. 1.5	4	14	5	13
176	25	27	24	13.5	4.5	15.5	2.5	5	15	6	14
177	26	28	25	14.5	5.5	16.5	3.5	6	16	7	15
178	27	29	26	15.5	6.5	17.5	4.5	7	17	8	16
179	28	30	27	16.5	7.5	18.5	5.4	8	18	9	17
180	29	31	29	17.5	8.5	19.5	6.5	9	19	10	18
181	30	June 1	29	18.5	9.5	20.5	7.5	10	20	11	19
182	July 1	2	30	19.5	10.5	21.5	8.5	11	21	12	20
183	2	3	31	20.5	11.5	22.5	9.5	12	22	13	21
184	3	4	Aug. 1	21.5	12.5	23.5	10.5	13	23	14	22
185	4	5	2	22.5	13.5	24.5	11.5	14	24	15	23
186	5	6	3	23.5	14.5	25.5	12.5	15	25	16	24
187	6	7	4	24.5	15.5	26.5	13.5	16	26	17	25
188	7	8	5	25.5	16.5	27.5	14.5	17	27	18	26
189	8	9	6	26.5	17.5	28.5	15.5	18	28	19	27
190	9	10	7	27.5	18.5	29.5	16.5	19	29	20	28

TABLE 57.—*Days having similar tides*—Continued.

Day of—		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
191	July 10	June 11	Ang. 8	Jan. 28.5	Dec. 19.5	Dec. 30.5	Jan. 17.5	July 20	June 30	June 21	Jul. 29
192	11	12	9	29.5	20.5	31.5	18.5	21	July 1	22	30
193	12	13	10	30.5	21.5	Jan. 1.5	19.5	22	2	23	31
194	13	14	11	31.5	22.5	2.5	20.5	23	3	24	Aug. 1
195	14	15	12	Feb. 1.5	23.5	3.5	21.5	24	4	25	2
196	13	16	13	2.5	24.5	4.5	22.5	25	5	26	3
197	16	17	14	3.5	25.5	5.5	23.5	26	6	27	4
198	17	18	15	4.5	26.5	6.5	24.5	27	7	28	5
199	18	19	16	5.5	27.5	7.5	25.5	28	8	29	6
200	19	20	17	6.5	28.5	8.5	26.5	29	9	30	7
201	20	21	18	7.5	29.5	9.5	27.5	30	10	July 1	8
202	21	22	19	8.5	30.5	10.5	28.5	31	11	2	9
203	22	23	20	9.5	31.5	11.5	29.5	Aug. 1	12	3	10
204	23	24	21	10.5	Jan. 1.5	12.5	30.5	2	13	4	11
205	24	25	22	11.5	2.5	13.5	31.5	3	14	5	12
206	25	26	23	12.5	3.5	14.5	Feb. 1.5	4	15	6	13
207	26	27	24	13.5	4.5	15.5	2.5	5	16	7	14
208	27	28	25	14.5	5.5	16.5	3.5	6	17	8	15
209	28	29	26	15.5	6.5	17.5	4.5	7	18	9	16
210	29	30	27	16.5	7.5	18.5	5.5	8	19	10	17
211	30	July 1	28	17.5	8.5	19.5	6.5	9	20	11	18
212	31	2	29	18.5	9.5	20.5	7.5	10	21	12	19
213	Aug. 1	3	30	19.5	10.5	21.5	8.5	11	22	13	20
214	2	4	31	20.5	11.5	22.5	9.5	12	23	14	21
215	3	5	Sept. 1	21.5	12.5	23.5	10.5	13	24	15	22
216	4	6	2	22.5	13.5	24.5	11.5	14	25	16	23
217	5	7	3	23.5	14.5	25.5	12.5	15	26	17	24
218	6	8	4	24.5	15.5	26.5	13.5	16	27	18	25
219	7	9	5	25.5	16.5	27.5	14.5	17	28	19	26
220	8	10	6	26.5	17.5	28.5	15.5	18	29	20	27
221	9	11	7	27.5	18.5	29.5	16.5	19	30	21	28
222	10	12	8	28.5	19.5	30.5	17.5	20	31	22	29
223	11	13	9	Mar. 1.5	20.5	31.5	18.5	21	Aug. 1	23	30
224	12	14	10	2.5	21.5	Feb. 1.5	19.5	22	2	24	31
225	13	15	11	3.5	22.5	2.5	20.5	23	3	25	Sept. 1
226	14	16	12	4.5	23.5	3.5	21.5	24	4	26	2
227	15	17	13	5.5	24.5	4.5	22.5	25	5	27	3
228	16	18	14	6.5	25.5	5.5	23.5	26	6	28	4
229	17	19	15	7.5	26.5	6.5	24.5	27	7	29	5
230	18	20	16	8.5	27.5	7.5	25.5	28	8	30	6
231	19	21	17	9.5	28.5	8.5	26.5	29	9	31	7
232	20	22	18	10.5	29.5	9.5	27.5	30	10	Aug. 1	8
233	21	23	19	11.5	30.5	10.5	28.5	31	11	2	9
234	22	24	20	12.5	31.5	11.5	Mar. 1.5	Sept. 1	12	3	10
235	23	25	21	13.5	Feb. 1.5	12.5	2.5	2	13	4	11
236	24	26	22	14.5	2.5	13.5	3.5	3	14	5	12

TABLE 57.—*Days having similar tides*—Continued.

Day of—		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
237	Aug. 25	July 27	Sept. 23	Mar. 15.5	Feb. 3.5	Feb. 14.5	Mar. 4.5	Sept. 4	Aug. 15	Aug. 6	Sept 13
238	26	28	24	16.5	4.5	15.5	5.5	5	16	7	14
239	27	29	25	17.5	5.5	16.5	6.5	6	17	8	15
240	28	30	26	18.5	6.5	17.5	7.5	7	18	9	16
241	29	31	27	19.5	7.5	18.5	8.5	8	19	10	17
242	30	Aug. 1	28	20.5	8.5	19.5	9.5	9	20	11	18
243	31	2	29	21.5	9.5	20.5	10.5	10	21	12	19
244	Sept. 1	3	30	22.5	10.5	21.5	11.5	11	22	13	20
245	2	4	Oct. 1	23.5	11.5	22.5	12.5	12	23	14	21
246	3	5	2	24.5	12.5	23.5	13.5	13	24	15	22
247	4	6	3	25.5	13.5	24.5	14.5	14	25	16	23
248	5	7	4	26.5	14.5	25.5	15.5	15	26	17	24
249	6	8	5	27.5	15.5	26.5	16.5	16	27	18	25
250	7	9	6	28.5	16.5	27.5	17.5	17	28	19	26
251	8	10	7	29.5	17.5	28.5	18.5	18	29	20	27
252	9	11	8	30.5	18.5	Mar. 1.5	19.5	19	30	21	28
253	10	12	9	31.5	19.5	2.5	20.5	20	31	22	29
254	11	13	10	Apr. 1.5	20.5	3.5	21.5	21	Sept. 1	23	30
255	12	14	11	2.5	21.5	4.5	22.5	22	2	24	Oct. 1
256	13	15	12	3.5	22.5	5.5	23.5	23	3	25	2
257	14	16	13	4.5	23.5	6.5	24.5	24	4	26	3
258	15	17	14	5.5	24.5	7.5	25.5	25	5	27	4
259	16	18	15	6.5	25.5	8.5	26.5	26	6	28	5
260	17	19	16	7.5	26.5	9.5	27.5	27	7	29	6
261	18	20	17	8.5	27.5	10.5	28.5	28	8	30	7
262	19	21	18	9.5	28.5	11.5	29.5	29	9	31	8
263	20	22	19	10.5	Mar. 1.5	12.5	30.5	30	10	Sept. 1	9
264	21	23	20	11.5	2.5	13.5	31.5	Oct. 1	11	2	10
265	22	24	21	12.5	3.5	14.5	Apr. 1.5	2	12	3	11
266	23	25	22	13.5	4.5	15.5	2.5	3	13	4	12
267	24	26	23	14.5	5.5	16.5	3.5	4	14	5	13
268	25	27	24	15.5	6.5	17.5	4.5	5	15	6	14
269	26	28	25	16.5	7.5	18.5	5.5	6	16	7	15
270	27	29	26	17.5	8.5	19.5	6.5	7	17	8	16
271	28	30	27	18.5	9.5	20.5	7.5	8	18	9	17
272	29	31	28	19.5	10.5	21.5	8.5	9	19	10	18
273	30	Sept. 1	29	20.5	11.5	22.5	9.5	10	20	11	19
274	Oct. 1	2	30	21.5	12.5	23.5	10.5	11	21	12	20
275	2	3	31	22.5	13.5	24.5	11.5	12	22	13	21
276	3	4	Nov. 1	23.5	14.5	25.5	12.5	13	23	14	22
277	4	5	2	24.5	15.5	26.5	13.5	14	24	15	23
278	5	6	3	25.5	16.5	27.5	14.5	15	25	16	24
279	6	7	4	26.5	17.5	28.5	15.5	16	26	17	25
280	7	8	5	27.5	18.5	29.5	16.5	17	27	18	26
281	8	9	6	28.5	19.5	30.5	17.5	18	28	19	27
282	9	10	7	29.5	20.5	31.5	18.5	19	29	20	28

TABLE 57.—*Days having similar tides*—Continued.

Day of		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
283	Oct. 10	Sep. 11	Nov. 8	Apr. 30.5	Mar. 21.5	Apr. 1.5	Apr. 19.5	Oct. 20	Sep. 30	Sep. 21	Oct. 29
284	11	12	9	May 1.5	22.5	2.5	20.5	21	Oct. 1	22	30
285	12	13	10	2.5	23.5	3.5	21.5	22	2	23	31
286	13	14	11	3.5	24.5	4.5	22.5	23	3	24	Nov. 1
287	14	15	12	4.5	25.5	5.5	23.5	24	4	25	2
288	15	16	13	5.5	26.5	6.5	24.5	25	5	26	3
289	16	17	14	6.5	27.5	7.5	25.5	26	6	27	4
290	17	18	15	7.5	28.5	8.5	26.5	27	7	28	5
291	18	19	16	8.5	29.5	9.5	27.5	28	8	29	6
292	19	20	17	9.5	30.5	10.5	28.5	29	9	30	7
293	20	21	18	10.5	31.5	11.5	29.5	30	10	Oct. 1	8
294	21	22	19	11.5	Apr. 1.5	12.5	30.5	31	11	2	9
295	22	23	20	12.5	2.5	13.5	May 1.5	Nov. 1	12	3	10
296	23	24	21	13.5	3.5	14.5	2.5	2	13	4	11
297	24	25	22	14.5	4.5	15.5	3.5	3	14	5	12
298	25	26	23	15.5	5.5	16.5	4.5	4	15	6	13
299	26	27	24	16.5	6.5	17.5	5.5	5	16	7	14
300	27	28	25	17.5	7.5	18.5	6.5	6	17	8	15
301	28	29	26	18.5	8.5	19.5	7.5	7	18	9	16
302	29	30	27	19.5	9.5	20.5	8.5	8	19	10	17
303	30	Oct. 1	28	20.5	10.5	21.5	9.5	9	20	11	18
304	31	2	29	21.5	11.5	22.5	10.5	10	21	12	19
305	Nov. 1	3	30	22.5	12.5	23.5	11.5	11	22	13	20
306	2	4	Dec. 1	23.5	13.5	24.5	12.5	12	23	14	21
307	3	5	2	24.5	14.5	25.5	13.5	13	24	15	22
308	4	6	3	25.5	15.5	26.5	14.5	14	25	16	23
309	5	7	4	26.5	16.5	27.5	15.5	15	26	17	24
310	6	8	5	27.5	17.5	28.5	16.5	16	27	18	25
311	7	9	6	28.5	18.5	29.5	17.5	17	28	19	26
312	8	10	7	29.5	19.5	30.5	18.5	18	29	20	27
313	9	11	8	30.5	20.5	May 1.5	19.5	19	30	21	28
314	10	12	9	31.5	21.5	2.5	20.5	20	31	22	29
315	11	13	10	June 1.5	22.5	3.5	21.5	21	Nov. 1	23	30
316	12	14	11	2.5	23.5	4.5	22.5	22	2	24	Dec. 1
317	13	15	12	3.5	24.5	5.5	23.5	23	3	25	2
318	14	16	13	4.5	25.5	6.5	24.5	24	4	26	3
319	15	17	14	5.5	26.5	7.5	25.5	25	5	27	4
320	16	18	15	6.5	27.5	8.5	26.5	26	6	28	5
321	17	19	16	7.5	28.5	9.5	27.5	27	7	29	6
322	18	20	17	8.5	29.5	10.5	28.5	28	8	30	7
323	19	21	18	9.5	30.5	11.5	29.5	29	9	31	8
324	20	22	19	10.5	May 1.5	12.5	30.5	30	10	Nov. 1	9
325	21	23	20	11.5	2.5	13.5	31.5	Dec. 1	11	2	10
326	22	24	21	12.5	3.5	14.5	June 1.5	2	12	3	11
327	23	25	22	13.5	4.5	15.5	2.5	3	13	4	12
328	24	26	23	14.5	5.5	16.5	3.5	4	14	5	13
329	25	27	24	15.5	6.5	17.5	4.5	5	15	6	14
330	26	28	25	16.5	7.5	18.5	5.5	6	16	7	15
331	27	29	26	17.5	8.5	19.5	6.5	7	17	8	16

TABLE 57.—*Days having similar tides*—Continued.

Day of		29 days		162.5 days		191.5 days		355 days		384 days	
Year	Month	Before	After	Before	After	Before	After	Before	After	Before	After
332	Nov. 28	Oct. 30	Dec. 27	June 18.5	May 9.5	May 20.5	June 7.5	Dec. 8	Nov. 18	Nov. 9	Dec. 17
333	29	31	28	19.5	10.5	21.5	8.5	9	19	10	18
334	30	Nov. 1	29	20.5	11.5	22.5	9.5	10	20	11	19
335	Dec. 1	2	30	21.5	12.5	23.5	10.5	11	21	12	20
336	2	3	31	22.5	13.5	24.5	11.5	12	22	13	21
337	3	4	Jan. 1	23.5	14.5	25.5	12.5	13	23	14	22
338	4	5	2	24.5	15.5	26.5	13.5	14	24	15	23
339	5	6	3	25.5	16.5	27.5	14.5	15	25	16	24
340	6	7	4	26.5	17.5	28.5	15.5	16	26	17	25
341	7	8	5	27.5	18.5	29.5	16.5	17	27	18	26
342	8	9	6	28.5	19.5	30.5	17.5	18	28	19	27
343	9	10	7	29.5	20.5	31.5	18.5	19	29	20	28
344	10	11	8	30.5	21.5	June 1.5	19.5	20	30	21	29
345	11	12	9	July 1.5	22.5	2.5	20.5	21	Dec. 1	22	30
346	12	13	10	2.5	23.5	3.5	21.5	22	2	23	31
347	13	14	11	3.5	24.5	4.5	22.5	23	3	24	Jan. 1
348	14	15	12	4.5	25.5	5.5	23.5	24	4	25	2
349	15	16	13	5.5	26.5	6.5	24.5	25	5	26	3
350	16	17	14	6.5	27.5	7.5	25.5	26	6	27	4
351	17	18	15	7.5	28.5	8.5	26.5	27	7	28	5
352	18	19	16	8.5	29.5	9.5	27.5	28	8	29	6
353	19	20	17	9.5	30.5	10.5	28.5	29	9	30	7
354	20	21	18	10.5	31.5	11.5	29.5	30	10	Dec. 1	8
355	21	22	19	11.5	June 1.5	12.5	30.5	31	11	2	9
356	22	23	20	12.5	2.5	13.5	July 1.5	Jan. 1	12	3	10
357	23	24	21	13.5	3.5	14.5	2.5	2	13	4	11
358	24	25	22	14.5	4.5	15.5	3.5	3	14	5	12
359	25	26	23	15.5	5.5	16.5	4.5	4	15	6	13
360	26	27	24	16.5	6.5	17.5	5.5	5	16	7	14
361	27	28	25	17.5	7.5	18.5	6.5	6	17	8	15
362	28	29	26	18.5	8.5	19.5	7.5	7	18	9	16
363	29	30	27	19.5	9.5	20.5	8.5	8	19	10	17
364	30	Dec. 1	28	20.5	10.5	21.5	9.5	9	20	11	18
365	31	2	29	21.5	11.5	22.5	10.5	10	21	12	19

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950.*

1850	1851	1852	1853	1854	1855
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
A Jan. 12 12.0	A Jan. 5 17.0	P Jan. 12 16.7	P Jan. 4 21.7	A Jan. 11 21.4	A Jan. 5 2.4
P Jan. 26 6.7	P Jan. 19 11.7	A Jan. 26 11.4	A Jan. 18 16.4	P Jan. 25 16.1	P Jan. 18 21.1
A Feb. 9 1.3	A Feb. 2 6.3	P Feb. 9 6.0	P Feb. 1 11.0	A Feb. 8 10.7	A Feb. 1 15.7
P Feb. 22 20.0	P Feb. 16 1.0	A Feb. 23 0.7	A Feb. 15 5.7	P Feb. 22 5.4	P Feb. 15 10.4
A Mar. 8 14.6	A Mar. 1 19.7	P Mar. 7 19.3	P Mar. 1 0.3	A Mar. 8 0.0	A Mar. 1 5.0
P Mar. 22 9.3	P Mar. 15 14.3	A Mar. 21 14.0	A Mar. 14 19.0	P Mar. 21 18.7	P Mar. 14 23.7
A Apr. 5 3.9	A Mar. 29 9.0	P Apr. 4 8.6	P Mar. 28 13.7	A Apr. 4 13.3	A Mar. 28 18.4
P Apr. 18 22.6	P Apr. 12 3.6	A Apr. 18 3.3	A Apr. 11 8.3	P Apr. 18 8.0	P Apr. 11 13.0
A May 2 17.3	A Apr. 25 22.3	P May 1 21.9	P Apr. 25 3.0	A May 2 2.6	A Apr. 25 7.7
P May 16 11.9	P May 9 16.9	A May 15 16.6	A May 8 21.6	P May 15 21.3	P May 9 2.3
A May 30 6.6	A May 23 11.6	P May 29 11.3	P May 22 16.3	A May 29 16.0	A May 22 21.0
P June 13 1.2	P June 6 6.2	A June 12 5.9	A June 5 10.9	P June 12 10.6	P June 5 15.6
A June 26 19.9	A June 20 0.9	P June 26 0.6	P June 19 5.6	A June 26 5.3	A June 19 10.3
P July 10 14.5	P July 3 19.5	A July 9 19.2	A July 3 0.2	P July 9 23.9	P July 3 4.9
A July 24 9.2	A July 17 14.2	P July 23 13.9	P July 16 18.9	A July 23 18.6	A July 16 23.6
P Aug. 7 3.8	P July 31 8.9	A Aug. 6 8.5	A July 30 13.5	P Aug. 6 13.2	P July 30 18.2
A Aug. 20 22.5	A Aug. 14 3.5	P Aug. 20 3.2	P Aug. 13 8.2	A Aug. 20 7.9	A Aug. 13 12.9
P Sept. 3 17.1	P Aug. 27 22.2	A Sept. 2 21.8	A Aug. 27 2.9	P Sept. 3 2.5	P Aug. 27 7.6
A Sept. 17 11.8	A Sept. 10 16.8	P Sept. 16 16.5	P Sept. 9 21.5	A Sept. 16 21.2	A Sept. 10 2.2
P Oct. 1 6.5	P Sept. 24 11.5	A Sept. 30 11.1	A Sept. 23 16.2	P Sept. 30 15.8	P Sept. 23 20.9
A Oct. 15 1.1	A Oct. 8 6.1	P Oct. 14 5.8	P Oct. 7 10.8	A Oct. 14 10.5	A Oct. 7 15.5
P Oct. 28 19.8	P Oct. 22 0.8	A Oct. 28 0.5	A Oct. 21 5.5	P Oct. 28 5.2	P Oct. 21 10.2
A Nov. 11 14.4	A Nov. 4 19.4	P Nov. 10 19.1	P Nov. 4 0.1	A Nov. 10 23.8	A Nov. 4 4.8
P Nov. 25 9.1	P Nov. 18 14.1	A Nov. 24 13.8	A Nov. 17 18.8	P Nov. 24 18.5	P Nov. 17 23.5
A Dec. 9 3.7	A Dec. 2 8.7	P Dec. 8 8.4	P Dec. 1 13.4	A Dec. 8 13.1	A Dec. 1 18.1
P Dec. 22 22.4	P Dec. 16 3.4	A Dec. 22 3.1	A Dec. 15 8.1	P Dec. 22 7.8	P Dec. 15 12.8
	A Dec. 29 22.1		P Dec. 29 2.7		A Dec. 29 7.4

1856	1857	1858	1859	1860	1861
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
P Jan. 12 2.1	P Jan. 4 7.1	A Jan. 11 6.8	A Jan. 4 11.8	P Jan. 11 11.5	P Jan. 3 16.5
A Jan. 25 20.8	A Jan. 18 1.8	P Jan. 25 1.4	P Jan. 18 6.5	A Jan. 25 6.1	A Jan. 17 11.2
P Feb. 8 15.4	P Jan. 31 20.4	A Feb. 7 20.1	A Feb. 1 1.1	P Feb. 8 0.8	P Jan. 31 5.8
A Feb. 22 10.1	A Feb. 14 15.1	P Feb. 21 14.8	P Feb. 14 19.8	A Feb. 21 19.5	A Feb. 14 0.5
P Mar. 7 4.7	P Feb. 28 9.7	A Mar. 7 9.4	A Feb. 28 14.4	P Mar. 6 14.1	P Feb. 27 19.1
A Mar. 20 23.4	A Mar. 14 4.4	P Mar. 21 4.1	P Mar. 14 9.1	A Mar. 20 8.8	A Mar. 13 13.8
P Apr. 3 18.0	P Mar. 27 23.0	A Apr. 3 22.7	A Mar. 28 3.7	P Apr. 3 3.4	P Mar. 27 8.4
A Apr. 17 12.7	A Apr. 10 17.7	P Apr. 17 17.4	P Apr. 10 22.4	A Apr. 16 22.1	A Apr. 10 3.1
P May 1 7.3	P Apr. 24 12.4	A May 1 12.0	A Apr. 24 17.0	P Apr. 30 16.7	P Apr. 23 21.7
A May 15 2.0	A May 8 7.0	P May 15 6.7	P May 8 11.7	A May 14 11.4	A May 7 16.4
P May 28 20.6	P May 22 1.7	A May 29 1.3	A May 22 6.4	P May 28 6.0	P May 21 11.1
A June 11 15.3	A June 4 20.3	P June 11 20.0	P June 5 1.0	A June 11 0.7	A June 4 5.7
P June 25 10.0	P June 18 15.0	A June 25 14.6	A June 18 19.7	P June 24 19.3	P June 18 0.4
A July 9 4.6	A July 2 9.6	P July 9 9.3	P July 2 14.3	A July 8 14.0	A Jnly 1 19.0
P July 22 23.3	P July 16 4.3	A July 23 4.0	A July 16 9.0	P July 22 8.7	P July 15 13.7
A Aug. 5 17.9	A July 29 22.9	P Aug. 5 22.6	P July 30 3.6	A Aug. 5 3.3	A July 29 8.3
P Aug. 19 12.6	P Aug. 12 17.6	A Aug. 19 17.3	A Aug. 12 22.3	P Aug. 18 22.0	P Aug. 12 3.0
A Sept. 2 7.2	A Aug. 26 12.2	P Sept. 2 11.9	P Aug. 26 16.9	A Sept. 1 16.6	A Aug. 25 21.6
P Sept. 16 1.9	P Sept. 9 6.9	A Sept. 16 6.6	A Sept. 9 11.6	P Sept 15 11.3	P Sept. 8 16.3
A Sept. 29 20.5	A Sept. 23 1.6	P Sept. 30 1.2	P Sept. 23 6.2	A Sept. 29 5.9	A Sept. 22 10.9
P Oct. 13 15.2	P Oct. 6 20.2	A Oct. 13 19.9	A Oct. 7 0.9	P Oct. 13 0.6	P Oct. 6 5.6
A Oct. 27 9.8	A Oct. 20 14.9	P Oct. 27 14.5	P Oct. 20 19.6	A Oct. 26 19.2	A Oct. 20 0.3
P Nov. 10 4.5	P Nov. 3 9.5	A Nov. 10 9.2	A Nov. 3 14.2	P Nov. 9 13.9	P Nov. 2 18.9
A Nov. 23 23.2	A Nov. 17 4.2	P Nov. 24 3.8	P Nov. 17 8.9	A Nov. 23 8.5	A Nov. 16 13.6
P Dec. 7 17.8	P Nov. 30 22.8	A Dec. 7 22.5	A Dec. 1 3.5	P Dec. 7 3.2	P Nov. 30 8.2
A Dec. 21 12.5	A Dec. 14 17.5	P Dec. 21 17.2	P Dec. 14 22.2	A Dec. 20 21.9	A Dec. 14 2.9
	P Dec. 28 12.1		A Dec. 28 16.8		P Dec. 27 21.5

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TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1862	1863	1864	1865	1866	1867
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
A Jan. 10 16.2	A Jan. 3 21.2	P Jan. 10 20.9	P Jan. 3 1.9	A Jan. 10 1.6	A Jan. 3 6.6
P Jan. 24 10.8	P Jan. 17 15.9	A Jan. 24 15.5	A Jan. 16 20.5	P Jan. 23 20.2	P Jan. 17 1.2
A Feb. 7 5.5	A Jan. 31 10.5	P Feb. 7 10.2	P Jan. 30 15.2	A Feb. 6 14.9	A Jan. 30 19.9
P Feb. 21 0.1	P Feb. 14 5.2	A Feb. 21 4.8	A Feb. 13 9.9	P Feb. 20 9.5	P Feb. 13 14.6
A Mar. 6 18.8	A Feb. 27 23.8	P Mar. 5 23.5	P Feb. 27 4.5	A Mar. 6 4.2	A Feb. 27 9.2
P Mar. 20 13.5	P Mar. 13 18.5	A Mar. 19 18.1	A Mar. 12 23.2	P Mar. 19 22.8	P Mar. 13 3.9
A Apr. 3 8.1	A Mar. 27 13.1	P Apr. 2 12.8	P Mar. 26 17.8	A Apr. 2 17.5	A Mar. 26 22.5
P Apr. 17 2.8	P Apr. 10 7.8	A Apr. 16 7.5	A Apr. 9 12.5	P Apr. 16 12.2	P Apr. 9 17.2
A Apr. 30 21.4	A Apr. 24 2.4	P Apr. 30 2.1	P Apr. 23 7.1	A Apr. 30 6.8	A Apr. 23 11.8
P May 14 16.1	P May 7 21.1	A May 13 20.8	A May 7 1.8	P May 14 1.5	P May 7 6.5
A May 28 10.7	A May 21 15.7	P May 27 15.4	P May 20 20.4	A May 27 20.1	A May 21 1.1
P June 11 5.4	P June 4 10.4	A June 10 10.1	A Jnne 3 15.1	P June 10 14.8	P June 3 19.8
A June 25 0.0	A June 18 5.1	P June 24 4.7	P June 17 9.7	A June 24 9.4	A June 17 14.4
P July 8 18.7	P July 1 23.7	A July 7 23.4	A July 1 4.4	P July 8 4.1	P July 1 9.1
A July 22 13.3	A July 15 18.4	P July 21 18.0	P July 14 23.1	A July 21 22.7	A July 15 3.8
P Aug. 5 8.0	P July 29 13.0	A Aug. 4 12.7	A July 28 17.7	P Aug. 4 17.4	P July 28 22.4
A Aug. 19 2.7	A Aug. 12 7.7	P Aug. 18 7.3	P Aug. 11 12.4	A Aug. 18 12.0	A Aug. 11 17.1
P Sept. 1 21.3	P Aug. 26 2.3	A Sept. 1 2.0	A Aug. 25 7.0	P Sept. 1 6.7	P Aug. 25 11.7
A Sept. 15 16.0	A Sept. 8 21.0	P Sept. 14 20.7	P Sept. 8 1.7	A Sept. 15 1.4	A Sept. 8 6.4
P Sept. 29 10.6	P Sept. 22 15.6	A Sept. 28 15.3	A Sept. 21 20.3	P Sept. 28 20.0	P Sept. 22 1.0
A Oct. 13 5.3	A Oct. 6 10.3	P Oct. 12 10.0	P Oct. 5 15.0	A Oct. 12 14.7	A Oct. 5 19.7
P Oct. 27 0.0	P Oct. 20 4.9	A Oct. 26 4.6	A Oct. 19 9.6	P Oct. 26 9.3	P Oct. 19 14.3
A Nov. 9 18.6	A Nov. 2 23.6	P Nov. 8 23.3	P Nov. 2 4.3	A Nov. 9 4.0	A Nov. 2 9.0
P Nov. 23 13.2	P Nov. 16 18.2	A Nov. 22 17.9	A Nov. 15 22.9	P Nov. 22 22.6	P Nov. 16 3.6
A Dec. 7 7.9	A Nov. 30 12.9	P Dec. 6 12.6	P Nov. 29 17.6	A Dec. 6 17.3	A Nov. 29 22.3
P Dec. 21 2.5	P Dec. 14 7.6	A Dec. 20 7.2	A Dec. 13 12.3	P Dec. 20 11.9	P Dec. 13 17.0
	A Dec. 28 2.2		P Dec. 27 6.9		A Dec. 27 11.6

1868	1869	1870	1871	1872	1873
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
P Jan. 10 6.3	P Jan. 2 11.3	A Jan. 9 11.0	A Jan. 2 16.0	P Jan. 9 15.7	P Jan. 1 20.7
A Jan. 24 0.9	A Jan. 16 5.9	P Jan. 23 5.6	P Jan. 16 10.6	A Jan. 23 10.3	A Jan. 15 15.3
P Feb. 6 19.6	P Jan. 30 0.6	A Feb. 6 0.3	A Jan. 30 5.3	P Feb. 6 5.0	P Jan. 29 10.0
A Feb. 20 14.2	A Feb. 12 19.2	P Feb. 19 18.9	P Feb. 12 23.9	A Feb. 19 23.6	A Feb. 12 4.6
P Mar. 5 8.9	P Feb. 26 13.9	A Mar. 5 13.6	A Feb. 26 18.6	P Mar. 4 18.3	P Feb. 25 23.3
A Mar. 19 3.5	A Mar. 12 8.6	P Mar. 19 8.2	P Mar. 12 13.2	A Mar. 18 12.9	A Mar. 11 17.9
P Apr. 1 22.2	P Mar. 26 3.2	A Apr. 2 2.9	A Mar. 26 7.9	P Apr. 1 7.6	P Mar. 25 12.6
A Apr. 15 16.8	A Apr. 8 21.9	P Apr. 15 21.5	P Apr. 9 2.6	A Apr. 15 2.2	A Apr. 8 7.3
P Apr. 29 11.5	P Apr. 22 16.5	A Apr. 29 16.2	A Apr. 22 21.2	P Apr. 28 20.9	P Apr. 22 1.9
A May 13 6.2	A May 6 11.2	P May 13 10.8	P May 6 15.9	A May 12 15.5	A May 5 20.6
P May 27 0.8	P May 20 5.8	A May 27 5.5	A May 20 10.5	P May 26 10.2	P May 19 15.2
A June 9 19.5	A June 3 0.5	P June 10 0.2	P June 3 5.2	A June 9 4.9	A June 2 9.9
P June 23 14.1	P June 16 19.1	A June 23 18.8	A June 16 23.8	P June 22 23.5	P June 16 4.5
A July 7 8.8	A June 30 13.8	P July 7 13.5	P June 30 18.5	A July 6 18.2	A June 29 23.2
P July 21 3.4	P July 14 8.4	A July 21 8.1	A July 14 13.1	P July 20 12.8	P July 13 17.8
A Aug. 3 22.1	A July 28 3.1	P Aug. 4 2.8	P July 28 7.8	A Aug. 3 7.5	A July 27 12.5
P Aug. 17 16.7	P Aug. 10 21.8	A Aug. 17 21.4	A Aug. 11 2.4	P Aug. 17 2.1	P Aug. 10 7.1
A Aug. 31 11.4	A Aug. 24 16.4	P Aug. 31 16.2	P Aug. 24 21.1	A Aug. 30 20.8	A Aug. 24 1.8
P Sept. 14 6.0	P Sept. 7 11.1	A Sept. 14 10.7	A Sept. 7 15.8	P Sept. 13 15.4	P Sept. 6 20.5
A Sept. 28 0.7	A Sept. 21 5.7	P Sept. 28 5.4	P Sept. 21 10.4	A Sept. 27 10.1	A Sept. 20 15.1
P Oct. 11 19.4	P Oct 5 0.4	A Oct. 12 0.0	A Oct. 5 5.1	P Oct. 11 4.7	P Oct. 4 9.8
A Oct. 25 14.0	A Oct. 18 19.0	P Oct. 25 18.7	P Oct. 18 23.7	A Oct. 24 23.4	A Oct. 18 4.4
P Nov. 8 8.7	P Nov. 1 13.7	A Nov. 8 13.4	A Nov. 1 18.4	P Nov. 7 18.1	P Oct. 31 23.1
A Nov. 22 3.3	A Nov. 15 8.3	P Nov. 22 8.0	P Nov. 15 13.0	A Nov. 21 12.7	A Nov. 14 17.7
P Dec. 5 22.0	P Nov. 29 3.0	A Dec. 6 2.7	A Nov. 29 7.7	P Dec. 5 7.4	P Nov. 28 12.4
A Dec. 19 16.6	A Dec. 12 21.6	P Dec. 19 21.3	P Dec. 13 2.3	A Dec. 19 2.0	A Dec. 12 7.0
	P Dec. 26 16.3		A Dec. 26 21.0		P Dec. 26 1.7

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1874	1875	1876	1877	1878	1879
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
A Jan. 8 20.3	A Jan. 2 1.4	P Jan. 9 1.0	P Jan. 1 6.1	A Jan. 8 5.7	A Jan. 1 10.8
P Jan. 22 15.0	P Jan. 15 20.0	A Jan. 22 19.7	A Jan. 15 0.7	P Jan. 22 0.4	P Jan. 15 5.4
A Feb. 5 9.7	A Jan. 29 14.7	P Feb. 5 14.3	P Jan. 28 19.4	A Feb. 4 19.0	A Jan. 29 0.1
P Feb. 19 4.3	P Feb. 12 9.3	A Feb. 19 9.0	A Feb. 11 14.0	P Feb. 18 13.7	P Feb. 11 18.7
A Mar. 4 23.0	A Feb. 26 4.0	P Mar. 4 3.7	P Feb. 25 8.7	A Mar. 4 8.4	A Feb. 25 13.4
P Mar. 18 17.6	P Mar. 11 22.6	A Mar. 17 22.3	A Mar. 11 3.3	P Mar. 18 3.0	P Mar. 11 8.0
A Apr. 1 12.3	A Mar. 25 17.3	P Mar. 31 17.0	P Mar. 24 22.0	A Mar. 31 21.7	A Mar. 25 2.8
P Apr. 15 6.9	P Apr. 8 11.9	A Apr. 14 11.6	A Apr. 7 16.6	P Apr. 14 16.3	P Apr. 7 21.3
A Apr. 29 1.6	A Apr. 22 6.6	P Apr. 28 6.3	P Apr. 21 11.3	A Apr. 28 11.0	A Apr. 21 16.0
P May 12 20.2	P May 6 1.3	A May 12 0.9	A May 5 5.9	P May 12 5.6	P May 5 10.6
A May 26 14.9	A May 19 19.9	P May 25 19.6	P May 19 0.6	A May 26 0.3	A May 19 5.3
P June 9 9.5	P June 2 14.6	A June 8 14.2	A June 1 19.3	P June 8 18.9	P June 2 0.0
A June 23 4.2	A June 16 9.2	P June 22 8.9	P June 15 13.9	A June 22 13.6	A June 15 18.6
P July 6 22.9	P June 30 3.9	A July 6 3.5	A June 29 8.6	P July 6 8.2	P June 29 13.3
A July 20 17.5	A July 13 22.5	P July 19 22.2	P July 13 3.2	A July 20 2.9	A July 13 7.9
P Aug. 3 12.2	P July 27 17.2	A Aug. 2 16.9	A July 26 21.9	P Aug. 2 21.6	P July 27 2.6
A Aug. 17 6.8	A Aug. 10 11.8	P Aug. 16 11.5	P Aug. 9 16.5	A Aug. 16 16.2	A Aug. 9 21.2
P Aug. 31 1.5	P Aug. 24 6.5	A Aug. 30 6.2	A Aug. 23 11.2	P Aug. 30 10.9	P Aug. 23 15.9
A Sept. 13 20.1	A Sept. 7 1.1	P Sept. 13 0.8	P Sept. 6 5.8	A Sept. 13 5.5	A Sept. 6 10.5
P Sept. 27 14.8	P Sept. 20 19.8	A Sept. 26 19.5	A Sept. 20 0.5	P Sept. 27 0.2	P Sept. 20 5.2
A Oct. 11 9.4	A Oct. 4 14.5	P Oct. 10 14.1	P Oct. 3 19.1	A Oct. 10 18.8	A Oct. 3 23.8
P Oct. 25 4.1	P Oct. 18 9.1	A Oct. 24 8.8	A Oct. 17 13.8	P Oct. 24 13.5	P Oct. 17 18.5
A Nov. 7 22.7	A Nov. 1 3.8	P Nov. 7 3.4	P Oct. 31 8.5	A Nov. 7 8.1	A Oct. 31 13.2
P Nov. 21 17.4	P Nov. 14 22.4	A Nov. 20 22.1	A Nov. 14 3.1	P Nov. 21 2.8	P Nov. 14 7.8
A Dec. 5 12.1	A Nov. 28 17.1	P Dec. 4 16.7	P Nov. 27 21.8	A Dec. 4 21.4	A Nov. 28 2.5
P Dec. 19 6.7	P Dec. 12 11.7	A Dec. 18 11.4	A Dec. 11 16.4	P Dec. 18 16.1	P Dec. 11 21.1
	A Dec. 26 6.4		P Dec. 25 11.1		A Dec. 25 15.8

1880	1881	1882	1883	1884	1885
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
P Jan. 8 10.4	A Jan. 14 10.1	A Jan. 7 15.1	P Jan. 14 14.8	P Jan. 7 19.8	A Jan. 13 19.5
A Jan. 22 5.1	P Jan. 28 4.8	P Jan. 21 9.8	A Jan. 28 9.4	A Jan. 21 14.5	P Jan. 27 14.1
P Feb. 4 23.7	A Feb. 10 23.4	A Feb. 4 4.4	P Feb. 11 4.1	P Feb. 4 9.1	A Feb. 10 8.8
A Feb. 18 18.4	P Feb. 24 18.1	P Feb. 17 23.0	A Feb. 24 22.8	A Feb. 18 3.8	P Feb. 24 3.5
P Mar. 3 13.0	A Mar. 10 12.7	A Mar. 3 17.7	P Mar. 10 17.4	P Mar. 2 22.4	A Mar. 9 22.1
A Mar. 17 7.7	P Mar. 24 7.4	P Mar. 17 12.4	A Mar. 24 12.1	A Mar. 16 17.1	P Mar. 23 16.8
P Mar. 31 2.4	A Apr. 7 2.0	A Mar. 31 7.0	P Apr. 7 6.7	P Mar. 30 11.7	A Apr. 6 11.4
A Apr. 13 21.0	P Apr. 20 20.7	P Apr. 14 1.7	A Apr. 21 1.4	A Apr. 13 6.4	P Apr. 20 6.1
P Apr. 27 15.7	A May 4 15.3	A Apr. 27 20.4	P May 4 20.0	P Apr. 27 1.1	A May 4 0.7
A May 11 10.3	P May 18 10.0	P May 11 15.0	A May 18 14.7	A May 10 19.7	P May 17 19.4
P May 25 5.0	A June 1 4.6	A May 25 9.7	P June 1 9.3	P May 24 14.4	A May 31 14.0
A June 7 23.6	P June 14 23.3	P June 8 4.3	A June 15 4.0	A June 7 9.0	P June 14 8.7
P June 21 18.3	A June 28 18.0	A June 21 23.0	P June 28 22.6	P June 21 3.7	A June 28 3.3
A July 5 12.9	P July 12 12.6	P July 5 17.6	A July 12 17.3	A July 4 22.3	P July 11 22.0
P July 19 7.6	A July 26 7.3	A July 19 12.3	P July 26 12.0	P July 18 17.0	A July 25 16.7
A Aug. 2 2.2	P Aug. 9 1.9	P Aug. 2 6.9	A Aug. 9 6.6	A Aug. 1 11.6	P Aug. 8 11.3
P Aug. 15 20.9	A Aug. 22 20.6	A Aug. 16 1.6	P Aug. 23 1.3	P Aug. 15 6.3	A Aug. 22 6.0
A Aug. 29 15.6	P Sept. 5 15.2	P Aug. 29 20.2	A Sept. 5 19.9	A Aug. 29 0.9	P Sept. 5 0.6
P Sept. 12 10.2	A Sept. 19 9.9	A Sept. 12 14.9	P Sept. 19 14.6	P Sept. 11 19.6	A Sept. 18 19.3
A Sept. 26 4.9	P Oct. 3 4.5	P Sept. 26 9.6	A Oct. 3 9.2	A Sept. 25 14.3	P Oct. 2 13.9
P Oct. 9 23.5	A Oct. 16 23.2	A Oct. 10 4.2	P Oct. 17 3.9	P Oct. 9 8.9	A Oct. 16 8.6
A Oct. 23 18.2	P Oct. 30 17.8	P Oct. 23 22.9	A Oct. 30 22.5	A Oct. 23 3.6	P Oct. 30 3.2
P Nov. 6 12.8	A Nov. 13 12.5	A Nov. 6 17.5	P Nov. 13 17.2	P Nov. 5 22.2	A Nov. 12 21.9
A Nov. 20 7.5	P Nov. 27 7.2	P Nov. 20 12.2	A Nov. 27 11.9	A Nov. 19 16.9	P Nov. 26 16.5
P Dec. 4 2.1	A Dec. 11 1.8	A Dec. 4 6.8	P Dec. 11 6.5	P Dec. 3 11.5	A Dec. 10 11.1
A Dec. 17 20.8	P Dec. 24 20.5	P Dec. 18 1.5	A Dec. 25 1.2	A Dec. 17 6.2	P Dec. 24 5.9
P Dec. 31 15.4		A Dec. 31 20.1		P Dec. 31 0.8	

TABLE 58—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1886	1887	1888	1889	1890	1891
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
A Jan. 7 0.5	P Jan. 14 0.2	P Jan. 7 5.2	A Jan. 13 4.9	A Jan. 6 9.9	P Jan. 13 9.6
P Jan. 20 19.2	A Jan. 27 18.8	A Jan. 20 23.9	P Jan. 26 23.5	P Jan. 20 4.6	A Jan. 27 4.2
A Feb. 3 13.8	P Feb. 10 13.5	P Feb. 3 18.5	A Feb. 9 18.2	A Feb. 2 23.2	P Feb. 9 22.9
P Feb. 17 8.5	A Feb. 24 8.1	A Feb. 17 13.2	P Feb. 23 12.8	P Feb. 16 17.9	A Feb. 23 17.5
A Mar. 3 3.1	P Mar. 10 2.8	P Mar. 2 7.8	A Mar. 9 7.5	A Mar. 2 12.5	P Mar. 9 12.2
P Mar. 16 21.8	A Mar. 23 21.5	A Mar. 16 2.5	P Mar. 23 2.1	P Mar. 16 7.2	A Mar. 23 6.8
A Mar. 30 16.4	P Apr. 6 16.1	P Mar. 29 21.1	A Apr. 5 20.8	A Mar. 30 1.8	P Apr. 6 1.5
P Apr. 13 11.1	A Apr. 20 10.8	A Apr. 12 15.8	P Apr. 19 15.5	P Apr. 12 20.5	A Apr. 19 20.2
A Apr. 27 5.7	P May 4 5.4	P Apr. 26 10.4	A May 3 10.1	A Apr. 26 15.1	P May 3 14.8
P May 11 0.4	A May 18 0.1	A May 10 5.1	P May 17 4.8	P May 10 9.8	A May 17 9.5
A May 24 19.1	P May 31 18.7	P May 23 23.7	A May 30 23.4	A May 24 4.4	P May 31 4.1
P June 7 13.7	A June 14 13.4	A June 6 18.4	P June 13 18.1	P June 6 23.1	A June 13 22.8
A June 21 8.4	P June 28 8.0	P June 20 13.1	A June 27 12.7	A June 20 17.8	P June 27 17.4
P July 5 3.0	A July 12 2.7	A July 4 7.7	P July 11 7.4	P July 4 12.4	A July 11 12.1
A July 18 21.7	P July 25 21.3	P July 18 2.4	A July 25 2.0	A July 18 7.1	P July 25 6.7
P Aug. 1 16.3	A Aug. 8 16.0	A July 31 21.0	P Aug. 7 20.7	P Aug. 1 1.7	A Aug. 8 1.4
A Aug. 15 11.0	P Aug. 22 10.7	P Aug. 14 15.7	A Aug. 21 15.3	A Aug. 14 20.4	P Aug. 21 20.0
P Aug. 29 5.6	A Sept. 5 5.3	A Aug. 28 10.3	P Sept. 4 10.0	P Aug. 28 15.0	A Sept. 4 14.7
A Sept. 12 0.3	P Sept. 19 0.0	P Sept. 11 5.0	A Sept. 18 4.7	A Sept. 11 9.7	P Sept. 18 9.4
P Sept. 25 18.9	A Oct. 2 18.6	A Sept. 24 23.6	P Oct. 1 23.3	P Sept. 25 4.3	A Oct. 2 4.0
A Oct. 9 13.6	P Oct. 16 13.3	P Oct. 8 18.3	A Oct. 15 18.0	A Oct. 8 23.0	P Oct. 15 22.7
P Oct. 23 8.3	A Oct. 30 7.9	A Oct. 22 12.9	P Oct. 29 12.6	P Oct. 22 17.6	A Oct. 29 17.3
A Nov. 6 2.9	P Nov. 13 2.6	P Nov. 5 7.6	A Nov. 12 7.3	A Nov. 5 12.3	P Nov. 12 12.0
P Nov. 19 21.6	A Nov. 26 21.2	A Nov. 19 2.3	P Nov. 26 1.9	P Nov. 19 7.0	A Nov. 26 6.6
A Dec. 3 16.2	P Dec. 10 15.9	P Dec. 2 20.9	A Dec. 9 20.6	A Dec. 3 1.6	P Dec. 10 1.2
P Dec. 17 10.9	A Dec. 24 10.5	A Dec. 16 15.6	P Dec. 23 15.2	P Dec. 16 20.3	A Dec. 23 19.9
A Dec. 31 5.5		P Dec. 30 10.2		A Dec. 30 14.9	

1892	1893	1894	1895	1896	1897
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
P Jan. 6 14.6	A Jan. 12 14.3	A Jan. 5 19.3	P Jan. 12 19.0	P Jan. 6 0.0	A Jan. 11 23.7
A Jan. 20 9.2	P Jan. 26 8.9	P Jan. 19 13.9	A Jan. 26 13.6	A Jan. 19 18.6	P Jan. 25 18.3
P Feb. 3 3.9	A Feb. 9 3.6	A Feb. 2 8.6	P Feb. 9 8.3	P Feb. 2 13.3	A Feb. 8 13.0
A Feb. 16 22.6	P Feb. 22 22.2	P Feb. 16 3.2	A Feb. 23 2.9	A Feb. 16 7.9	P Feb. 22 7.6
P Mar. 1 17.2	A Mar. 8 16.9	A Mar. 1 21.9	P Mar. 8 21.6	P Mar. 1 2.6	A Mar. 8 2.3
A Mar. 15 11.9	P Mar. 22 11.5	P Mar. 15 16.6	A Mar. 22 16.2	A Mar. 14 21.3	P Mar. 21 20.9
P Mar. 29 6.5	A Apr. 5 6.2	A Mar. 29 11.2	P Apr. 5 10.9	P Mar. 28 15.9	A Apr. 4 15.6
A Apr. 12 1.2	P Apr. 19 0.8	P Apr. 12 5.9	A Apr. 19 5.5	A Apr. 11 10.6	P Apr. 18 10.2
P Apr. 25 19.8	A May 2 19.5	A Apr. 26 0.5	P May 3 0.2	P Apr. 25 5.2	A May 2 4.9
A May 9 14.5	P May 16 14.2	P May 9 19.2	A May 16 18.8	A May 8 23.9	P May 15 23.5
P May 23 9.1	A May 30 8.8	A May 23 13.8	P May 30 13.5	P May 22 18.5	A May 29 18.2
A June 6 3.8	P June 13 3.5	P June 6 8.5	A June 13 8.2	A June 5 13.2	P June 12 12.9
P June 19 22.4	A June 26 22.1	A June 20 3.1	P June 27 2.8	P June 19 7.8	A June 26 7.5
A July 3 17.1	P July 10 16.8	P July 3 21.8	A July 10 21.5	A July 3 2.5	P July 10 2.2
P July 17 11.8	A July 24 11.4	A July 17 16.4	P July 24 16.1	P July 16 21.1	A July 23 20.8
A July 31 6.4	P Aug. 7 6.1	P July 31 11.1	A Aug. 7 10.8	A July 30 15.8	P Aug. 6 15.5
P Aug. 14 1.1	A Aug. 21 0.7	A Aug. 14 5.8	P Aug. 21 5.4	P Aug. 13 10.5	A Aug. 20 10.1
A Aug. 27 19.7	P Sept. 3 19.4	P Aug. 28 0.4	A Sept. 4 0.1	A Aug. 27 5.1	P Sept. 3 4.8
P Sept. 10 14.4	A Sept. 17 14.0	A Sept. 10 19.1	P Sept. 17 18.7	P Sept. 9 23.8	A Sept. 16 23.4
A Sept. 24 9.0	P Oct. 1 8.7	P Sept. 24 13.7	A Oct. 1 13.4	A Sept. 23 18.4	P Sept. 30 18.1
P Oct. 8 3.7	A Oct. 15 3.4	A Oct. 8 8.4	P Oct. 15 8.0	P Oct. 7 13.1	A Oct. 14 12.7
A Oct. 21 22.3	P Oct. 28 22.0	P Oct. 22 3.0	A Oct. 29 2.7	A Oct. 21 7.7	P Oct. 28 7.4
P Nov. 4 17.0	A Nov. 11 16.7	A Nov. 4 21.7	P Nov. 11 21.4	P Nov. 4 2.4	A Nov. 11 2.1
A Nov. 18 11.6	P Nov. 25 11.3	P Nov. 18 16.3	A Nov. 25 16.0	A Nov. 17 21.0	P Nov. 24 20.7
P Dec. 2 6.3	A Dec. 9 6.0	A Dec. 2 11.0	P Dec. 9 10.7	P Dec. 1 15.7	A Dec. 8 15.4
A Dec. 16 1.0	P Dec. 23 0.6	P Dec. 16 5.6	A Dec. 23 5.3	A Dec. 15 10.3	P Dec. 22 10.0
P Dec. 29 19.6		A Dec. 30 0.3		P Dec. 29 5.0	

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1898	1899	1900	1901	1902	1903
hr.	hr.	hr.	hr.	hr.	hr.
A Jan. 5 4.7	P Jan. 12 4.3	P Jan. 5 9.4	A Jan. 12 9.0	A Jan. 5 4.1	P Jan. 12 13.7
P Jan. 18 23.3	A Jan. 25 23.0	A Jan. 19 4.0	P Jan. 26 3.7	P Jan. 19 8.7	A Jan. 26 8.4
A Feb. 1 18.0	P Feb. 8 17.7	P Feb. 1 22.7	A Feb. 8 22.3	A Feb. 2 3.4	P Feb. 9 3.0
P Feb. 15 12.6	A Feb. 22 12.3	A Feb. 15 17.3	P Feb. 22 17.0	P Feb. 15 22.0	A Feb. 22 21.7
A Mar. 1 7.3	P Mar. 8 7.0	P Mar. 1 12.0	A Mar. 8 11.7	A Mar. 1 16.7	P Mar. 8 16.4
P Mar. 15 1.9	A Mar. 22 1.6	A Mar. 15 6.6	P Mar. 22 6.3	P Mar. 15 11.3	A Mar. 22 11.0
A Mar. 28 20.6	P Apr. 4 20.3	P Mar. 29 1.3	A Apr. 5 1.0	A Mar. 29 6.0	P Apr. 5 5.7
P Apr. 11 15.3	A Apr. 18 14.9	A Apr. 11 19.9	P Apr. 18 19.6	P Apr. 12 0.6	A Apr. 19 0.3
A Apr. 25 9.9	P May 2 9.6	P Apr. 25 14.6	A May 2 14.3	A Apr. 25 19.3	P May 2 19.0
P May 9 4.6	A May 16 4.2	A May 9 9.3	P May 16 8.9	P May 9 14.0	A May 16 13.6
A May 22 23.2	P May 29 22.9	P May 23 3.9	A May 30 3.6	A May 23 8.6	P May 30 8.3
P June 5 17.9	A June 12 17.5	A June 5 22.6	P June 12 22.2	P June 6 3.3	A June 13 2.9
A June 19 12.5	P June 26 12.2	P June 19 17.2	A June 26 16.9	A June 19 21.9	P June 26 21.6
P July 3 7.2	A July 10 6.9	A July 3 11.9	P July 10 11.6	P July 3 16.6	A July 10 16.2
A July 17 1.8	P July 24 1.5	P July 17 6.5	A July 24 6.2	A July 17 11.2	P July 24 10.9
P July 30 20.5	A Aug. 6 20.2	A July 31 1.2	P Aug. 7 0.9	P July 31 5.9	A Aug. 7 5.6
A Aug. 13 15.1	P Aug. 20 14.8	P Aug. 13 19.8	A Aug. 20 19.5	A Aug. 14 0.5	P Aug. 21 0.2
P Aug. 27 9.8	A Sept. 3 9.5	A Aug. 27 14.5	P Sept. 3 14.2	P Aug. 27 19.2	A Sept. 3 18.9
A Sept. 10 4.5	P Sept. 17 4.1	P Sept. 10 9.1	A Sept. 17 8.8	A Sept. 10 13.8	P Sept. 17 13.5
P Sept. 23 23.1	A Sept. 30 22.8	A Sept. 24 3.8	P Oct. 1 3.5	P Sept. 24 8.5	A Oct. 1 8.2
A Oct. 7 17.6	P Oct. 14 17.4	P Oct. 7 22.5	A Oct. 14 22.1	A Oct. 8 3.2	P Oct. 15 2.8
P Oct. 21 12.4	A Oct. 28 12.1	A Oct. 21 17.1	P Oct. 28 16.8	P Oct. 21 21.8	A Oct. 28 21.5
A Nov. 4 7.1	P Nov. 11 6.7	P Nov. 4 11.8	A Nov. 11 11.4	A Nov. 4 16.5	P Nov. 11 16.1
P Nov. 18 1.7	A Nov. 25 1.4	A Nov. 18 6.4	P Nov. 25 6.1	P Nov. 18 11.1	A Nov. 25 10.8
A Dec. 1 20.4	P Dec. 8 20.1	P Dec. 2 1.1	A Dec. 9 0.8	A Dec. 2 5.8	P Dec. 9 5.4
P Dec. 15 15.0	A Dec. 22 14.7	A Dec. 15 19.7	P Dec. 22 19.4	P Dec. 16 0.4	A Dec. 23 0.1
A Dec. 29 9.7		P Dec. 29 14.4		A Dec. 29 19.1	

1904	1905	1906	1907	1908	1909
hr.	hr.	hr.	hr.	hr.	hr.
P Jan. 5 18.8	A Jan. 11 18.4	A Jan. 4 23.4	P Jan. 11 23.1	P Jan. 5 4.1	A Jan. 11 3.8
A Jan. 19 13.4	P Jan. 25 13.1	P Jan. 18 18.1	A Jan. 25 17.8	A Jan. 18 22.8	P Jan. 24 22.5
P Feb 2 8.1	A Feb. 8 7.7	A Feb. 1 12.8	P Feb. 8 12.4	P Feb. 1 17.5	A Feb. 7 17.1
A Feb. 16 2.7	P Feb. 22 2.4	P Feb. 15 7.4	A Feb. 22 7.1	A Feb. 15 12.1	P Feb. 21 11.8
P Feb. 29 21.4	A Mar. 7 21.0	A Mar. 1 2.1	P Mar. 8 1.7	P Feb. 29 6.8	A Mar. 7 6.4
A Mar. 14 16.0	P Mar. 21 15.7	P Mar. 14 20.7	A Mar. 21 20.4	A Mar. 14 1.4	P Mar. 21 1.1
P Mar. 28 10.7	A Apr. 4 10.4	A Mar. 28 15.4	P Apr. 4 15.0	P Mar. 27 20.1	A Apr. 3 19.7
A Apr. 11 5.3	P Apr. 18 5.0	P Apr. 11 10.0	A Apr. 18 9.7	A Apr. 10 14.7	P Apr. 17 14.4
P Apr. 25 0.0	A May 1 23.7	A Apr. 25 4.7	P May 2 4.4	P Apr. 24 9.4	A May 1 9.1
A May 8 18.6	P May 15 18.3	P May 8 23.3	A May 15 23.0	A May 8 4.0	P May 15 3.7
P May 22 13.3	A May 29 13.0	A May 22 18.0	P May 29 17.7	P May 21 22.7	A May 28 22.4
A June 5 8.0	P June 12 7.6	P June 5 12.6	A June 12 12.3	A June 4 17.3	P June 11 17.0
P June 19 2.6	A June 26 2.3	A June 19 7.3	P June 26 7.0	P June 18 12.0	A June 25 11.7
A July 2 21.3	P July 9 20.9	P July 3 2.0	A July 10 1.6	A July 2 6.7	P July 9 6.3
P July 16 15.9	A July 23 15.6	A July 16 20.6	P July 23 20.3	P July 16 1.3	A July 23 1.0
A July 30 10.6	P Aug. 6 10.2	P July 30 15.3	A Aug. 6 14.9	A July 29 20.0	P Aug. 5 19.6
P Aug. 13 5.2	A Aug. 20 4.9	A Aug. 13 9.9	P Aug. 20 9.6	P Aug. 12 14.6	A Aug. 19 14.3
A Aug. 26 23.9	P Sept. 2 23.6	P Aug. 27 4.6	A Sept. 3 4.3	A Aug. 26 9.3	P Sept. 2 8.9
P Sept. 9 18.5	A Sept. 16 18.2	A Sept. 9 23.2	P Sept. 16 22.9	P Sept. 9 3.9	A Sept. 16 3.6
A Sept. 23 13.2	P Sept. 30 12.9	P Sept. 23 17.9	A Sept. 30 17.6	A Sept. 22 22.6	P Sept. 29 22.3
P Oct. 7 7.8	A Oct. 14 7.5	A Oct. 7 12.5	P Oct. 14 12.2	P Oct. 6 17.2	A Oct. 13 16.9
A Oct. 21 2.5	P Oct. 28 2.2	P Oct. 21 7.2	A Oct. 28 6.9	A Oct. 20 11.9	P Oct. 27 11.6
P Nov. 3 21.2	A Nov. 10 20.8	A Nov. 4 1.8	P Nov. 11 1.5	P Nov. 3 6.5	A Nov. 10 6.2
A Nov. 17 15.8	P Nov. 24 15.5	P Nov. 17 20.5	A Nov. 24 20.2	A Nov. 17 1.2	P Nov. 24 0.9
P Dec. 1 10.5	A Dec. 8 10.1	A Dec. 1 15.2	P Dec. 8 14.8	P Nov. 30 19.9	A Dec. 7 19.5
A Dec. 15 5.1	P Dec. 22 4.8	P Dec. 15 9.8	A Dec. 22 9.5	A Dec. 14 14.5	P Dec. 21 14.2
P Dec. 28 23.8		A Dec. 29 4.5		P Dec. 28 9.2	

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1910	1911	1912	1913	1914	1915
hr.	hr.	hr.	hr.	hr.	hr.
A Jan. 4 8.8	P Jan. 11 8.5	P Jan. 4 13.5	A Jan. 10 13.2	A Jan. 3 18.2	P Jan. 10 17.9
P Jan. 18 3.5	A Jan. 25 3.2	A Jan. 18 8.2	P Jan. 24 7.9	P Jan. 17 12.9	A Jan. 24 12.6
A Jan. 31 22.1	P Feb. 7 21.8	P Feb. 1 2.8	A Feb. 7 2.5	A Jan. 31 7.5	P Feb. 7 7.2
P Feb. 14 16.8	A Feb. 21 16.5	A Feb. 14 21.5	P Feb. 20 21.2	P Feb. 14 2.2	A Feb. 21 1.9
A Feb. 28 11.5	P Mar. 7 11.1	P Feb. 28 16.1	A Mar. 6 15.8	A Feb. 27 20.8	P Mar. 6 20.5
P Mar. 14 6.1	A Mar. 21 5.8	A Mar. 13 10.8	P Mar. 20 10.5	P Mar. 13 15.5	A Mar. 20 15.2
A Mar. 28 0.8	P Apr. 4 0.4	P Mar. 27 5.5	A Apr. 3 5.1	A Mar. 27 10.2	P Apr. 3 9.8
P Apr. 10 19.4	A Apr. 17 19.1	A Apr. 10 0.1	P Apr. 16 23.8	P Apr. 10 4.8	A Apr. 17 4.5
A Apr. 24 14.1	P May 1 13.7	P Apr. 23 18.8	A Apr. 30 18.4	A Apr. 23 23.5	P Apr. 30 23.1
P May 8 8.7	A May 15 8.4	A May 7 13.4	P May 14 13.1	P May 7 18.1	A May 14 17.8
A May 22 3.4	P May 29 3.1	P May 21 8.1	A May 28 7.8	A May 21 12.8	P May 28 12.4
P June 4 22.0	A June 11 21.7	A June 4 2.7	P June 11 2.4	P June 4 7.4	A June 11 7.1
A June 18 16.7	P June 25 16.4	P June 17 21.4	A June 24 21.1	A June 18 2.1	P June 25 1.8
P July 2 11.3	A July 9 11.0	A July 1 16.0	P July 8 15.7	P July 1 20.7	A July 8 20.4
A July 16 6.0	P July 23 5.7	P July 15 10.7	A July 22 10.4	A July 15 15.4	P July 22 15.1
P July 30 0.7	A Aug. 6 0.3	A July 29 5.3	P Aug. 5 5.0	P July 29 10.0	A Aug. 5 9.7
A Aug. 12 19.3	P Aug. 19 19.0	P Aug. 12 0.0	A Aug. 18 23.7	A Aug. 12 4.7	P Aug. 19 4.4
P Aug. 26 14.0	A Sept. 2 13.6	A Aug. 25 18.7	P Sept. 1 18.3	P Aug. 25 23.4	A Sept. 1 23.0
A Sept. 9 8.6	P Sept. 16 8.3	P Sept. 8 13.3	A Sept. 15 13.0	A Sept. 8 18.0	P Sept. 15 17.7
P Sept. 23 3.3	A Sept. 30 2.9	A Sept. 22 8.0	P Sept. 29 7.6	P Sept. 22 12.7	A Sept. 29 12.3
A Oct. 6 21.9	P Oct. 13 21.6	P Oct. 6 2.6	A Oct. 13 2.3	A Oct. 6 7.3	P Oct. 13 7.0
P Oct. 20 16.6	A Oct. 27 16.3	A Oct. 19 21.3	P Oct. 26 21.0	P Oct. 20 2.0	A Oct. 27 1.6
A Nov. 3 11.2	P Nov. 10 10.9	P Nov. 2 15.9	A Nov. 9 15.6	A Nov. 2 20.6	P Nov. 9 20.3
P Nov. 17 5.9	A Nov. 24 5.6	A Nov. 16 10.6	P Nov. 23 10.3	P Nov. 16 15.3	A Nov. 23 15.0
A Dec. 1 0.5	P Dec. 8 0.2	P Nov. 30 5.2	A Dec. 7 4.9	A Nov. 30 9.9	P Dec. 7 9.6
P Dec. 14 19.2	A Dec. 21 18.9	A Dec. 13 23.9	P Dec. 20 23.6	P Dec. 14 4.6	A Dec. 21 4.3
A Dec. 28 13.9		P Dec. 27 18.6		A Dec. 27 23.2	

1916	1917	1918	1919	1920	1921
hr.	hr.	hr.	hr.	hr.	hr.
P Jan. 3 22.9	A Jan. 9 22.6	A Jan. 3 3.6	P Jan. 10 3.3	P Jan. 3 8.3	A Jan. 9 8.0
A Jan. 17 17.6	P Jan. 23 17.2	P Jan. 16 22.3	A Jan. 23 21.9	A Jan. 17 3.0	P Jan. 23 2.6
P Jan. 31 12.2	A Feb. 6 11.9	A Jan. 30 16.9	P Feb. 6 16.6	P Jan. 30 21.6	A Feb. 5 21.3
A Feb. 14 6.9	P Feb. 20 6.6	P Feb. 13 11.6	A Feb. 20 11.2	A Feb. 13 16.3	P Feb. 19 15.9
P Feb. 28 1.5	A Mar. 6 1.2	A Feb. 27 6.2	P Mar. 6 5.9	P Feb. 27 10.9	A Mar. 5 10.6
A Mar. 12 20.2	P Mar. 19 19.9	P Mar. 13 0.9	A Mar. 20 0.6	A Mar. 12 5.6	P Mar. 19 5.3
P Mar. 26 14.8	A Apr. 2 14.5	A Mar. 26 19.5	P Apr. 2 19.2	P Mar. 26 0.2	A Apr. 1 23.9
A Apr. 9 9.5	P Apr. 16 9.2	P Apr. 9 14.2	A Apr. 16 13.9	A Apr. 8 18.9	P Apr. 15 18.6
P Apr. 23 4.2	A Apr. 30 3.8	A Apr. 23 8.8	P Apr. 30 8.5	P Apr. 22 13.5	A Apr. 29 13.2
A May 6 22.8	P May 13 22.5	P May 7 3.5	A May 14 3.2	A May 6 8.2	P May 13 7.9
P May 20 17.4	A May 27 17.1	A May 20 22.2	P May 27 21.8	P May 20 2.9	A May 27 2.5
A June 3 12.1	P June 10 11.8	P June 3 16.8	A June 10 16.5	A June 2 21.5	P June 9 21.2
P June 17 6.8	A June 24 6.4	A June 17 11.5	P June 24 11.1	P June 16 16.2	A June 23 15.8
A July 1 1.4	P July 8 1.1	P July 1 6.1	A July 8 5.8	A June 30 10.8	P July 7 10.5
P July 14 20.1	A July 21 19.8	A July 15 0.8	P July 22 0.5	P July 14 5.5	A July 21 5.1
A July 28 14.7	P Aug. 4 14.4	P July 28 19.4	A Aug. 4 19.1	A July 28 0.1	P Aug. 3 23.8
P Aug. 11 9.4	A Aug. 18 9.1	A Aug. 11 14.1	P Aug. 18 13.8	P Aug. 10 18.8	A Aug. 17 18.5
A Aug. 25 4.0	P Sept. 1 3.7	P Aug. 25 8.7	A Sept. 1 8.4	A Aug. 24 13.4	P Aug. 31 13.1
P Sept. 7 22.7	A Sept. 14 22.4	A Sept. 8 3.4	P Sept. 15 3.1	P Sept. 7 8.1	A Sept. 14 7.8
A Sept. 21 17.4	P Sept. 28 17.0	P Sept. 21 22.0	A Sept. 28 21.7	A Sept. 21 2.7	P Sept. 28 2.4
P Oct. 5 12.0	A Oct. 12 11.7	A Oct. 5 16.7	P Oct. 12 16.4	P Oct. 4 21.4	A Oct. 11 21.1
A Oct. 19 6.7	P Oct. 26 6.3	P Oct. 19 11.4	A Oct. 26 11.0	A Oct. 18 16.1	P Oct. 25 15.7
P Nov. 2 1.3	A Nov. 9 1.0	A Nov. 2 6.0	P Nov. 9 5.7	P Nov. 1 10.7	A Nov. 8 10.4
A Nov. 15 20.0	P Nov. 22 19.6	P Nov. 16 0.7	A Nov. 23 0.3	A Nov. 15 5.4	P Nov. 22 5.0
P Nov. 29 14.6	A Dec. 6 14.3	A Nov. 29 19.3	P Dec. 6 19.0	P Nov. 29 0.0	A Dec. 5 23.7
A Dec. 13 9.3	P Dec. 20 9.0	P Dec. 13 14.0	A Dec. 20 13.6	A Dec. 12 18.7	P Dec. 19 18.3
P Dec. 27 3.9		A Dec. 27 8.6		P Dec. 26 13.3	

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1922	1923	1924	1925	1926	1927
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
A Jan. 2 13.0	P Jan. 9 12.7	P Jan. 2 17.7	A Jan. 8 17.4	A Jan. 1 22.4	P Jan. 8 22.1
P Jan. 16 7.7	A Jan. 23 7.3	A Jan. 16 12.3	P Jan. 22 12.0	P Jan. 15 17.0	A Jan. 22 16.7
A Jan. 30 2.3	P Feb. 6 2.0	P Jan. 30 7.0	A Feb. 5 6.7	A Jan. 29 11.7	P Feb. 5 11.4
P Feb. 12 21.0	A Feb. 19 20.6	A Feb. 13 1.7	P Feb. 19 1.3	P Feb. 12 6.4	A Feb. 19 6.0
A Feb. 26 15.6	P Mar. 5 15.3	P Feb. 26 20.3	A Mar. 4 20.0	A Feb. 26 1.0	P Mar. 5 0.7
P Mar. 12 10.3	A Mar. 19 9.9	A Mar. 11 15.0	P Mar. 18 14.6	P Mar. 11 19.7	A Mar. 18 19.3
A Mar. 26 4.9	P Apr. 2 4.6	P Mar. 25 9.6	A Apr. 1 9.3	A Mar. 25 14.3	P Apr. 1 14.0
P Apr. 8 23.6	A Apr. 15 23.3	A Apr. 8 4.3	P Apr. 15 3.9	P Apr. 8 9.0	A Apr. 15 8.6
A Apr. 22 18.2	P Apr. 29 17.9	P Apr. 21 22.9	A Apr. 28 22.6	A Apr. 22 3.6	P Apr. 29 3.3
P May 6 12.9	A May 13 12.6	A May 5 17.6	P May 12 17.3	P May 5 22.3	A May 12 22.0
A May 20 7.5	P May 27 7.2	P May 19 12.2	A May 26 11.9	A May 19 16.9	P May 26 16.6
P June 3 2.2	A June 10 1.9	A June 2 6.9	P June 9 6.6	P June 2 11.6	A June 9 11.3
A June 16 20.9	P June 23 20.5	P June 16 1.5	A June 23 1.2	A June 16 6.2	P June 23 5.9
P June 30 15.5	A July 7 15.2	A June 29 20.2	P July 6 19.9	P June 30 0.9	A July 7 0.6
A July 14 10.2	P July 21 9.8	P July 13 14.9	A July 20 14.5	A July 13 19.6	P July 20 19.2
P July 28 4.8	A Aug. 4 4.5	A July 27 9.5	P Aug. 3 9.2	P July 27 14.2	A Aug. 3 13.9
A Aug. 10 23.5	P Aug. 17 23.1	P Aug. 10 4.2	A Aug. 17 3.8	A Aug. 10 8.9	P Aug. 17 8.5
P Aug. 24 18.1	A Aug. 31 17.8	A Aug. 23 22.8	P Aug. 30 22.5	P Aug. 24 3.5	A Aug. 31 3.2
A Sept. 7 12.8	P Sept. 14 12.5	P Sept. 6 17.5	A Sept. 13 17.2	A Sept. 6 22.2	P Sept. 13 21.8
P Sept. 21 7.4	A Sept. 28 7.1	A Sept. 20 12.1	P Sept. 27 11.8	P Sept. 20 16.8	A Sept. 27 16.5
A Oct. 5 2.1	P Oct. 12 1.8	P Oct. 4 6.8	A Oct. 11 6.5	A Oct. 4 11.5	P Oct. 11 11.2
P Oct. 18 20.7	A Oct. 25 20.4	A Oct. 18 1.4	P Oct. 25 1.1	P Oct. 18 6.1	A Oct. 25 5.8
A Nov. 1 15.4	P Nov. 8 15.1	P Oct. 31 20.1	A Nov. 7 19.8	A Nov. 1 0.8	P Nov. 8 0.5
P Nov. 15 10.1	A Nov. 22 9.7	A Nov. 14 14.7	P Nov. 21 14.4	P Nov. 14 19.4	A Nov. 21 19.1
A Nov. 29 4.7	P Dec. 6 4.4	P Nov. 28 9.4	A Dec. 5 9.1	A Nov. 28 14.1	P Dec. 5 13.8
P Dec. 12 23.4	A Dec. 19 23.0	A Dec. 12 4.1	P Dec. 19 3.7	P Dec. 12 8.8	A Dec. 19 8.4
A Dec. 26 18.0		P Dec. 25 22.7		A Dec. 26 3.4	

1928	1929	1930	1931	1932	1933
hr.	*hr.*	*hr.*	*hr.*	*hr.*	*hr.*
P Jan. 2 3.1	A Jan. 8 2.8	A Jan. 1 7.8	P Jan. 8 7.4	P Jan. 1 12.5	A Jan. 7 12.1
A Jan. 15 21.7	P Jan. 21 21.4	P Jan. 15 2.4	A Jan. 22 2.1	A Jan. 15 7.1	P Jan. 21 6.8
P Jan. 29 16.4	A Feb. 4 16.1	A Jan. 28 21.1	P Feb. 4 20.8	P Jan. 29 1.8	A Feb. 4 1.5
A Feb. 12 11.0	P Feb. 18 10.7	P Feb. 11 15.7	A Feb. 18 15.4	A Feb. 11 20.4	P Feb. 17 20.1
P Feb. 26 5.7	A Mar. 4 5.4	A Feb. 25 10.4	P Mar. 4 10.1	P Feb. 25 15.1	A Mar. 3 14.8
A Mar. 11 0.4	P Mar. 18 0.0	P Mar. 11 5.0	A Mar. 18 4.7	A Mar. 10 9.7	P Mar. 17 9.4
P Mar. 24 19.0	A Mar. 31 18.7	A Mar. 24 23.7	P Mar. 31 23.4	P Mar. 24 4.4	A Mar. 31 4.1
A Apr. 7 13.7	P Apr. 14 13.3	P Apr. 7 18.4	A Apr. 14 18.0	A Apr. 6 23.1	P Apr. 13 22.7
P Apr. 21 8.3	A Apr. 28 8.0	A Apr. 21 13.0	P Apr. 28 12.7	P Apr. 20 17.7	A Apr. 27 17.4
A May 5 3.0	P May 12 2.6	P May 5 7.7	A May 12 7.3	A May 4 12.4	P May 11 12.0
P May 18 21.6	A May 25 21.3	A May 19 2.3	P May 26 2.0	P May 18 7.0	A May 25 6.7
A June 1 16.3	P June 8 16.0	P June 1 21.0	A June 8 20.7	A June 1 1.7	P June 8 1.3
P June 15 10.9	A June 22 10.6	A June 15 15.6	P June 22 15.3	P June 14 20.3	A June 21 20.0
A June 29 5.6	P July 6 5.3	P June 29 10.3	A July 6 10.0	A June 28 15.0	P July 5 14.7
P July 13 0.2	A July 19 23.9	A July 13 4.9	P July 20 4.6	P July 12 9.6	A July 19 9.3
A July 26 18.9	P Aug. 2 18.6	P July 26 23.6	A Aug. 2 23.3	A July 26 4.3	P Aug. 2 4.0
P Aug. 9 13.5	A Aug. 16 13.2	A Aug. 9 18.2	P Aug. 16 17.9	P Aug. 8 22.9	A Aug. 15 22.6
A Aug. 23 8.2	P Aug. 30 7.9	P Aug. 23 12.9	A Aug. 30 12.6	A Aug. 22 17.6	P Aug. 29 17.3
P Sept. 6 2.9	A Sept. 13 2.5	A Sept. 6 7.6	P Sept. 13 7.2	P Sept. 5 12.3	A Sept. 12 11.9
A Sept. 19 21.5	P Sept. 26 21.2	P Sept. 20 2.2	A Sept. 27 1.9	A Sept. 19 6.9	P Sept. 26 6.6
P Oct. 3 16.2	A Oct. 10 15.8	A Oct. 3 20.9	P Oct. 10 20.5	P Oct. 3 1.6	A Oct. 10 1.2
A Oct. 17 10.8	P Oct. 24 10.5	P Oct. 17 15.5	A Oct. 24 15.2	A Oct. 16 20.2	P Oct. 23 19.9
P Oct. 31 5.5	A Nov. 7 5.2	A Oct. 31 10.2	P Nov. 7 9.9	P Oct. 30 14.9	A Nov. 6 14.5
A Nov. 14 0.1	P Nov. 20 23.8	P Nov. 14 4.8	A Nov. 21 4.5	A Nov. 13 9.5	P Nov. 20 9.2
P Nov. 27 18.8	A Dec. 4 18.5	A Nov. 27 23.5	P Dec. 4 23.2	P Nov. 27 4.2	A Dec. 4 3.9
A Dec. 11 13.4	P Dec. 18 13.1	P Dec. 11 18.1	A Dec. 18 17.8	A Dec. 10 22.8	P Dec. 17 22.5
P Dec. 25 8.1		A Dec. 25 12.8		P Dec. 24 17.5	A Dec. 31 17.2

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1934	1935	1936	1937	1938	1939
hr	hr	hr	hr	hr	hr
P Jan. 14 11.8	P Jan. 7 16.8	A Jan. 14 16.5	A Jan. 6 21.5	P Jan. 13 21.2	P Jan. 7 2.2
A Jan. 28 6.5	A Jan. 21 11.5	P Jan. 28 11.2	P Jan. 20 16.2	A Jan. 27 15.9	A Jan. 20 20.9
P Feb. 11 1.1	P Feb. 4 6.1	A Feb. 11 5.8	A Feb. 3 10.8	P Feb. 10 10.5	P Feb. 3 15.5
A Feb. 24 19.8	A Feb. 18 0.8	P Feb. 25 0.5	P Feb. 17 5.5	A Feb. 24 5.2	A Feb. 17 10.2
P Mar. 10 14.4	P Mar. 3 19.5	A Mar. 9 19.1	A Mar. 3 0.2	P Mar. 9 23.8	P Mar. 3 4.8
A Mar. 24 9.1	A Mar. 17 14.1	P Mar. 23 13.8	P Mar. 16 18.8	A Mar. 23 18.5	A Mar. 16 23.5
P Apr. 7 3.7	P Mar. 31 8.8	A Apr. 6 8.4	A Mar. 30 13.5	P Apr. 6 13.1	P Mar. 30 18.2
A Apr. 20 22.4	A Apr. 14 3.4	P Apr. 20 3.1	P Apr. 13 8.1	A Apr. 20 7.8	A Apr. 13 12.8
P May 4 17.1	P Apr. 27 22.1	A May 3 21.7	A Apr. 27 2.8	P May 4 2.4	P Apr. 27 7.5
A May 18 11.7	A May 11 16.7	P May 17 16.4	P May 10 21.4	A May 17 21.1	A May 11 2.1
P June 1 6.4	P May 25 11.4	A May 31 11.1	A May 24 16.1	P May 31 15.8	P May 24 20.8
A June 15 1.0	A June 8 6.0	P June 14 5.7	P June 7 10.7	A June 14 10.4	A June 7 15.4
P June 28 19.7	P June 22 0.7	A June 28 0.4	A June 21 5.4	P June 28 5.1	P June 21 10.1
A July 12 14.3	A July 5 19.3	P July 11 19.0	P July 5 0.0	A July 11 23.7	A July 5 4.7
P July 26 9.0	P July 19 14.0	A July 25 13.7	A July 18 18.7	P July 25 18.4	P July 18 23.4
A Aug. 9 3.6	A Aug. 2 8.7	P Aug. 8 8.3	P Aug. 1 13.4	A Aug. 8 13.0	A Aug. 1 18.0
P Aug. 22 22.3	P Aug. 16 3.3	A Aug. 22 3.0	A Aug. 15 8.0	P Aug. 22 7.7	P Aug. 15 12.7
A Sept. 5 16.9	A Aug. 29 22.0	P Sept. 4 21.6	P Aug. 29 2.7	A Sept. 5 2.3	A Aug. 29 7.4
P Sept. 19 11.6	P Sept. 12 16.6	A Sept. 18 16.3	A Sept. 11 21.3	P Sept. 18 21.0	P Sept. 12 2.0
A Oct. 3 6.3	A Sept. 26 11.3	P Oct. 2 10.9	P Sept. 25 16.0	A Oct. 2 15.7	A Sept. 25 20.7
P Oct. 17 0.9	P Oct. 10 5.9	A Oct. 16 5.6	A Oct. 9 10.6	P Oct. 16 10.3	P Oct. 9 15.3
A Oct. 30 19.6	A Oct. 24 0.6	P Oct. 30 0.3	P Oct. 23 5.3	A Oct. 30 5.0	A Oct. 23 10.0
P Nov. 13 14.2	P Nov. 6 19.2	A Nov. 12 18.9	A Nov. 5 23.9	P Nov. 12 23.6	P Nov. 6 4.7
A Nov. 27 8.9	A Nov. 20 13.9	P Nov. 26 13.6	P Nov. 19 18.6	A Nov. 26 18.3	A Nov. 19 23.3
P Dec. 11 3.5	P Dec. 4 8.5	A Dec. 10 8.2	A Dec. 3 13.2	P Dec. 10 12.9	P Dec. 3 17.8
A Dec. 24 22.2	A Dec. 18 3.2	P Dec. 24 2.9	P Dec. 17 7.9	A Dec. 24 7.6	A Dec. 17 12.6
	P Dec. 31 21.9		A Dec. 31 2.6		P Dec. 31 7.2

1940	1941	1942	1943	1944	1945
hr	hr	hr	hr	hr	hr
A Jan. 14 1.9	A Jan. 6 6.9	P Jan. 13 6.6	P Jan. 6 11.6	A Jan. 13 11.3	A Jan. 5 16.3
P Jan. 27 20.6	P Jan. 20 1.6	A Jan. 27 1.2	A Jan. 20 6.3	P Jan. 27 5.9	P Jan. 19 11.0
A Feb. 10 15.2	A Feb. 2 20.2	P Feb. 9 19.9	P Feb. 3 0.9	A Feb. 10 0.6	A Feb. 2 5.6
P Feb. 24 9.9	P Feb. 16 14.9	A Feb. 23 14.6	A Feb. 16 19.6	P Feb. 23 19.3	P Feb. 16 0.3
A Mar. 9 4.5	A Mar. 2 9.5	P Mar. 9 9.2	P Mar. 2 14.2	A Mar. 8 13.9	A Mar. 1 18.9
P Mar. 22 23.2	P Mar. 16 4.2	A Mar. 23 3.9	A Mar. 16 8.9	P Mar. 22 8.6	P Mar. 15 13.6
A Apr. 5 17.8	A Mar. 29 22.8	P Apr. 5 22.5	P Mar. 30 3.5	A Apr. 5 3.2	A Mar. 29 8.2
P Apr. 19 12.5	P Apr. 12 17.5	A Apr. 19 17.2	A Apr. 12 22.2	P Apr. 18 21.9	P Apr. 12 2.9
A May 3 7.1	A Apr. 26 12.2	P May 3 11.8	P Apr. 26 16.9	A May 2 16.5	A Apr. 25 21.5
P May 17 1.8	P May 10 6.8	A May 17 6.5	A May 10 11.5	P May 16 11.2	P May 9 16.2
A May 30 20.4	A May 24 1.5	P May 31 1.1	P May 24 6.2	A May 30 5.8	A May 23 10.9
P June 13 15.1	P June 6 20.1	A June 13 19.8	A June 7 0.8	P June 13 0.5	P June 6 5.5
A June 27 9.8	A June 20 14.8	P June 27 14.4	P June 20 19.5	A June 26 19.1	A June 20 0.2
P July 11 4.4	P July 4 9.4	A July 11 9.1	A July 4 14.1	P July 10 13.8	P July 3 18.8
A July 24 23.1	A July 18 4.1	P July 25 3.8	P July 18 8.8	A July 24 8.5	A July 17 13.5
P Aug. 7 17.7	P July 31 22.7	A Aug. 7 22.4	A Aug. 1 3.4	P Aug. 7 3.1	P July 31 8.1
A Aug. 21 12.4	A Aug. 14 17.4	P Aug. 21 17.1	P Aug. 14 22.1	A Aug. 20 21.8	A Aug. 14 2.8
P Sept. 4 7.0	P Aug. 28 12.0	A Sept. 4 11.7	A Aug. 28 16.7	P Sept. 3 16.4	P Aug. 27 21.4
A Sept. 18 1.7	A Sept. 11 6.7	P Sept. 18 6.4	P Sept. 11 11.4	A Sept. 17 11.1	A Sept. 10 16.1
P Oct. 1 20.3	P Sept. 25 1.4	A Oct. 2 1.0	A Sept. 25 6.1	P Oct. 1 5.7	P Sept. 24 10.7
A Oct. 15 15.0	A Oct. 8 20.0	P Oct. 15 19.7	P Oct. 9 0.7	A Oct. 15 0.4	A Oct. 8 5.4
P Oct. 29 9.6	P Oct. 22 14.7	A Oct. 29 14.3	A Oct. 22 19.4	P Oct. 28 19.0	P Oct. 22 0.1
A Nov. 12 4.3	A Nov. 5 9.3	P Nov. 12 9.0	P Nov. 5 14.0	A Nov. 11 13.7	A Nov. 4 18.7
P Nov. 25 23.0	P Nov. 19 4.0	A Nov. 26 3.6	A Nov. 19 8.7	P Nov. 25 8.3	P Nov. 18 13.4
A Dec. 9 17.6	A Dec. 2 22.6	P Dec. 9 22.3	P Dec. 3 3.3	A Dec. 9 3.0	A Dec. 2 8.0
P Dec. 23 12.3	P Dec. 16 17.3	A Dec. 23 17.0	A Dec. 16 22.0	P Dec. 22 21.7	P Dec. 16 2.7
	A Dec. 30 11.9		P Dec. 30 16.6		A Dec. 29 21.3

TABLE 58.—*Greenwich mean civil times of mean perigee and apogee, 1850–1950*—Con.

1946		1947		1948		1949		1950	
	hr.		*hr.*		*hr.*		*hr.*		*hr.*
P Jan. 12	16.0	P Jan. 5	21.0	A Jan. 12	20.7	A Jan. 5	1.7	P Jan. 12	1.4
A Jan. 26	10.6	A Jan. 19	15.7	P Jan. 26	15.3	P Jan. 18	20.4	A Jan. 25	20.0
P Feb. 9	5.3	P Feb. 2	10.3	A Feb. 9	10.0	A Feb. 1	15.0	P Feb. 8	14.7
A Feb. 22	23.9	A Feb. 16	5.0	P Feb. 23	4.6	P Feb. 15	9.7	A Feb. 22	9.3
P Mar. 8	18.6	P Mar. 1	23.6	A Mar. 7	23.3	A Mar. 1	4.3	P Mar. 8	4.0
A Mar. 22	13.3	A Mar. 15	18.3	P Mar. 21	17.9	P Mar. 14	23.0	A Mar. 21	22.6
P Apr. 5	7.9	P Mar. 29	12.9	A Apr. 4	12.6	A Mar. 28	17.7	P Apr. 4	17.3
A Apr. 19	2.6	A Apr. 12	7.6	P Apr. 18	7.3	P Apr. 11	12.3	A Apr. 18	12.0
P May 2	21.2	P Apr. 26	2.2	A May 2	1.9	A Apr. 25	6.9	P May 2	6.6
A May 16	15.9	A May 9	20.9	P May 15	20.6	P May 9	1.6	A May 16	1.3
P May 30	10.5	P May 23	15.5	A May 29	15.2	A May 22	20.2	P May 29	19.9
A June 13	5.2	A June 6	10.2	P June 12	9.9	P June 5	14.9	A June 12	14.6
P June 26	23.8	P June 20	4.9	A June 26	4.5	A June 19	9.6	P June 26	9.2
A July 10	18.5	A July 3	23.5	P July 9	23.2	P July 3	4.2	A July 10	3.9
P July 24	13.1	P July 17	18.2	A July 23	17.8	A July 16	22.9	P July 23	22.5
A Aug. 7	7.8	A July 31	12.8	P Aug. 6	12.5	P July 30	17.5	A Aug. 6	17.2
P Aug. 21	2.5	P Aug. 14	7.5	A Aug. 20	7.1	A Aug. 13	12.2	P Aug. 20	11.8
A Sept. 3	21.1	A Aug. 28	2.1	P Sept. 3	1.8	P Aug. 27	6.8	A Sept. 3	6.5
P Sept. 17	15.8	P Sept. 10	20.8	A Sept. 16	20.5	A Sept. 10	1.5	P Sept. 17	1.2
A Oct. 1	10.4	A Sept. 24	15.4	P Sept. 30	15.1	P Sept. 23	20.1	A Sept. 30	19.8
P Oct. 15	5.1	P Oct. 8	10.1	A Oct. 14	9.8	A Oct. 7	14.8	P Oct. 14	14.5
A Oct. 28	23.7	A Oct. 22	4.7	P Oct. 28	4.4	P Oct. 21	9.4	A Oct. 28	9.1
P Nov. 11	18.4	P Nov. 4	23.4	A Nov. 10	23.1	A Nov. 4	4.1	P Nov. 11	3.8
A Nov. 25	13.0	A Nov. 18	18.1	P Nov. 24	17.7	P Nov. 17	22.8	A Nov. 24	22.4
P Dec. 9	7.7	P Dec. 2	12.7	A Dec. 8	12.4	A Dec. 1	17.4	P Dec. 8	17.1
A Dec. 23	2.3	A Dec. 16	7.4	P Dec. 22	7.0	P Dec. 15	12.1	A Dec. 22	11.7
		P Dec. 30	2.0			A Dec. 29	6.7		

The value of the anomalistic month, of p and of s, used in constructing this table, are given in sections 13 and 21, Part II.

TABLE 59.—*Variation in mean semirange of spring and neap tides due to parallax and evectional waves composed of* N_2, L_2, $2L$, ν_2, *and* λ_2.

INCREASE IN MEAN SEMIRANGE OF SPRING TIDES.

Time		Length of half group			Time		Length of half group		
		0 tides	2 tides	4 tides			0 tides	2 tides	4 tides
	d. h.					d. h.			
After perigean tides	0 00	+1.11 N_2	+1.11 N_2	+1.10 N_2	After apogean tides	0 00	−0.91 N_2	−0.91 N_2	−0.91 N_2
	0 06	+1.11 "	+1.11 "	+1.10 "		0 06	−0.91 "	−0.91 "	−0.90 "
	0 12	+1.10 "	+1.10 "	+1.09 "		0 12	−0.91 "	−0.91 "	−0.90 "
	0 18	+1.09 "	+1.09 "	+1.08 "		0 18	−0.90 "	−0.90 "	−0.90 "
	1 00	+1.07 "	+1.07 "	+1.06 "		1 00	−0.90 "	−0.89 "	−0.89 "
	1 06	+1.05 "	+1.05 "	+1.04 "		1 06	−0.89 "	−0.88 "	−0.88 "
	1 12	+1.03 "	+1.03 "	+1.02 "		1 12	−0.87 "	−0.87 "	−0.87 "
	1 18	+1.00 "	+1.00 "	+0.99 "		1 18	−0.86 "	−0.86 "	−0.86 "
	2 00	+0.97 "	+0.97 "	+0.96 "		2 00	−0.85 "	−0.84 "	−0.84 "
	2 06	+0.93 "	+0.93 "	+0.92 "		2 06	−0.83 "	−0.83 "	−0.82 "
	2 12	+0.89 "	+0.89 "	+0.88 "		2 12	−0.81 "	−0.81 "	−0.80 "
	2 18	+0.85 "	+0.85 "	+0.84 "		2 18	−0.79 "	−0.78 "	−0.78 "
	3 00	+0.80 "	+0.80 "	+0.79 "		3 00	−0.76 "	−0.76 "	−0.75 "
	3 06	+0.75 "	+0.75 "	+0.74 "		3 06	−0.73 "	−0.73 "	−0.73 "
	3 12	+0.70 "	+0.70 "	+0.69 "		3 12	−0.71 "	−0.70 "	−0.70 "
Before midtime tides	3 12	+0.72 "	+0.72 "	+0.72 "	Before midtime tides	3 12	−0.72 "	−0.72 "	−0.71 "
	3 06	+0.67 "	+0.67 "	+0.66 "		3 06	−0.69 "	−0.69 "	−0.68 "
	3 00	+0.61 "	+0.61 "	+0.61 "		3 00	−0.66 "	−0.66 "	−0.65 "
	2 18	+0.56 "	+0.56 "	+0.55 "		2 18	−0.62 "	−0.62 "	−0.62 "
	2 12	+0.50 "	+0.50 "	+0.50 "		2 12	−0.59 "	−0.58 "	−0.58 "
	2 06	+0.44 "	+0.44 "	+0.44 "		2 06	−0.55 "	−0.55 "	−0.54 "
	2 00	+0.38 "	+0.38 "	+0.38 "		2 00	−0.51 "	−0.50 "	−0.50 "
	1 18	+0.32 "	+0.32 "	+0.32 "		1 18	−0.46 "	−0.46 "	−0.46 "
	1 12	+0.26 "	+0.26 "	+0.26 "		1 12	−0.42 "	−0.42 "	−0.41 "
	1 06	+0.19 "	+0.19 "	+0.20 "		1 06	−0.37 "	−0.37 "	−0.36 "
	1 00	+0.13 "	+0.13 "	+0.13 "		1 00	−0.32 "	−0.32 "	−0.31 "
	0 18	+0.07 "	+0.07 "	+0.07 "		0 18	−0.27 "	−0.27 "	−0.26 "
	0 12	+0.01 "	+0.01 "	+0.02 "		0 12	−0.22 "	−0.21 "	−0.21 "
	0 06	−0.05 "	−0.05 "	−0.04 "		0 06	−0.16 "	−0.16 "	−0.16 "
	0 00	−0.10 "	−0.10 "	−0.10 "		0 00	−0.10 "	−0.10 "	−0.10 "
After midtime tides	0 00	−0.10 "	−0.10 "	−0.10 "	After midtime tides	0 00	−0.10 "	−0.10 "	−0.10 "
	0 06	−0.16 "	−0.16 "	−0.16 "		0 06	−0.05 "	−0.05 "	−0.04 "
	0 12	−0.22 "	−0.21 "	−0.21 "		0 12	+0.01 "	+0.01 "	+0.02 "
	0 18	−0.27 "	−0.27 "	−0.26 "		0 18	+0.07 "	+0.07 "	+0.07 "
	1 00	−0.32 "	−0.32 "	−0.31 "		1 00	+0.13 "	+0.13 "	+0.13 "
	1 06	−0.37 "	−0.37 "	−0.36 "		1 06	+0.19 "	+0.19 "	+0.20 "
	1 12	−0.42 "	−0.42 "	−0.41 "		1 12	+0.26 "	+0.26 "	+0.26 "
	1 18	−0.46 "	−0.46 "	−0.46 "		1 18	+0.32 "	+0.32 "	+0.32 "
	2 00	−0.51 "	−0.50 "	−0.50 "		2 00	+0.38 "	+0.38 "	+0.38 "
	2 06	−0.55 "	−0.55 "	−0.54 "		2 06	+0.44 "	+0.44 "	+0.44 "
	2 12	−0.59 "	−0.58 "	−0.58 "		2 12	+0.50 "	+0.50 "	+0.50 "
	2 18	−0.62 "	−0.62 "	−0.62 "		2 18	+0.56 "	+0.56 "	+0.55 "
	3 00	−0.66 "	−0.66 "	−0.65 "		3 00	+0.61 "	+0.61 "	+0.61 "
	3 06	−0.69 "	−0.69 "	−0.68 "		3 06	+0.67 "	+0.67 "	+0.66 "
	3 12	−0.72 "	−0.72 "	−0.71 "		3 12	+0.72 "	+0.72 "	+0.72 "

TABLE 59.—*Variation in mean semirange of spring and neap tides due to parallax and evectional waves composed of* N_2, L_2, $2L$, ν_2, *and* λ_2—Continued.

INCREASE IN MEAN SEMIRANGE OF SPRING TIDES—continued.

	Time	Length of half group				Time.	Length of half group		
		0 tides	2 tides	4 tides			0 tide	2 tides	4 tides
	d. h.					*d. h.*			
Before apogean tides	3 12	−0.71 N_2	−0.70 N_2	−0.70 N_2	Before perigean tides	3 12	+0.70 N_2	+0.70 N_2	+0.69 N_2
	3 06	−0.73 "	−0.73 "	−0.73 "		3 06	+0.75 "	+0.75 "	+0.74 "
	3 00	−0.76 "	−0.76 "	−0.75 "		3 00	+0.80 "	+0.80 "	+0.79 "
	2 18	−0.79 "	−0.78 "	−0.78 "		2 18	+0.85 "	+0.85 "	+0.84 "
	2 12	−0.81 "	−0.81 "	−0.80 "		2 12	+0.89 "	+0.89 "	+0.88 "
	2 06	−0.83 "	−0.83 "	−0.82 "		2 06	+0.93 "	+0.93 "	+0.92 "
	2 00	−0.85 "	−0.84 "	−0.84 "		2 00	+0.97 "	+0.97 "	+0.96 "
	1 18	−0.86 "	−0.86 "	−0.86 "		1 18	+1.00 "	+1.00 "	+0.99 "
	1 12	−0.87 "	−0.87 "	−0.87 "		1 12	+1.03 "	+1.03 "	+1.02 "
	1 06	−0.89 "	−0.88 "	−0.88 "		1 06	+1.05 "	+1.05 "	+1.04 "
	1 00	−0.90 "	−0.89 "	−0.89 "		1 00	+1.07 "	+1.07 "	+1.06 "
	0 18	−0.90 "	−0.90 "	−0.90 "		0 18	+1.09 "	+1.09 "	+1.08 "
	0 12	−0.91 "	−0.91 "	−0.90 "		0 12	+1.10 "	+1.10 "	+1.09 "
	0 06	−0.91 "	−0.91 "	−0.90 "		0 06	+1.11 "	+1.11 "	+1.10 "
	0 00	−0.91 "	−0.91 "	−0.91 "		0 00	+1.11 "	+1.11 "	+1.10 "

This table applies best to cases where S_2/M_2 has its theoretical value. If this ratio is small, Tables 25 and 34 may be used.

TABLE 59.—*Variation in mean semirange of spring and neap tides due to parallax and evectional waves composed of* N_2, L_2, $2N$, ν_2 *and* λ_2—Continued.

INCREASE IN MEAN SEMIRANGE OF NEAP TIDES.

	Time	Length of half group: 0 tides	2 tides	4 tides
	d. h.			
After perigean tides	0 00	+0.73 N_2	+0.73 N_2	+0.72 N_2
	0 06	+0.73 "	+0.73 "	+0.72 "
	0 12	+0.72 "	+0.72 "	+0.72 "
	0 18	+0.72 "	+0.72 "	+0.71 "
	1 00	+0.71 "	+0.71 "	+0.70 "
	1 06	+0.69 "	+0.69 "	+0.69 "
	1 12	+0.68 "	+0.68 "	+0.67 "
	1 18	+0.66 "	+0.66 "	+0.65 "
	2 00	+0.64 "	+0.64 "	+0.63 "
	2 06	+0.62 "	+0.61 "	+0.61 "
	2 12	+0.59 "	+0.59 "	+0.58 "
	2 18	+0.56 "	+0.56 "	+0.56 "
	3 00	+0.53 "	+0.53 "	+0.53 "
	3 06	+0.50 "	+0.50 "	+0.50 "
	3 12	+0.47 "	+0.47 "	+0.46 "
Before midtime tides	3 12	+0.48 "	+0.48 "	+0.48 "
	3 06	+0.45 "	+0.45 "	+0.44 "
	3 00	+0.41 "	+0.41 "	+0.41 "
	2 18	+0.38 "	+0.38 "	+0.37 "
	2 12	+0.34 "	+0.34 "	+0.34 "
	2 06	+0.30 "	+0.30 "	+0.30 "
	2 00	+0.26 "	+0.26 "	+0.26 "
	1 18	+0.22 "	+0.22 "	+0.22 "
	1 12	+0.18 "	+0.18 "	+0.18 "
	1 06	+0.15 "	+0.15 "	+0.15 "
	1 00	+0.11 "	+0.11 "	+0.11 "
	0 18	+0.07 "	+0.07 "	+0.07 "
	0 12	+0.03 "	+0.03 "	+0.03 "
	0 06	−0.01 "	−0.01 "	0.00 "
	0 00	−0.04 "	−0.04 "	−0.04 "
After midtime tides	0 00	−0.04 "	−0.04 "	−0.04 "
	0 06	−0.08 "	−0.08 "	−0.08 "
	0 12	−0.11 "	−0.11 "	−0.11 "
	0 18	−0.15 "	−0.15 "	−0.15 "
	1 00	−0.18 "	−0.18 "	−0.18 "
	1 06	−0.21 "	−0.21 "	−0.21 "
	1 12	−0.25 "	−0.25 "	−0.24 "
	1 18	−0.28 "	−0.28 "	−0.27 "
	2 00	−0.31 "	−0.31 "	−0.30 "
	2 06	−0.34 "	−0.34 "	−0.33 "
	2 12	−0.36 "	−0.36 "	−0.36 "
	2 18	−0.39 "	−0.39 "	−0.39 "
	3 00	−0.42 "	−0.42 "	−0.42 "
	3 06	−0.44 "	−0.44 "	−0.44 "
	3 12	−0.47 "	−0.47 "	−0.47 "

	Time	Length of half group: 0 tides	2 tides	4 tides
	d. h.			
After apogean tides	0 00	−0.67 N_2	−0.66 N_2	−0.66 N_2
	0 06	−0.66 "	−0.66 "	−0.66 "
	0 12	−0.66 "	−0.66 "	−0.65 "
	0 18	−0.65 "	−0.65 "	−0.65 "
	1 00	−0.65 "	−0.64 "	−0.64 "
	1 06	−0.63 "	−0.63 "	−0.63 "
	1 12	−0.62 "	−0.62 "	−0.62 "
	1 18	−0.61 "	−0.60 "	−0.60 "
	2 00	−0.59 "	−0.59 "	−0.58 "
	2 06	−0.57 "	−0.57 "	−0.57 "
	2 12	−0.55 "	−0.55 "	−0.55 "
	2 18	−0.53 "	−0.53 "	−0.53 "
	3 00	−0.51 "	−0.51 "	−0.50 "
	3 06	−0.48 "	−0.48 "	−0.48 "
	3 12	−0.46 "	−0.46 "	−0.46 "
Before midtime tides	3 12	−0.47 "	−0.47 "	−0.47 "
	3 06	−0.44 "	−0.44 "	−0.44 "
	3 00	−0.42 "	−0.42 "	−0.42 "
	2 18	−0.39 "	−0.39 "	−0.39 "
	2 12	−0.36 "	−0.36 "	−0.36 "
	2 06	−0.34 "	−0.34 "	−0.33 "
	2 00	−0.31 "	−0.31 "	−0.30 "
	1 18	−0.28 "	−0.28 "	−0.27 "
	1 12	−0.25 "	−0.25 "	−0.24 "
	1 06	−0.21 "	−0.21 "	−0.21 "
	1 00	−0.18 "	−0.18 "	−0.18 "
	0 18	−0.15 "	−0.15 "	−0.15 "
	0 12	−0.11 "	−0.11 "	−0.11 "
	0 06	−0.08 "	−0.08 "	−0.08 "
	0 00	−0.04 "	−0.04 "	−0.04 "
After midtime tides	0 00	−0.04 "	−0.04 "	−0.04 "
	0 06	−0.01 "	−0.01 "	0.00 "
	0 12	+0.03 "	+0.03 "	+0.03 "
	0 18	+0.07 "	+0.07 "	+0.07 "
	1 00	+0.11 "	+0.11 "	+0.11 "
	1 06	+0.15 "	+0.15 "	+0.15 "
	1 12	+0.18 "	+0.18 "	+0.18 "
	1 18	+0.22 "	+0.22 "	+0.22 "
	2 00	+0.26 "	+0.26 "	+0.26 "
	2 06	+0.30 "	+0.30 "	+0.30 "
	2 12	+0.34 "	+0.34 "	+0.34 "
	2 18	+0.38 "	+0.38 "	+0.37 "
	3 00	+0.41 "	+0.41 "	+0.41 "
	3 06	+0.45 "	+0.45 "	+0.44 "
	3 12	+0.48 "	+0.48 "	+0.48 "

TABLE 59.—*Variation in mean semirange of spring and neap tides due to parallax and evectional waves composed of* N_2, L_2, $2N$, ν_2, *and* λ_2—Continued.

INCREASE IN MEAN SEMIRANGE OF NEAP TIDES—continued.

	Time	Length of half group				Time	Length of half group		
		0 tides	2 tides	4 tides			0 tides	2 tides	4 tides
	d. h.					*d. h.*			
Before apogean tides	3 12	−0.46 N_2	−0.46 N_2	−0.46 N_2	Before perigean tides	3 12	+0.47 N_2	+0.47 N_2	+0.47 N_2
	3 06	−0.48 "	−0.48 "	−0.48 "		3 06	+0.50 "	+0.50 "	+0.50 "
	3 00	−0.51 "	−0.51 "	−0.50 "		3 00	+0.53 "	+0.53 "	+0.53 "
	2 18	−0.53 "	−0.53 "	−0.53 "		2 18	+0.56 "	+0.56 "	+0.56 "
	2 12	−0.55 "	−0.55 "	−0.55 "		2 12	+0.59 "	+0.59 "	+0.58 "
	2 06	−0.57 "	−0.57 "	−0.57 "		2 06	+0.62 "	+0.61 "	+0.61 "
	2 00	−0.59 "	−0.59 "	−0.58 "		2 00	+0.64 "	+0.64 "	+0.63 "
	1 18	−0.61 "	−0.60 "	−0.60 "		1 18	+0.66 "	+0.66 "	+0.65 "
	1 12	−0.62 "	−0.62 "	−0.62 "		1 12	+0.68 "	+0.68 "	+0.67 "
	1 06	−6.63 "	−0.63 "	−0.63 "		1 06	+0.69 "	+0.69 "	+0.69 "
	1 00	−0.65 "	−0.64 "	−0.64 "		1 00	+0.71 "	+0.71 "	+0.70 "
	0 18	−0.65 "	−0.65 "	−0.65 "		0 18	+0.72 "	+0.72 "	+0.71 "
	0 12	−0.66 "	−0.66 "	−0.65 "		0 12	+0.72 "	+0.72 "	+0.72 "
	0 06	−0.66 "	−0.66 "	−0.66 "		0 06	+0.73 "	+0.73 "	+0.72 "
	0 00	−0.67 "	−0.66 "	−0.66 "		0 00	+0.73 "	+0.73 "	+0.72 "

This table applies best to cases where S_2/M_2 has its theoretical value. If this ratio is small, Tables 25 and 34 may be used.

TABLE 60.—*Time of maximum*

Time by which maximum downward slope toward body having

[The amplitude of the larger tide is taken as unity.]

Cot. hour of smaller tide—cot. hour of larger		0	⅓	⅔	1	1⅓	1⅔	2	2⅓	2⅔	3
		h	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*
Amplitude of smaller tide.	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.1	0.000	0.037	0.072	0.104	0.133	0.156	0.174	0.185	0.191	0.190
	0.2	0.000	0.083	0.161	0.230	0.288	0.332	0.363	0.380	0.384	0.377
	0.3	0.000	0.141	0.271	0.382	0.468	0.530	0.567	0.581	0.577	0.557
	0.4	0.000	0.218	0.412	0.567	0.678	0.747	0.781	0.784	0.765	0.727
	0.5	0.000	0.323	0.596	0.793	0.917	0.982	1.000	0.985	0.944	0.886
	0.6	0.000	0.476	0.840	1.066	1.184	1.227	1.219	1.178	1.114	1.032
	0.7	0.000	0.712	1.166	1.388	1.471	1.476	1.433	1.362	1.271	1.167
	0.8	0.000	1.107	1.594	1.749	1.767	1.720	1.637	1.533	1.415	1.289
	0.9	0.000	1.799	2.113	2.129	2.059	1.952	1.826	1.690	1.547	1.399
	1.0	0.000	2.833	2.667	2.500	2.333	2.167	2.000	1.833	1.667	1.500
Cot. hour of larger tide—cot. hour of smaller		0	⅓	⅔	1	1⅓	1⅔	2	2⅓	2⅔	3

Time by which maximum downward slope toward body having

TABLE 61.—*Difference in surface elevation for the two*

[The amplitude of the larger tide is taken as unity.]

Cot. hour of smaller tide—cot. hour of larger		0	⅓	⅔	1	1⅓	1⅔	2	2⅓	2⅔
		h	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*
Amplitude of smaller tide.	0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	0.1	0.9000	0.9017	0.9067	0.9148	0.9256	0.9389	0.9540	0.9703	0.9875
	0.2	0.8000	0.8038	0.8150	0.8329	0.8565	0.8848	0.9166	0.9504	0.9852
	0.3	0.7000	0.7065	0.7253	0.7552	0.7940	0.8392	0.8888	0.9407	0.9929
	0.4	0.6000	0.6100	0.6389	0.6835	0.7397	0.8036	0.8717	0.9415	1.0104
	0.5	0.5000	0.5150	0.5571	0.6197	0.6957	0.7792	0.8660	0.9529	1.0375
	0.6	0.4000	0.4222	0.4820	0.5664	0.6639	0.7672	0.8718	0.9744	1.0731
	0.7	0.3000	0.3336	0.4176	0.5269	0.6462	0.7682	0.8889	1.0055	1.1167
	0.8	0.2000	0.2536	0.3694	0.5044	0.6437	0.7819	0.9165	1.0454	1.1672
	0.9	0.1000	0.1933	0.3443	0.5009	0.6566	0.8081	0.9339	1.0929	1.2237
	1.0	0.0000	0.1744	0.3472	0.5176	0.6840	0.8452	1.0000	1.1472	1.2856
Cot. hour of larger tide—cot. hour of smaller		0	⅓	⅔	1	1⅓	1⅔	2	2⅓	2⅔

slope of the surface.

smaller tide precedes high water of body having larger tide.

[The amplitude of the larger tide is taken as unity.]

Cot. hour of smaller tide—cot. hour of larger	3⅓	3⅔	4	4⅓	4⅔	5	5⅓	5⅔	6
Amplitude of smaller tide.	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.1	0.184	0.173	0.157	0.137	0.114	0.088	0.059	0.030	0.000
0.2	0.359	0.333	0.298	0.258	0.212	0.162	0.110	0.056	0.000
0.3	0.523	0.478	0.424	0.363	0.297	0.229	0.153	0.077	0.000
0.4	0.674	0.610	0.537	0.457	0.371	0.282	0.189	0.095	0.000
0.5	0.812	0.729	0.637	0.539	0.436	0.330	0.221	0.111	0.000
0.6	0.938	0.836	0.726	0.612	0.493	0.372	0.249	0.125	0.000
0.7	1.053	0.932	0.806	0.677	0.544	0.410	0.274	0.137	0.000
0.8	1.156	1.018	0.878	0.734	0.589	0.443	0.296	0.148	0.000
0.9	1.249	1.096	0.942	0.787	0.630	0.473	0.316	0.158	0.000
1.0	1.333	1.167	1.000	0.833	0.667	0.500	0.333	0.167	0.000
Cot. hour of larger tide—cot. hour of smaller	3⅓	3⅔	4	4⅓	4⅔	5	5⅓	5⅔	6

smaller tide follows high water of body having larger tide.

ends of the strait at the time of maximum slope.

[The amplitude of the larger tide is taken at unity.]

Cot. hour of smaller tide—cot. hour of larger	3	3⅓	3⅔	4	4⅓	4⅔	5	5⅓	5⅔	6
Amplitude of smaller tide.	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*	*h*
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	1.0050	1.0221	1.0385	1.0536	1.0670	1.0785	1.0877	1.0945	1.0986	1.1000
0.2	1.0198	1.0532	1.0849	1.1135	1.1389	1.1603	1.1775	1.1899	1.1975	1.2000
0.3	1.0440	1.0928	1.1381	1.1790	1.2148	1.2448	1.2687	1.2860	1.2965	1.3000
0.4	1.0770	1.1397	1.1973	1.2490	1.2939	1.3315	1.3611	1.3827	1.3957	1.4000
0.5	1.1180	1.1931	1.2618	1.3228	1.3758	1.4198	1.4546	1.4798	1.4949	1.5000
0.6	1.1662	1.2523	1.3306	1.4000	1.4599	1.5097	1.5490	1.5772	1.5943	1.6000
0.7	1.2207	1.3165	1.4032	1.4798	1.5459	1.6007	1.6439	1.6749	1.6937	1.7000
0.8	1.2806	1.3849	1.4789	1.5620	1.6336	1.6928	1.7395	1.7730	1.7932	1.8000
0.9	1.3453	1.4569	1.5575	1.6463	1.7225	1.7858	1.8354	1.8712	1.8928	1.9000
1.0	1.4142	1.5320	1.6384	1.7320	1.8126	1.8794	1.9318	1.9696	1.9924	2.0000
Cot. hour of larger tide—cot. hour of smaller	3	3⅓	3⅔	4	4⅓	4⅔	5	5⅓	5⅔	6

TABLE 62.—*Pressure and density of sea water at various depths.*

Depths		Pressures				Height of homogeneous column	Densities	
Fathoms	Feet	Megadynes per sq. cm.	Atmospheres	Pounds per sq. in.	Pounds per sq. ft.		Surface=1	Surface=64 pounds per cu. ft.
0	0	0.9997	0.9866	14.500	2 088.0	0.00	1.00000	64.000
	1	1.0303	1.0168	14.944	2 152.0	1.00	000	000
	2	.0610	.0471	15.389	2 216.0	2.00	000	000
	3	.0916	.0773	15.833	2 280.0	3.00	000	000
	4	.1223	.1076	16.278	2 344.0	4.00	1.00001	000
	5	.1529	.1378	16.722	2 408.0	5.00	001	000
1	6	1.1836	1.1681	17.167	2 472.0	6.00	001	000
	7	.2142	.1983	17.611	2 536.0	7.00	001	64.001
	8	.2448	.2286	18.056	2 600.0	8.00	001	001
	9	.2755	.2588	18.500	2 664.0	9.00	001	001
	10	.3061	.2890	18.944	2 728.0	10.00	001	001
	11	.3368	.3193	19.389	2 792.0	11.00	001	001
2	12	1.3674	1.3495	19.833	2 856.0	12.00	1.00002	001
	13	.3981	.3798	20.278	2 920.0	13.00	002	001
	14	.4287	.4100	20.722	2 984.0	14.00	002	001
	15	.4593	.4403	21.167	3 048.0	15.00	002	001
	16	.4900	.4705	21.611	3 112.0	16.00	002	001
	17	.5206	.5008	22.056	3 176.0	17.00	002	001
3	18	1.5513	1.5310	22.500	3 240.0	18.00	002	64.002
	19	.5819	.5613	22.945	3 304.0	19.00	1.00003	002
	20	.6126	.5915	23.389	3 368.0	20.00	003	002
	21	.6432	.6217	23.834	3 432.0	21.00	003	002
	22	.6738	.6520	24.278	3 496.0	22.00	003	002
	23	.7045	.6822	24.722	3 560.0	23.00	003	002
4	24	1.7351	1.7125	25.167	3 624.0	24.00	003	002
5	30	1.9190	1.8939	27.834	4 008.0	30.00	1.00004	64.003
6	36	2.1028	2.0753	30.500	4 392.1	36.00	005	003
7	42	.2867	.2568	33.167	4 776.1	42.00	005	004
8	48	.4706	.4383	35.834	5 160.1	48.00	006	004
9	54	.6544	.6197	38.501	5 544.1	54.00	007	005
10	60	2.8383	2.8012	41.168	5 928.1	60.00	008	005
15	90	3.7577	3.7085	54.502	7 848.3	90.01	1.00012	64.008
20	120	4.6770	4.6160	67.838	9 768.6	120.01	016	010
30	180	6.5159	6.4308	94.510	13 609	180.02	024	015
40	240	8.3550	8.2456	121.18	17 450	240.04	032	020
50	300	10.194	10.061	147.86	21 292	300.06	040	025
60	360	12.034	11.876	174.54	25 133	360.09	047	030
70	420	13.873	13.692	201.22	28 975	420.12	055	035
80	480	15.713	15.507	227.90	32 803	480.15	063	041
90	540	17.552	17.323	254.58	36 646	540.19	071	046
100	600	19.392	19.139	281.27	40 489	600.24	079	051
150	900	28.594	28.220	414.74	59 708	900.53	1.00119	64.076
200	1 200	37.799	37.306	548.26	78 934	1 200.9	158	101
300	1 800	56.220	55.487	815.43	115 840	1 802.1	237	151
400	2 400	74.656	73.677	1082.8	155 930	2 403.8	315	202
500	3 000	93.106	91.886	1 350.4	194 460	3 005.9	394	252
600	3 600	111.57	110.11	1 618.2	233 030	3 608.4	472	302
700	4 200	130.05	128.35	1 886.3	271 620	4 211.5	550	352
800	4 800	148.54	146.60	2 154.5	310 250	4 815.0	627	402
900	5 400	167.05	164.87	2 423.0	348 910	5 419.1	705	451
1 000	6 000	185.57	183.15	2 691.6	387 590	6 023.5	782	501

TABLE 62.—*Pressure and density of of sea water at various depths*—Continued.

Depths		Pressures				Height of homogeneous column	Densities	
Fathoms	Feet	Megadynes per sq. cm.	Atmosphere	Pounds per sq. in.	Pounds per sq. ft.		Surface=1	Surface=64 pounds per cu. ft.
1 500	9 000	278.39	274.75	4 037.9	581 460	9 052.6	1.01167	64.747
2 000	12 000	371.57	366.71	5 389.4	776 070	12 094	546	990
3 000	18 000	558.94	551.65	8 107.3	1 167 400	18 209	1.02293	65.467
4 000	24 000	747.70	·737.93	10 845	1 561 700	24 368	1.03023	935
5 000	30 000	937.79	925.53	13 602	1 958 700	30 572	737	66.392
6 000	36 000	1 129.1	1 114.3	16 377	2 358 300	36 816	1.04436	839
7 000	42 000	1 321.8	1 304.5	19 171	2 760 700	43 103	1.05121	67.278
8 000	48 000	1 515.7	1 495.9	21 984	3 165 700	49 431	792	707
9 000	54 000	1 710.8	1 688.4	24 814	3 573 200	55 798	1.06451	68.129
10 000	60 000	1 838.1	1 882.2	27 661	3 983 200	62 206	1.07097	542

1 atmosphere = pressure of 76 cm. of mercury at 0° C. in latitude 45° at sea level; $g=32.1722$ ft. $-\frac{dv}{dp}\Big/v$ has been placed equal to $\frac{a}{1+bp}$ instead of $a(1-bp)$.

This table was computed with Professor Tait's constants, published in his Scientific Papers, Vol. II, p. 27.

Approximate expressions are: $p'=64\,y+0.0000422\,y^2$, $\rho=\rho_0\,(1+0.00001318\,y)$, p' denoting water pressure only.

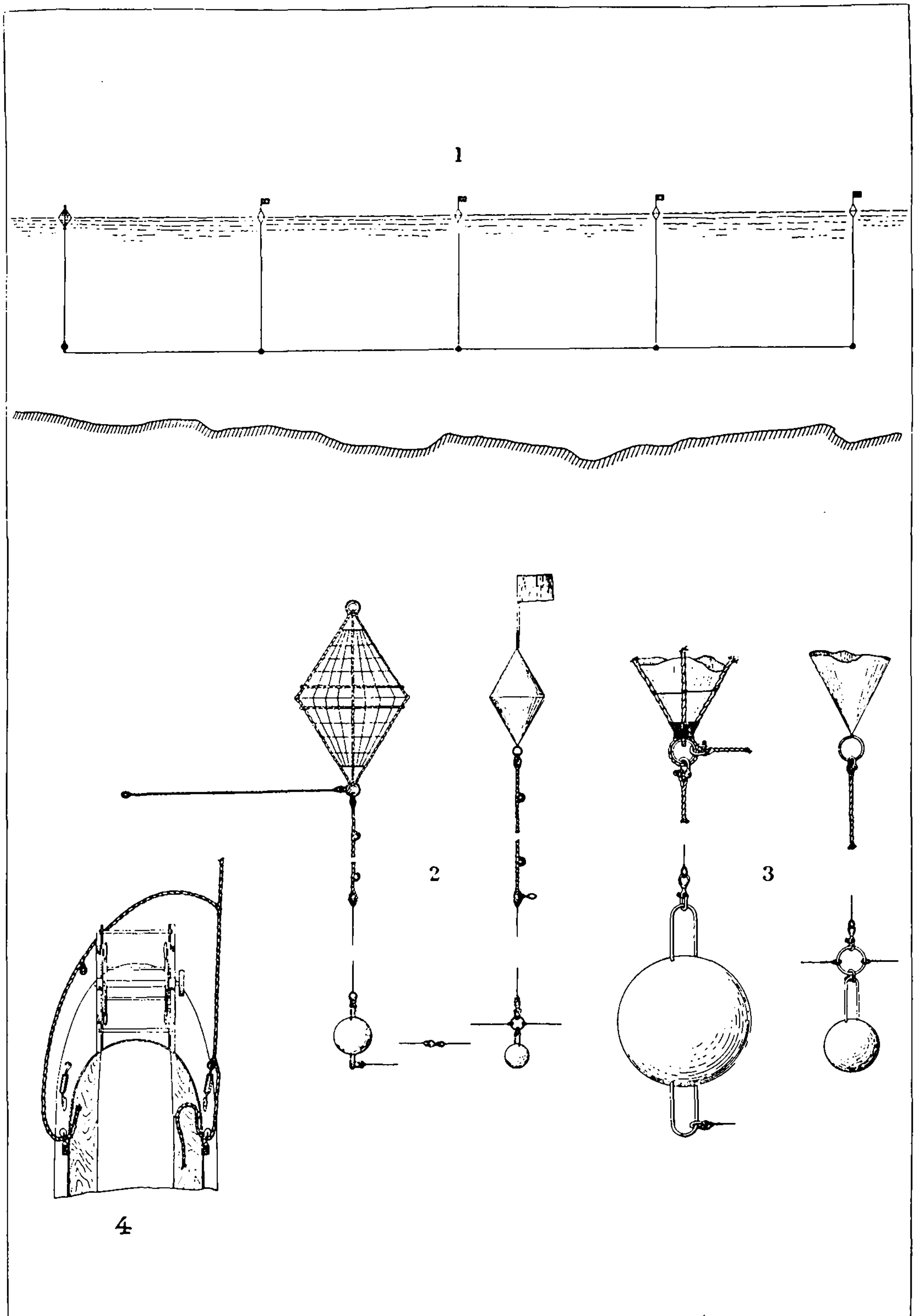
APPENDIX 7

REPORT 1907

LONG WIRE DRAG

By

N. H. HECK
Assistant



1. HALF SECTION OF 480-FOOT DRAG. 2. LARGE AND SMALL UPRIGHTS. 3. DETAILS OF UPRIGHTS. 4. ARRANGEMENT OF TOWLINE.

LONG WIRE DRAG.

By N. H. Heck, *Assistant.*

The success of the harbor and channel sweep, which was introduced in 1902, at once created an urgent demand not only for the dragging of the limited areas for which it was adapted, but also for the same class of work over areas too great to be covered economically by it. Happily, the use by the French hydrographic service of a seine-like device in dragging one of their harbors suggested the use of a single wire supported by buoys at short intervals. It was believed that such a form of drag could be operated in navigable channels without interfering with the passage of vessels, and that its depth below the surface could be regulated with a reasonable degree of certainty.

A wire drag 1 000 feet long, constructed in July, 1904, in accordance with this idea, is described in the Report of the Superintendent of the Coast and Geodetic Survey for 1905.* Since that article was written, experience in the use of the drag under highly dissimilar conditions has suggested improvements in the details of construction, in the methods of operation, and in the preparation of the final results. The drag has been tested by use in the deep water on the coast of Maine, and in the shoal water about Key West, Fla., and in all kinds of weather, and under the most varied conditions has proved its effectiveness in detecting all obstructions within the depth at which it is set. Pinnacle rocks which ordinarily escape the sounding lead are always revealed by it. It is equally effective in discovering uncharted bowlders, ledges, coral reefs, and heads. The statement that a region has been explored with a device which gives absolute assurance that no such obstruction can have escaped the surveyor gives a value to the chart that nothing in the past has afforded, and relieves the navigator of the mental strain that only those who have been charged with the safety of lives and property under the ordinary conditions can appreciate.

The rapidity with which large areas can be searched is one of the drag's great values. It can be operated at from 1 to 2 miles per hour, and, under the most unfavorable conditions that will permit of work, half a square mile can be covered in a day, while three times that area can be swept under favorable conditions. The drag can be used when hydrographic work with a single launch would be too hazardous to be permissible.

The drags that have proved most satisfactory are of the following lengths:

	Length of drag	Length of sections	Effective width		Power boats required
	Feet	*Feet*	*Meters*	*Feet*	*Number*
A	1 000	100	290	951	3
B	600	60	175	574	3
C	480	60	140	460	2
D	1 400	100			3

* Description of Long Wire Sweep, by D. B. Wainwright, Assistant, Appendix 6, Report for 1905.

The cost of the completed work has been computed as follows:

Locality	Drag used	Uncharted obstructions discovered, per square mile	Approximate cost, per square mile	Working days per month, average
		Number	*Dollars*	
Key West	C	2.5	600	10
Maine	A and B	0.5	180	20

In this is included the expense of superintendence, pay and maintenance of officers and men, transportation to and from the field, cost of material, hire and maintenance of launches, and all incidental expenses.

The drags A and D are used in open waters where existing surveys indicate no shoals with less than the depth sought. B is used to cover narrow areas outside of those covered with A, and near or among shoals. C is used for the same purpose as B, and is especially useful in narrow channels.

In order to avoid confusion the following definitions of terms used in this paper are given:

Length of upright: The distance from the center of the buoy to the bottom of the weight.

Drag depth: The distance between the surface of the water and the bottom wire of the drag while in use.

Effective depth: The distance between the plane of mean low water and the bottom wire of the drag while in use.

Depth to be verified: The depth, below the plane of reference, above which obstructions are sought.

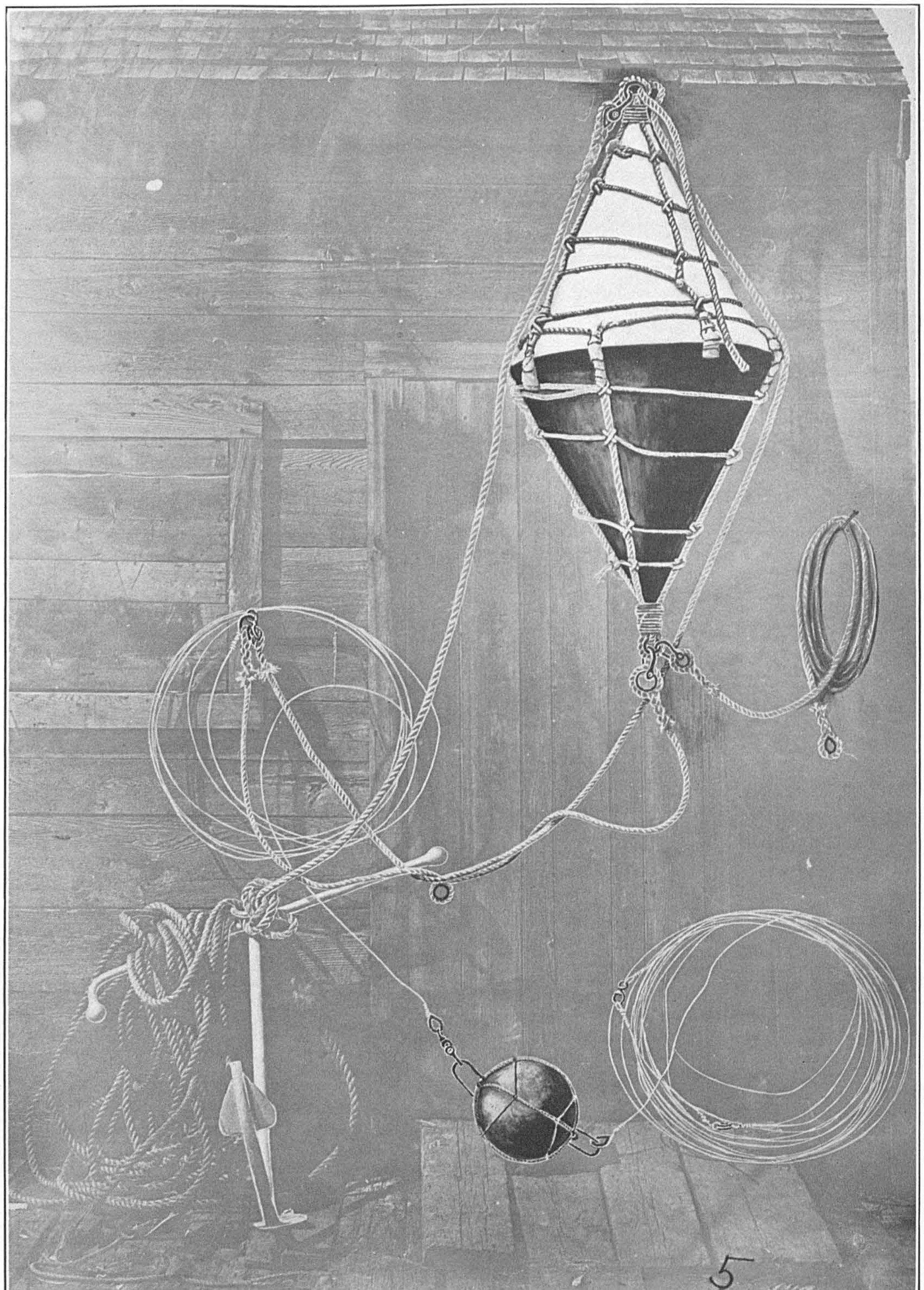
CONSTRUCTION.

The drag consists of a horizontal member composed of a number of sections of No. 10 American gauge galvanized wire, supported at intervals by vertical wires and buoys and provided with suitable weights. At the ends, and in the center when three launches are used, the buoys are of sufficient size to prevent their submersion when the device is being towed. The intermediate buoys are smaller and just sufficient to support the weight and leave their upper cones above water. Tow lines are attached at the lower points of the large buoys, and the weights and lengths of the vertical members are so proportioned as to keep the sweeping wire at the same distance below the surface throughout its length during the operation of sweeping.

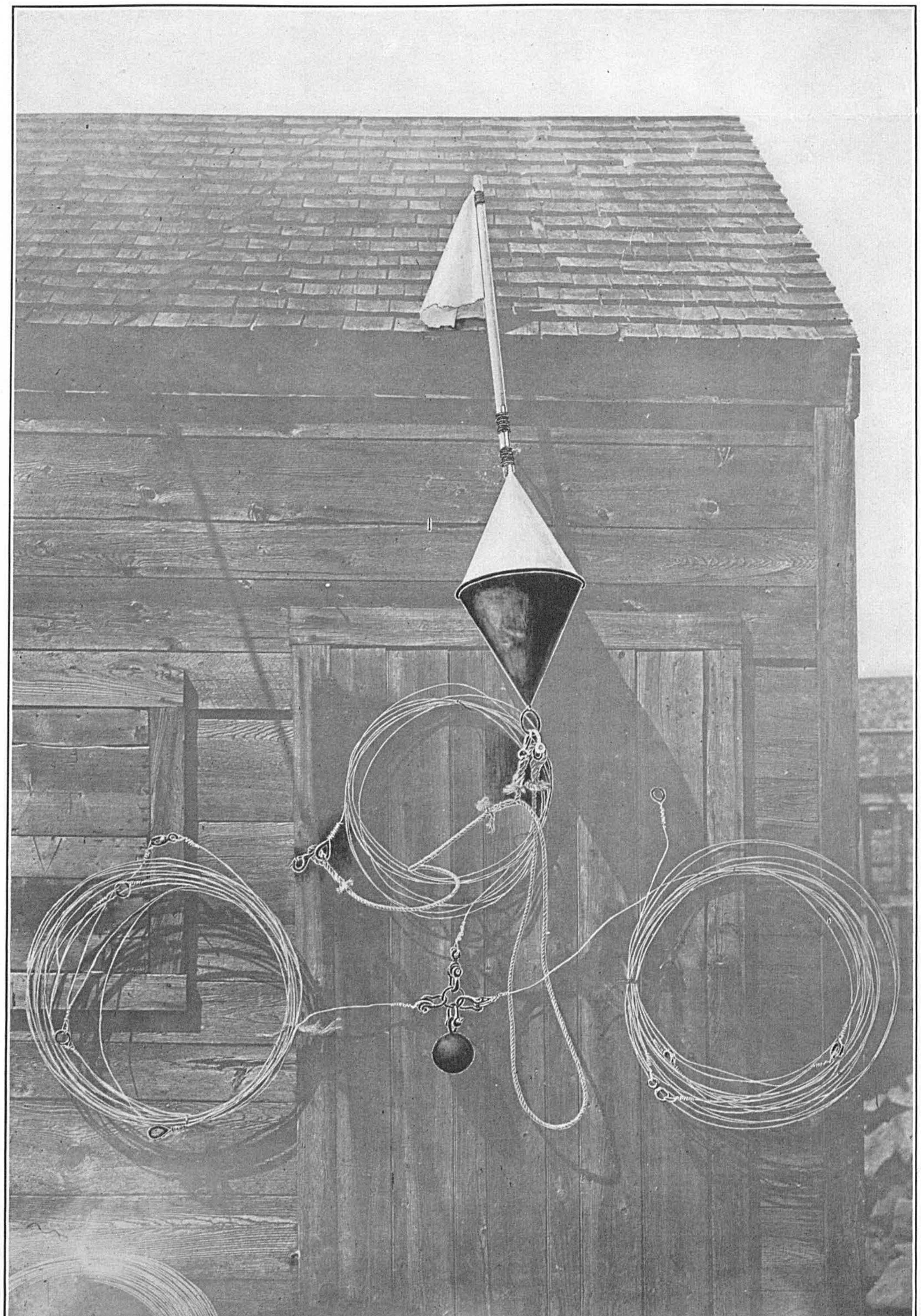
DIMENSIONS.

The length of the uprights of the drag depends on the locality, the range of the tide, the depth of the water, and the depth to be verified. For example, on the coast of Maine the conditions are: Generally deep water; mean range of tide, 10 feet; the depth to be verified, 36 feet at mean low water.

The results of a preliminary computation were tested by experiments and the lengths in feet of uprights adopted for the conditions on the coast of Maine, given



LARGE UPRIGHT AND CONNECTIONS.



SMALL UPRIGHT AND CONNECTIONS.

above, were 60–56, 56–52, and 52–48, the first number in each case referring to the large uprights, and the second number to the small uprights, the proper length to be used depending upon the state of the tide. In the vicinity of Key West, Fla., where the depth of the water exceeds but slightly the depth to be verified and the range of tide is 2 feet, in verifying depths of 35 and 30 feet at mean low water 42–42, and 37–37 were used.

MATERIALS.

Buoys.—The large buoys, one at each end of the drag, and one at the middle when three launches are used, are double cones, each cone 24 inches high and 24 inches in diameter at its base, strengthened by a 1-inch flange at the junction of the two cones and a stay rod running through lengthwise and projecting 2 inches at each end. These stay rods are provided with a head at one end and a thread and nut at the other, which aid in clamping the two cones together.

A galvanized-iron cap covers each end of the stay rod and is soldered to the cone. Two thimbles are strapped to the buoy in the manner shown in illustrations 3 and 5. The advantages of this arrangement are that the manila strapping gives great flexibility in a seaway, and the buoy is not liable to leak.

In illustrations 2 and 3 the method of attaching the towline is shown. The end section of the towline, 6 feet in length, is permanently attached by means of a wire rope thimble to the lower thimble of the buoy. When not in use the free end is fastened to the top of the buoy. The hoisting line (see illustration 5), which is used for changing the length of the uprights, is permanently attached to the lower thimble of the rope section of the upright. The free end is attached by a snap hook to a small ring on the upper part of the buoy, and it can be carried directly to a ring on the drum of the reel when it is desired to change the length of the upright. The anchor line (see illustration 5), when in use, is attached ot the top of the buoy by means of a thimble in shackles.

The small buoys are similar in construction to the large ones with cones, each 12 inches high and 12 inches in diameter. Galvanized-iron stay rods of one-fourth inch iron extend through the buoys with an eye below and projecting 6 inches at the top, where the flagstaff is attached. The stay rods are soldered to the buoys where they enter and leave them. These buoys do not leak even when pulled under.

Uprights.—The large upright is in two parts. The upper section is 8 feet long and consists of a 2-inch manila rope, with three thimbles at regular intervals. In changing the length of the upright, the thimble corresponding to the desired length is shackled to the bottom thimble of the buoy. The lower section of No. 10 American gauge wire, double galvanized, 0.107 inch in diameter, is attached to the lower thimble of the rope section by a round turn and Western Union joint, a form of connection used throughout. At the lower end of the wire there is a swivel, and this is shackled to the upper staple of the weight.

The large weight is a cast-iron ball with staples, as shown in illustration 3. Under the conditions met with on the Maine coast, balls 9½ inches in diameter, weighing 126 pounds, proved satisfactory, while on the Key West work balls 10 inches in diameter and weighing 140 pounds were found necessary. The heavier weights cause a greater strain on the buoys, but they make it possible to decrease the length of the uprights. The staples in each case are 4 inches high and of one-half inch round iron. The bottom wire is attached to the bottom staple of the large weight by a swivel and shackle. There is a swivel at the middle of each bottom section. At the intermediate uprights the connection is made as shown in illustration 3.

A more recent form of connection which has successfully stood trial deserves a brief description. A ring 2½ inches in diameter is cut and passed through the eyes of two swivels and a snap hook and then welded. The bottom wires are attached directly to the swivels, the small weight is attached to the snap hook, and the upright is shackled to the ring.

The intermediate or small uprights are similar to the large ones except in the following particulars: The rope section consists of 1-inch manila rope, and has a thimble at the upper end which is shackled to the bottom ring of the buoy. Snap hooks are used instead of thimbles at the middle and lower end of the rope section. The connection with the wire upright is made by means of a thimble. At the bottom the wire is attached to the ring by means of a swivel and shackle. The small weight is similar to the large weight except that there is a staple only at the top. The diameter is 4½ inches, the weight is 12 pounds, and the staples, of three-eighths inch iron, are 4 inches high.

TABLE 1.

Length of uprights.

	Large uprights		Small uprights	
	Maine	Key West	Maine	Key West
	Feet	*Feet*	*Feet*	*Feet.*
Buoy	2	2	1	1
Weight	1½	1½	½	½
Wire No 10	48	33	46	35
Rope	8	5	8	5
Fittings	½	½	½	½
Total	60	42	56	42

Towlines.—The construction and method of using the towline is clearly shown in illustration 4. The length from the spring balance on the boat to the point of attachment at the bottom of the buoy is 15 fathoms. The connection with the part of the towline attached to the buoy is made with a snap hook. A spring balance is secured on each quarter, and the towline is shifted from one to the other in swinging the boats. Anchors, weighing 40 pounds, with length of line suitable to the depth of the water, are used at each end of the drag for anchoring it when not in use.

The material required for a 480-foot drag, as used at Key West, Fla., with 60-foot sections, length of uprights 42–42, where the depth of the water but slightly exceeds the depth to be verified (in this case 35 feet), is shown below:

TABLE 2.

EACH END UPRIGHT AND SECTION.

A. Buoy with fittings:
- 1 buoy, height 52 inches, diameter 25 inches.
- 2 thimbles, 2-inch, round.
- 42 feet of 1-inch manila rope, for straps.
- 108 feet of ½-inch manila rope, for straps.
- 2 square feet of rigging leather between buoy and thimble.
- 1 shackle, ½-inch at top, for anchoring.
- 2 shackles, ¾-inch at bottom, for upright and towline.

B. Rope, and wire sections with fittings:
- 6 feet of 2-inch manila rope.
- 33½ feet of No. 10 gauge double galvanized wire.
- 2 thimbles (wire rope), ¾-inch groove.
- 2 thimbles (rope), 1-inch, round.
- 2 thimbles, 1-inch, round, split (for wire).
- 1 swivel, 2 inches.

C. Weights:
- Diameter 10 inches (cast iron).
- Staples, 4 inches high, ½-inch round iron.
- 2 shackles, ⅜-inch.

D. Bottom wire, end section:
- 30 feet of No. 10 Am. gauge double galvanized wire.
- 2 thimbles, ½-inch, round, split.
- 1 swivel, 2-inch.

EACH INTERMEDIATE SECTION

A. Buoy with fittings:
- 1 buoy, height 24 inches, diameter 12 inches
- 1 ring, 2-inch, formed in stay rod at bottom.
- 1 rod, extending 6 inches above top of buoy.
- 1 flag, 1 foot square, black cloth, attached to stick 1 foot long to be lashed to rod and weighted at top.
- 1 shackle, ¼-inch

B. Rope and wire sections with fittings:
- 6 feet 1-inch manila rope.
- 35 feet of No. 10 gauge double galvanized wire.
- 2 thimbles (wire rope) ½-inch groove.
- 2 thimbles (rope) 1-inch, round.
- 2 thimbles (wire) 1-inch, round.
- 1 swivel, 2-inch.

C Weight:
- Diameter 4½ inches of cast iron.
- 1 staple, 4 inches high, of ⅜-inch round iron.

D. Bottom wire:
- Two 30-foot sections No. 10 gauge double galvanized wire.
- 4 thimbles, ½-inch, round, split.
- 1 swivel, 2-inch.
- 2 shackles, ¼-inch.
- 1 ring, 2½ inches in diameter

TOWLINE.

150 feet of 1-inch manila rope.
4 thimbles (wire rope) ¾-inch groove.
2 blocks, 2-inch diam.
2 spring balances, graduated to 5 pounds up to 200 pounds

FOR ANCHORING, AT EACH END.

15 fathoms of 1½-inch manila rope.
2 thimbles (wire rope) ¾-inch groove.
2 shackles, ⅜-inch.
1 anchor, 40 pounds.

LAUNCHES.

Covered gasoline launches, 28 to 34 feet in length, with 9 to 13 horsepower engines are used.

The middle launch carries a drafting table, reel, and drag. The boat shown in illustration 7 is an ideal center launch. Each of the end launches carries a reel, but no drafting table, and may be smaller than the middle launch. Two small boats are in constant use as tenders. The gasoline engines are not so reliable as steam, but the economy of space for a given size and speed of launch makes them very convenient. It is usually necessary to construct a working platform and to place towing cleats on the launches. (See illustration 7.)

The reel is made of wrought iron. Its essential parts are a drum with handles and a brake wheel on the same shaft, a supporting frame, and a roller over which the wire passes.

The party consists of two officers, a coxswain, and line tender for each launch, except the guiding launch, which, in addition, carries a foreman, who supervises the work of setting out the drag and of repairing it when necessary.

ASSEMBLING AND OPERATING.

For assembling, a wharf where there is sufficient room to stretch out the parts is used. Illustration 8 shows the men at work constructing a drag under the direction of the officers of the party. Pegs are set at the proper distances, and the finished uprights and ground wires are made to correspond. In cutting the wire and rope, one foot must be allowed for each joint and splice.

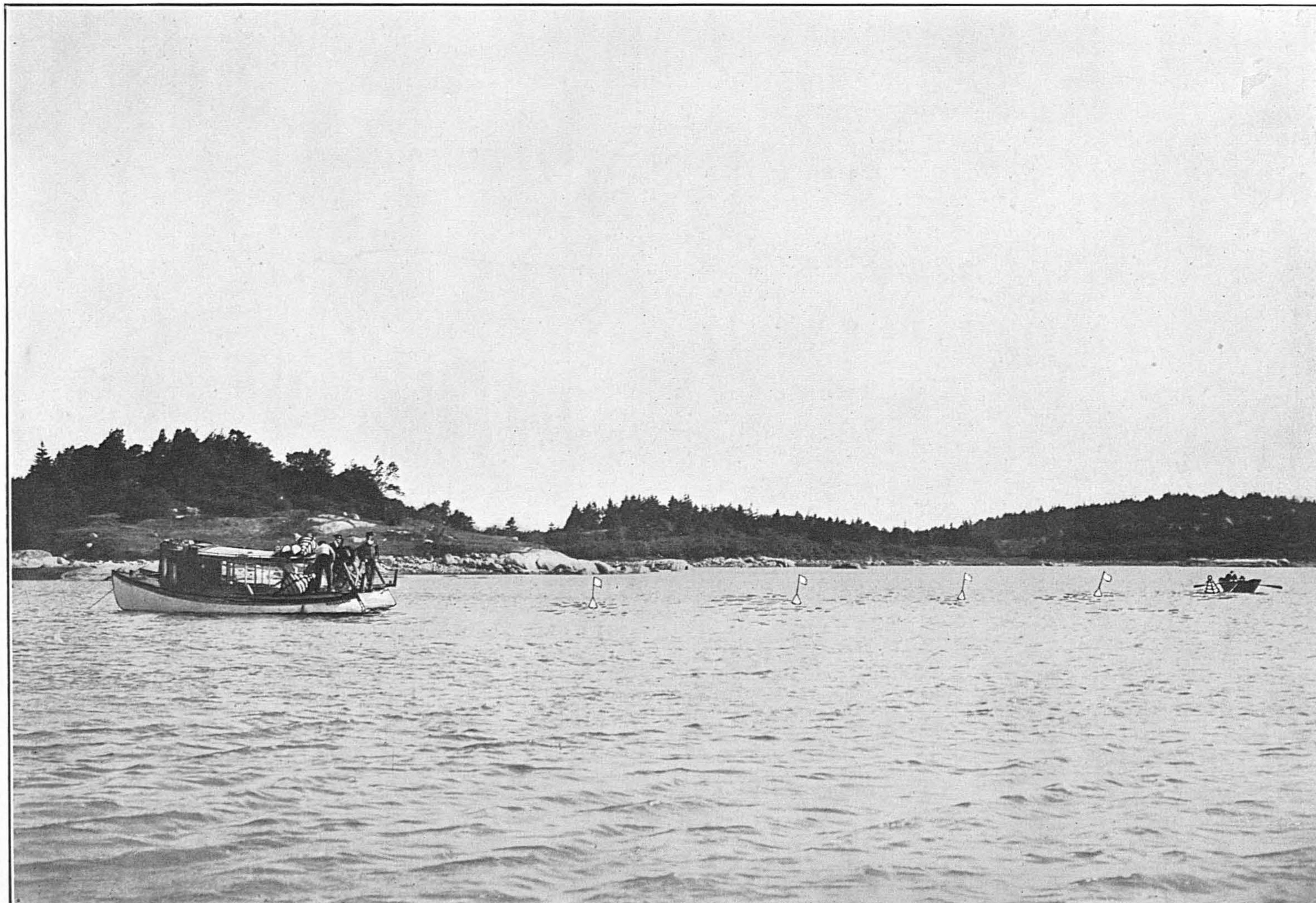
When completed this portion of the drag is placed on the reel in the following order: End upright, first section of bottom wire, intermediate upright, and second section of bottom wire, each intermediate section being wound on the drum of the reel with the corresponding section of the ground wire, and this process is continued until the entire drag is on the reel. The free end of each upright is made fast to the bottom wire to keep it separate from the other sections. Spare parts, properly tagged, are carried in each launch.

Setting out the drag (illustration 9) is the reverse of the process just described. The buoys and weights are attached in their proper places as the wire is unreeled, one man seeing that the uprights are kept clear of the bottom wire. Chain hooks are used to handle the heavy weights, and marline spikes and pliers are used to turn the pins of the shackles.

MIDDLE LAUNCH.

No. 8.

CONSTRUCTING THE DRAG.



SETTING OUT THE DRAG.

No. 10.

DRAG IN USE.

In setting out it is necessary for one of the launches or small boats to tow the drag against the tide, or in a strong tide to anchor and hold it to prevent its drifting on shoals. This operation requires about thirty minutes for a 600-foot drag.

The work of running lines with the drag so as entirely to cover an area is much more difficult than running lines with a sounding boat. Cooperation between the launches is necessary. The plotting is done in the middle launch, which directs the movements of the others. The end launches (see illustration 10) keep at the proper distances from the middle launch, changing course when it does, but preserving the proper pull on the spring balance. At the end of the lines signals, usually made with flags, are given from the middle launch to indicate the necessary maneuver to reach the next line. Megaphones are used in case of a misunderstanding. The necessity of overlapping lines, and of keeping the drag clear of the charted shoals, and the strong relative effect of wind and tide, make the conditions rigid. However, with experienced officers and men, complicated maneuvers can be made without missing any area.

At the end of a line in deep water, the drag is towed to the next line. In shoal water it is turned back on the same line, both of the end launches turning outward, and keeping a sufficient tension to prevent grounding the drag. After the turn is completed the drag is kept in a diagonal direction until the next line is reached. In case of a sharp turn in a line the outer launch comes in a little toward the middle launch during the turn. This increases her speed and enables her to reach her new position more quickly. If the inner launch turns directly away from the middle launch at an angle of about 120° from the direction taken by the middle launch, and retains this direction until she reaches her proper distance, and then follows the new direction, no area will be missed in turning. Sextant angles to determine positions are taken in all the launches without any effort to make them simultaneous. Angles are taken every four minutes by each pair of observers when running on straight lines, but on the turns they are taken more frequently and at such intervals that the path of the drag will be known.

The changes in the pull on the spring balance can be made by changing the speed of the engine. At slow speeds difficulty is found in regulating the speed of a gasoline engine, without danger of its stopping at a critical moment. This is obviated in the following manner:

A wooden frame in the shape of an equilateral triangle with sides 3 feet long is towed astern of each launch. When at rest, this floats with the vertex down, a weight being attached at that point, so that the base is at the surface of the water. Lines from each end of the base extend to a crowfoot, made by splicing the lines to a thimble. From this thimble a line extends to the boat, where it passes through two small blocks, and thence back to the crowfoot and through the thimble to the vertex of the speed regulator. (See illustration 11.) By means of a lever this speed regulator can be set at any inclination, and the resistance varies from a maximum of about 30 pounds at the usual speed to a practically negligible amount when it is horizontal.

The drag depth is regulated by the pull on the spring balance. A memorandum showing the hourly tides (prepared from the tide table, using table for hourly tides) with the proper pulls for each hour, and the times of changing pull, is furnished to the officers in charge of launches each morning. (See Table 7, p. 560.) For the final reduction of drag depths to effective depths, tide observations are made as in ordinary hydrography.

The effective depth for any given pull is measured by using a lead line graduated to feet, with the lead pointed at the top, so that it will not catch on the wire. A small boat goes ahead of the drag, and the lead line is dropped in the path of any desired section, at a depth several feet greater than that anticipated. As the wire is felt, the lead line is raised until the lead passes clear of the wire, when the depth is noted. It is found that for the form of drag described above the depth varies very little throughout its length. The minimum depth so determined is adopted as the drag depth. One-half hour is sufficient time to test a 1 000-foot drag.

When a shoal is struck, there are three ways in which the fact is indicated: By the tipping over of the nearest small buoys as the bottom wire comes to rest, by sudden very marked fluctuations of the pointer on the spring balance, and by a sudden increase of the pull and the stopping of the launches. As soon as the drag is aground, one launch disconnects its tow line and, accompanied by the two small row boats, proceeds to the locality indicated, and determines the least water on the shoal by sounding over the shoal area, positions being located by angles. The determination of positions is greatly facilitated by the buoys on the drag. (See illustration 12.) After the least water is found an attempt is made to remove the drag from the shoal by raising the parts which are aground by means of launches and small boats, and towing it off with one of the launches. If it is impossible to get it clear in this way, the drag is taken up, and if the wire is broken the necessary repairs are made before setting out the drag again in deep water. In making repairs a broken upright must be replaced, but a bottom wire may be spliced temporarily. Occasionally the wire breaks while the drag is in use, and in order to avoid doubt the area affected must be covered again.

At the close of each day the drag is anchored by carrying out anchors from each end and dropping them with 3 to 4 fathoms of slack line. The ends are shackled to the tops of the buoys as stated above. In this position the drag will ride out a gale without damage. Bad weather, when it is impossible to operate the drag, is utilized in making the necessary repairs and in constructing new sections to replace those worn out.

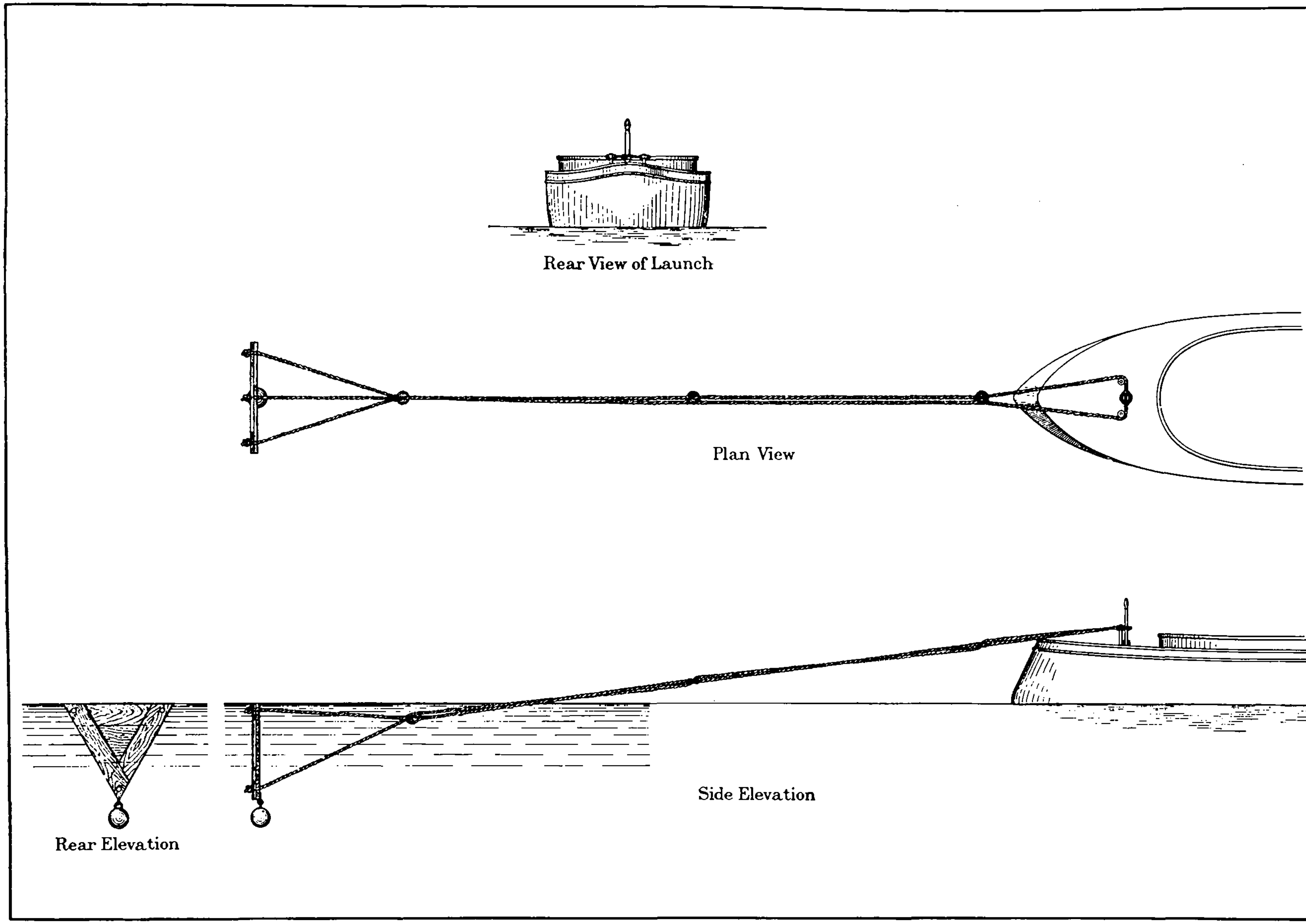
Under ordinary conditions certain of the galvanized portions of the drag become corroded after being in use for six weeks, and then rapidly lose their strength. In the vicinity of Key West, Fla., where it was not an unusual occurrence to ground the drag on shoals four times in one day, it was necessary to replace the wire after using it for two weeks.

Computation of the Drag Depths.

For the purpose of illustration the form of drag described as B on page 551 is analyzed. Length 600 feet, 60 feet sections, large weights, 126 pounds, lengths of uprights 60–56, 56–52, and 52–48.

The areas exposed to resistance are assumed as follows:

Buoys, triangular area of lower half. This would probably be too much if the surface of the large buoys were smooth, but the strapping and various fittings probably make it nearly correct.



DRAG FOR REGULATING THE SPEED OF THE BOATS.

No. 12.

DRAG CAUGHT ON A SHOAL.

Weights.—The effective area of a sphere exposed to the resistance of water may be assumed as one-half the area of the great circle.

Wire and rope.—The area of the circumscribed rectangle is assumed as correct.

Fittings.—The area is taken as three-fourths of the sum of the circumscribed rectangles for each part.

Towline.—This, for the end launches, is taken as one-half its length × its diameter × cos. 45° (the approximate angle between the direction of the towline and the direction of the progress of the drag). For the middle launch the resistance of the towline is negligible, as the direction of the towline is the same as the direction of the drag.

TABLE 3.

Areas exposed to resistance, and weight in water.

	Large uprights			Small uprights	
	Dimensions		Weight in water	Dimensions	Weight in water
	Middle	End			
	Sq. feet	*Sq. feet*	*Pounds*	*Sq. feet*	*Pounds*
Buoy	2.0	2.0	+	0.5	—
Weight	0.24	0.24	110.0	0.055	10.5
Rope	0.42	0.42	0.2	0.21	0.1
Wire (48+60)	0.97 (48+30)	0.70	2.7	0.95	2.7
Fittings	0.10	0.10	2.5	0.10	2.5
Towline	neglect	0.83			
Total	3.73	4.29	115.4	1.815	15.8

The diameter of the wire is 0.107 inch = 0.009 foot; of the rope for the large uprights, 0.052 foot; for small uprights, 0.026 foot.

The principle upon which the computation of the drag depth is based is that the middle launch tows the quarter section of the drag on each side of it, or one-half the drag, and that the pull (P) of the launch divided by the resistance of this part of the drag (R) is equal to the resistance in pounds per square foot of the area exposed to resistance (r).

Then $R = 3.73 + 4 \times 1.815 = 10.99$ square feet

and $r = \dfrac{P}{10.99}$.

In Trautwine's Engineers' Pocket Book it is stated that "The resistance of water against a flat surface moving through it at right angles is nearly as the square of the velocity, and according to Hutton its amount in pounds per square foot, approximately, equals the square of velocity in feet per second."

Consequently it is assumed that V (the theoretical velocity of the drag in feet per second) is approximately equal to the square root of r.

V_2 (the actual velocity of the drag for different conditions of the tidal currents) is scaled from a hydrographic sheet covering an area which has been investigated and represents the mean of a large number of measurements. The resulting values are given for comparison in the following table:

TABLE 4.

P	r	V_1		V_2 (in nautical miles per hour)		
		Feet per second	Nautical miles per hour	Fair tide	Slack tide	Head tide
100	9.10	3.02	1.79	1.60		
120	10.92	3.30	1.95	1.90	1.41	0.95
140	12.74	3.57	2.12	2.02	1.60	1.15
160	14.56	3.82	2.27	2.06	1.76	1.36
180	16.38	4.05	2.40		2.04	

By taking the means of V_1 and V_2 for corresponding cases, it is found that $V_2 = C\ V_1$, where C is constant. For fair tide $C=0.93$, for slack tide 0.78, and for head tide 0.55. The mean for fair and head tide, 0.74, shows very close agreement with that for slack tide.

Illustration 13 indicates the manner in which the drag depth at the middle large upright is computed. The system is considered as in equilibrium about the bottom of the large buoy, and the moments are taken about this point, the various resistances being kept in equilibrium by the large weight. All resistances and weights, except the resistance of the rope and wire sections of the upright, are assumed to act at the bottom of the large weight. Then $115.4 \times 58 \sin A = [(7.26+0.24+0.10+0.54)\ 58 + (0.44 \times 32\tfrac{1}{2}) + (0.42 \times 4)]\ r \cos A$

and
$$\tan A = 0.073\ r$$

when A is the angle of inclination of the upright and $d=D \cos A$, where D= length of upright, and d= computed drag depth.

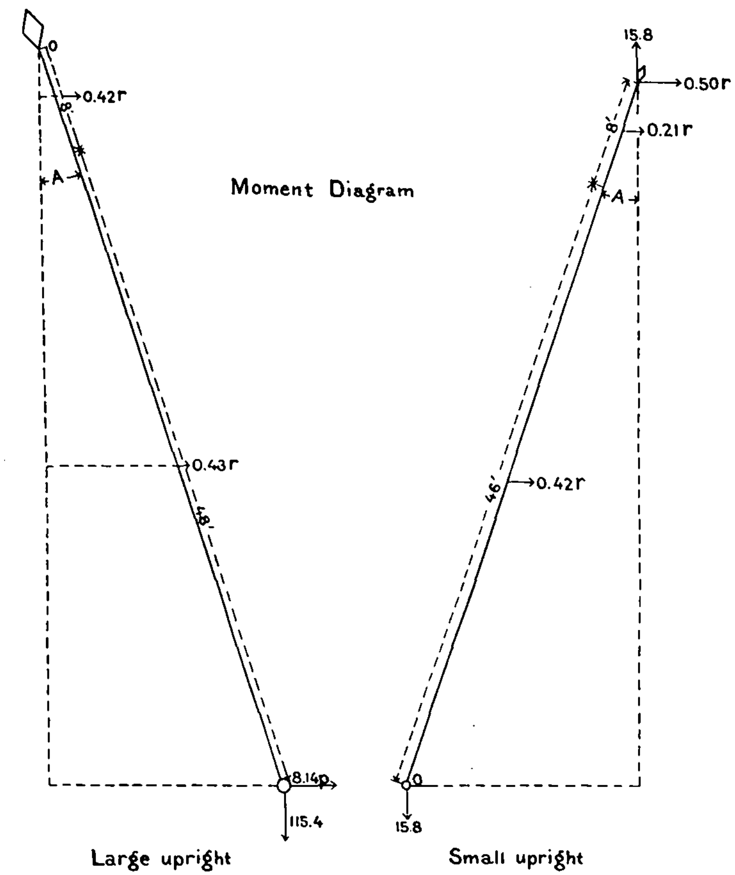
The following table gives the values of A, and d for given values of D, also for the sake of comparison the measured drag depths:

TABLE 5.

P=Pull on scale	Nat. tan A	A	Computed depths			Measured depths		
			D=60	D=56	D=52	D=60	D=56	D=52
100	0.664	33° 35′	50.0	46.6	43.3		47	43
120	0.797	38 33	46.9	43.8	40.7		44	40
140	0.930	42 55	43.9	41.0	38.1	45	42	38
160	1.063	46 45	41.1	38.4	35.6	42	39	
180	1.196	50 06	38.5	35.9	33.3	40	37	

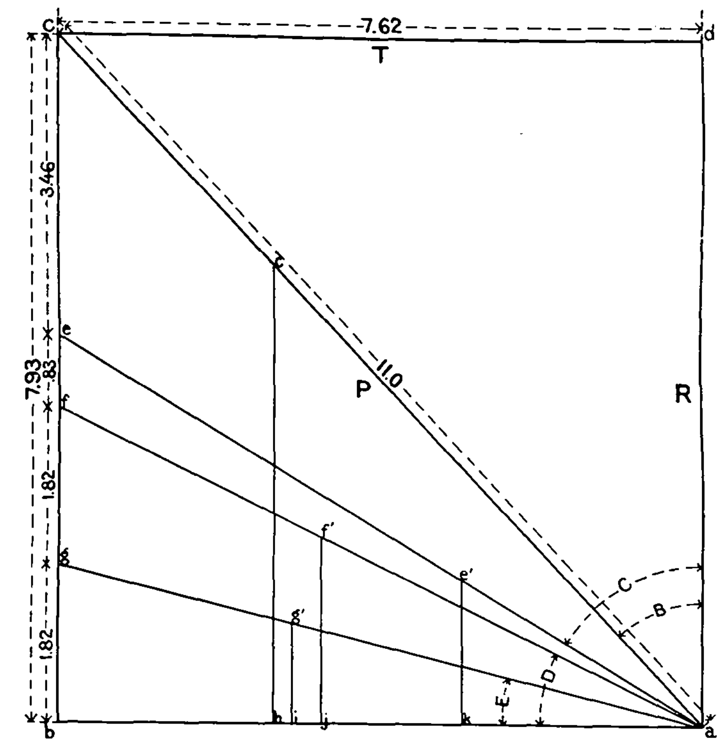
The depth at the end uprights is obtained by the same method, the pull (P) is the same, and the angle (C) between direction of progress of the drag and the vertical plane

No. 13.



Moment Diagram.

No. 14.



Direction, Distance, and Stress Diagram

of the end upright is obtained as shown in illustration 14. Each end launch is assumed to tow one-quarter of the drag, and preserves the necessary tension to keep the drag in its proper position.

Then

$$115.4 \times 58 \sin A = (4.24 \times 58 + 14.5 + 1.7) r \cos A \sec C$$
$$\tan A = 0.0390 \sec C\, r$$
$$\sec C = 1.976$$
$$\tan A = 0.077 r$$

This makes the computed drag depth ½ to 1 foot less than at the middle upright. As the measured drag depth is the same as at the middle uprights, a slight error in the assumptions is indicated. The drag depth at the intermediate uprights is obtained by taking moments about the bottom weight, the resistances of the upright being held in equilibrium by the vertical reaction at the small buoy equal to the weight.

Then

$$15.8 \times 55 \sin A = (0.5 \times 55 + 0.21 \times 51 + 0.41 \times 23) \cos A$$
$$\tan A = 0.0540\, r$$

TABLE 6.

Computed drag depths at small uprights

Pull	tan A	A	$D=56$	$D=52$	$D=48$
		° ′			
100	.499	26 32	50.1	46.5	43.0
120	.598	30 53	48.0	44.6	41.2
140	.698	34 55	45.9	42.6	39.4
160	.798	38 35	43.8	40.7	37.5
180	.898	41 55	41.7	38.7	35.7

The measured values are the same as in Table 5. The method used above is approximate, but it is sufficiently accurate for the purpose of comparison. The true form of all parts of the wire is a curve, but the change in length due to this cause is negligible.

In illustration 14, the directions, distances, and stresses in the drag are shown in one diagram. The values given are for the drag discussed above, but the method is applicable to one of any length.

P = pull in lbs. = $K_1 r$ represented by line ac

R = resistance of ¼ of the length of the drag = $K_2 r$ represented by line bc

T = tension throughout drag = $K_3 r$ represented by line ab

where K_1, K_2, and K_3 are constants depending on the length and the form of the drag.

Then ce = area from the middle of the towline to the middle of the large upright.

ef = area from the middle of the large upright to the middle of the first bottom section.

fg = area from the middle of the first section to the middle of the second section.

gh = area from the middle of the second section to the middle of the third section.

TABLE 7.

	Direction	Length	H	V	Stress
		Feet.	*Feet.*	*Feet.*	
Towline	ac	$ac'=90$	$ah=62$	$c'h=65$	ac
End upright	ae	$ae'=42$	$ak=36$	$e'k=21$	ae
First section	af	$af'=60$	$aj=54$	$f'g=26$	af
Second section	ag	$ag'=60$	$ai=58$	$g'i=14$	ag
Third section	ab	$\frac{1}{2}ag'=130$	$\frac{1}{2}ag=30$	$0=0$	ab
			240	126	

In the table, V is the horizontal component of the length of each section in the direction of the progress of the drag, and H is the component normal to this direction. $ac'=D \sin A$, where $\tan A=.077\,r$. In this case the r is taken from Table 4, for $P=140$. The width between the boats is then $2(62+39)+4\times54+4\times58+2\times60=764$ feet $=$ 233 meters.

Effective width of drag $=568$ feet $=175$ meters.

The necessary overlap of lines when the boats are at their full distance (233 meters) is 60 meters, when the drag is properly extended. The greatest ordinate of the curve of the bottom wire from the boat is 40 meters, which indicates the position of the bottom wire of the drag with reference to the positions of the boats.

By following this general method, any form of drag may be analyzed, and the drag depth obtained approximately. This is of great advantage in designing a drag to meet special conditions.

TABLE 8.

Measured drag depths

Pull	1000-foot drag, 100-foot sections, 3 launches			600-foot drag, 60-foot sections, 3 launches			480-foot drag, 60-foot sections, 2 launches	
	60–56*	56–52*	52–48*	60–56*	56–52*	52–48*	42–42*	37–37*
100		48	44		47	43		
120		46	42		44	40	37	32
140	47	44	40	45	42	38		
160	45	42	38	42	39			
180	43	40		42	37			

* Length of uprights.

The values given above are entered in the record as the drag depths, and by applying a correction for tide to them, the effective depths are obtained. It is necessary to obtain a similar set of values, by actual measurement, for every form of drag used.

The memorandum of tides and pulls which is furnished to each boat every day, must be derived from the tables similar to those given above, and from the tide tables, by allowing such a margin of safety that the effective depth will always exceed the depth to be verified.

TABLE 9.

Memorandum for a 600-foot drag, 60-foot section, 3 launches

Time	Heights of tide	Pull 56-52*	Time	Heights of tide	Pull 56-52*
a. m.			p. m.		
7	9.0	110	12.30		170
8	8.9	110	1	0.7	180
9	7.8	120	2	0.8	170
9.30		130	2 30		160
10	6.1	140	3	2.3	150
11	4.1	140	4	4.2	140
11.30		150	4.30		130
			5	6.4	130
12	2.2	160			

* Length of uprights.

For length of upright 60–56 pull 20 pounds more, and for 52–48 pull 20 pounds less.

RECORD AND PREPARATION OF FINAL RESULTS.

A page from the record is reproduced below, which shows the method of recording while the drag is in use and when a shoal is found:

N. H. HECK, assistant in charge, 4 R, sextant No. 267.

G. A. STANTON, aid, observer and recorder, sextant No. 216.

W. P. GOMEZ, hand, coxswain; T. HUTCHINSON, hand, line tender.

Sextants, clocks, and lead lines correct.

Left wharf at 7.05 a. m., reached working grounds, distant 7 miles, at 8 a. m., and took up anchor of drag.

Drag.—Length, 600 feet; 60 ft. sections. Length of uprights, 56–52.

Tide gauges.—Stonington, Me., H. Ware, observer; Burnt Coat Harbor, Me., T. Smith, observer. Reducers for A day entered from Stonington, tide gauge.

Weather.—Clear; calm.

12770—07——36

Locality. *Sublocality.*

SOUNDINGS: Coast of Maine. Year, 1907; month, July; day of month, 22d. Jericho Bay. Boat used, No. 1. A* day.

	Time Mer. 75 a.m.	Soundings Feet	Soundings Tenths	Red. for tide, feet.	Reduced soundings Pull, feet	Reduced soundings Drag depth, tenths	Bottom, effective depth		Boat's head by compass	Angles and ranges	Remarks and course
	h. m. s.										
< 1	8 15	......	....	5.1	140	42	36.9	< 1	N. by W.	Spruce to Mark 70 Hal 34 68 37	Line begins at < 1, port side of drag.
< 10	8 51	......	....	7.9	110	45.5	37.6	< 10	S.	Cask to Egg 38 Long 40 51 17	Turned back on line. Starboard side of drag.
< 14	9 03	......	....	8.4	110	45.5	36.9	< 14		Cask to Egg 36 Hal 10 40 17	Drag aground near middle launch. Launch and two boats sounding on shoal.
	Drag aground on uncharted shoal.										
< 15	9 30	34	0	8.7	25	3	Rky.	< 15		Cask to Egg 35 Hal 20 41 10	< 15. Position of least water.
	The shoal is a small pinnacle rock.								At 9.30 removed drag from shoal, and broke end upright. Repaired drag and set it out again; resumed work at 10.		
< 102	4 32	......	....	1.2	160	39	37.8			Cask to Egg 24 Long 40 50 37	Line ends at < 102.
	Number of miles, 10.5. Number of angles, 204. Number of soundings, 7.								End of day's work. Anchored drag and proceeded to wharf, distant 6 miles.		

A smooth hydrographic sheet is furnished to the field parties, with the limiting curves and such soundings as will be useful in keeping the drag from grounding on charted shoals plotted on it. In Maine, where the shores and edges of shoals are generally bold, and the depth to be verified is 36 feet, the 8-fathom curve is shown. In the vicinity of Key West, where the general depth is 37–42 feet, and the depth to be verified is 35 feet, the 35-foot curve is shown. Lines showing the positions of the middle launch are drawn on the boat sheet, and those for the end launches are drawn on the smooth sheet.

A color is assigned to each boat, and the lines of each boat are always plotted in its proper color. After the work has been plotted on the smooth sheet, the question of the overlapping of the lines is carefully considered, and in case of doubt the area affected is transferred to the boat sheet and covered later.

ALPHABETICAL INDEX.

(Exclusive of Appendices 3 to 7.)

LIST OF PUBLICATIONS OF THE COAST AND GEODETIC SURVEY (EXCEPT MAPS AND CHARTS), JANUARY, 1903, TO DECEMBER, 1907, INCLUSIVE.

This list supplements the "List and Catalogue of the Publications of the United States Coast and Geodetic Survey, 1816–1902." The list and catalogue and all of the publications listed here, except Coast Pilots and Tide Tables which are sold at the cost of paper and printing, may be obtained free of charge upon application to the Superintendent of the Coast and Geodetic Survey, Washington, D. C.

The publications of the Coast and Geodetic Survey consist of Annual Reports, Appendices to Annual Reports, Charts (the charts are listed biennially in the Catalogue of Charts, Coast Pilots, and Tide Tables, and therefore will not be listed here), Coast Pilots, Sailing Directions for the Philippine Islands, Notices to Mariners (until January 1, 1908, see below under Notices to Mariners), Tide Tables, Bulletins, separately issued Publications and Chart Catalogues.

ANNUAL REPORTS.

These consist of a review of the progress of the work during the year in the field and in the office. Professional papers relating to methods and results are published with the reports, and also published separately.

Report of the Superintendent of the Coast and Geodetic Survey, showing the progress of the work for the years 1902 (799 p.), 1903 (1032 p.), 1904 (774 p.), 1905 (347 p.), 1906 (230 p.), and 1907 (565 p.).

APPENDICES TO ANNUAL REPORTS.

The appendices, with the exception of appendices 1 and 2, for each year, which contain details of field and office operations, are here arranged under the various subjects of which they treat:

GEODESY.

Telegraphic longitudes. The Pacific arcs from San Francisco to Manila, 1903–4. By E. Smith. 13 illus. Report for 1904. Appendix 4.

A test of a transit micrometer. By J. F. Hayford. Report for 1904. Appendix 8.

Six primary bases measured with steel and invar tapes. By O. B. French. Report for 1907. Appendix 4.

A bibliography of geodesy. Second edition. By J. H. Gore. Report for 1902. Appendix 8.

Precise leveling in the United States, 1900–1903. By J. F. Hayford. 2 views, 14 maps and sketches, 6 diags. Report for 1903. Appendix 3.

Precise leveling from Red Desert, Wyoming, to Owyhee, Idaho, 1903. By J. F. Hayford. Report for 1904. Appendix 6.

Precise leveling from Holland to New Braunfels, Tex., 1903. By J. F. Hayford. Report for 1904. Appendix 7.

Precise leveling from Red Desert, Wyoming, to Seattle, Wash., 1903–4. By J. F. Hayford. Report for 1905. Appendix 4.

Triangulation in Kansas. By J. F. Hayford. 5 sketch maps. Report for 1902. Appendix 3.

Triangulation southward along the ninety-eighth meridian in 1902. By J. F. Hayford. 5 views, 5 maps and sketches, 5 diags. Report for 1903. Appendix 4.

Triangulation in California. By A. L. Baldwin. 21 illus. Report for 1904. Appendix 9.

Triangulation along the ninety-eighth meridian, Lampasas to Seguin, Tex. By J. F. Hayford. 2 diags. Report for 1905. Appendix 5.

Earth movements in the California earthquake of 1906. By J. F. Hayford and A. L. Baldwin. Report for 1907. Appendix 3.

TOPOGRAPHY.

The hypsograph. Designed by F. Morse. 2 views. Report for 1902. Appendix 4. (Exhausted.)

A plane table manual. By D. B. Wainwright. 6 illus., 27 diags. Report for 1905. Appendix 7.

HYDROGRAPHY.

Channel and harbor sweep. Description by D. B. Wainwright. 1 view. Report for 1903. Appendix 6

Long wire sweep. By D. B. Wainwright. 2 diags. Report for 1905. Appendix 6.

Description of long wire drag. By N. H. Heck. Report for 1907. Appendix 7.

Manual of tides, Part IV B.—Cotidal lines for the world. By R. A. Harris. 41 illus. Report for 1904. Appendix 5.

Manual of tides, Part V.—Currents, shallow-water tides, meteorological tides, and miscellaneous waters. By R. A. Harris. Report for 1907. Appendix 6.

TERRESTRIAL MAGNETISM.

The magnetic observatories of the United States Coast and Geodetic Survey in operation on July 1, 1902. By L. A. Bauer and J. A. Fleming. 8 views, 3 maps and sketches, 5 diags. Report for 1902. Appendix 5.

Magnetic dip and intensity observations January, 1897, to June, 30, 1902. By D. L. Hazard, with preface by L. A. Bauer. 3 views. Report for 1902. Appendix 6.

Results of magnetic observations made by the Coast and Geodetic Survey between July 1, 1902, and June 30, 1903. By L. A. Bauer. Report for 1903. Appendix 5.

Results of magnetic observations made by the Coast and Geodetic Survey between July 1, 1903, and June 30, 1904. By L. A. Bauer. Report for 1904. Appendix 3.

Results of magnetic observations made by the Coast and Geodetic Survey between July 1, 1904, and June 30, 1905. By L. A. Bauer. Report for 1905. Appendix 3.

Results of magnetic observations made by the Coast and Geodetic Survey between July 1, 1905, and June 30, 1906. By L. A. Bauer. 1 illus. Report for 1906. Appendix 3.

Distribution of the magnetic declination in the United States for January 1, 1905. By L. A. Bauer. 1 map. Report for 1906. Appendix 4.

Results of magnetic observations made by the Coast and Geodetic Survey between July 1, 1906, and June 30, 1907. By R. L. Faris. Report for 1907. Appendix 5.

GEOGRAPHY.

Hawaiian geographic names. Compiled by W. D. Alexander. Report for 1902. Appendix 7.

BULLETINS.

These are no longer issued except as new editions of bulletins already issued.

Bulletin No. 36. Table of depths for channels and harbors, coasts of the United States, including Porto Rico, the Hawaiian Islands, and the Philippine Islands. Third edition. 1907. 150 p.

Bulletin No. 40. Alaska. Coast-pilot notes on the Fox Island Passes, Unalaska Bay, Bering Sea, and Arctic Ocean as far as Point Barrow. Fifth edition. May 20, 1904. 77 p., 5 views.

SEPARATELY ISSUED PUBLICATIONS.

These are papers that have been published on a variety of professional, scientific, bibliographical, or administrative subjects in separate form and without serial number:

1902. List and catalogue of the publications issued by the United States Coast and Geodetic Survey, 1816–1902. By E. L. Burchard. 237 p.

1903. United States magnetic declination tables and isogonic charts and principal facts relating to the earth's magnetism. Second edition. By L. A. Bauer. 405 p., 32 figs., 3 pls.

1903. Report on geodetic operations in the United States to the International Geodetic Association. By O. H. Tittmann. 28 p., 1 illus.

1904. Alaska. Coast-pilot notes on Warren Channel and Davidson Inlet, west coast of Prince of Wales Island, Southeast Alaska. 4 p., 1 map.

1905. Work of the Coast and Geodetic Survey. Reprint of leaflets describing the operations of the survey. 160 p.

CONTENTS: No. 1. The Coast and Geodetic Survey. 5 p.—No. 2. Triangulation and reconnaissance. 4 p.—No. 3. Base apparatus. 10 p., 1 pl.—No. 4. Time, latitude, longitude, and azimuth. 4 p.—No. 5. Terrestrial magnetism. 4 p., 1 pl.—No. 6. Hydrography. 4 p., 1 pl.—No. 7. Topography. 4 p., 1 pl.—No. 8. Tides and tidal currents. 4 p.—No. 9. Leveling. 4 p., 1 pl.—No. 10. Coast pilots. 4 p.—No. 11. Chart publications. 4 p.—No. 12. Gravity. 4 p., 1 pl.—No. 13. Geodesy or measurement of the earth. 5 p.

1906. Geodetic operations in the United States, 1903–1906. A report to the International Geodetic Association. By O. H. Tittmann and J. F. Hayford. 45 p. (Exhausted.)

1906. General instructions for coast surveys in the Philippine Islands. 92 pp., figs.

1907. Survey of oyster bars, Anne Arundel County, Md. Description of boundaries and land marks and report of work of United States Coast and Geodetic Survey in cooperation with Maryland Shell Fish Commission. By C. C. Yates. 106 p., map.

COAST PILOTS.

These are a series of volumes covering the coast of the United States, containing descriptions of the coast and harbors, sailing directions, and general information, etc., for the use of mariners. They are corrected to date of issue as nearly as practicable and new editions issued from time to time.

U. S. Coast Pilot: Atlantic coast. Parts I–II. From St. Croix to Cape Ann. Second edition. 1903. 243 p. (Supplement. 1906. 12 p.)

U. S. Coast Pilot: Atlantic coast. Part III. From Cape Ann to Point Judith. Second edition. 1903. 199 p. (Supplement. 1906. 8 p.)

U. S. Coast Pilot: Atlantic coast. Part IV. From Point Judith to New York. Fourth edition. 1904. 208 p. (Supplement. 1906. 7 p.)

U. S. Coast Pilot: Atlantic coast. Part V. From New York to Chesapeake Bay entrance. Third edition. 1904. 149 p. (Supplement. 1906. 7 p.)

U. S. Coast Pilot: Atlantic coast. Part VI. Chesapeake Bay and tributaries. Third edition. 1907. 192 p.

U. S. Coast Pilot: Atlantic coast. Part VII. From Chesapeake Bay entrance to Key West. Third edition. 1906. 223 p.

U. S. Coast Pilot: Atlantic coast. Part VIII. Gulf of Mexico from Key West to the Rio Grande. (Supplement. 1906. 28 p.)

U. S. Coast Pilot: Pacific coast. California, Oregon, and Washington. 1903. 215 p. (Supplement. 1906. 11 p.)

U. S. Coast Pilot: Pacific coast: Alaska. Part I. Dixon entrance to Yakutat Bay, with inland passage from Juan de Fuca Strait to Dixon entrance. (Supplement. 1906. 26 p.)

U. S. Coast Pilot: West Indies. Porto Rico. 1906. 116 p.

SAILING DIRECTIONS FOR THE PHILIPPINE ISLANDS.

These contain descriptions of the coasts and harbors of the Philippine Islands together with sailing directions for those coasts and harbors:

Philippine Islands: Sailing Directions. Section I. North and west coasts of Luzon and adjacent islands, from Cape Engaño to Manila Bay. Third edition. 1906. 101 p.

Philippine Islands: Sailing Directions. Section II. Southwest and south coasts of Luzon and adjacent islands, between Manila and San Bernardino Strait. Third edition. 1906. 69 p.

Philippine Islands: Sailing Directions. Section III. Coast of Panay, Negros, Cebu, and adjacent islands. Third edition. 1906. 109 p.

Philippine Islands: Sailing Directions. Section IV. Coasts of Samar and Leyte, and the east coast of Luzon. Second edition. 1904. 87 p. (Exhausted.) (Supplement. 1906. 8 p.)

Philippine Islands: Sailing Directions. Section V. Coasts of Mindanao and adjacent islands. 72 p. (Supplement. 1907. 5 p.)

Philippine Islands: Sailing Directions. Sections VI and VII. Mindoro Strait, Palawan Island, and Sulu sea and archipelago. Second edition. 1906. 230 p.

NOTICES TO MARINERS.

These contain corrections that are to be applied to charts in order to keep them up to date. Commencing with January 1, 1908, the monthly Notice to Mariners will, by direction of the Secretary of Commerce and Labor, be consolidated with and made a part of the weekly Notice to Mariners issued by the Light-House Board and hence commencing with January 1, 1908, will be discontinued as a publication of the Survey:

Notice to Mariners. Coasts of the United States, adjacent territories, and islands under the jurisdiction of the United States: 1903, Nos. 294–306; 1904, Nos. 307–320; 1905, Nos. 321–333; 1906, Nos. 334–346; 1907, Nos. 347–359.

Notice to Mariners. Philippine Islands: 1903, Nos. 1–12; 1904, Nos. 1–12; 1905, Nos. 1–14; 1906, Nos. 1–10; 1907, Nos. 1–12.

TIDE TABLES.

These contain predictions for the ports of the United States, including Porto Rico, Alaska, Hawaii, and the Philippine Islands, and also predictions for the principal foreign ports:

Tide Tables for the year. 1908. 524 p.

Tide Tables for the Atlantic coast of the United States, including Canada and the West Indies. (Reprinted from the Tide Tables.) 1908. 171 p.

Tide Tables for the Pacific coast of the United States. (Reprinted from the Tide Tables.) 1908. 160 p.

CHART CATALOGUES.

These contain lists of the latest Coast Pilots, Tide Tables, Sailing Directions, Miscellaneous Maps and Plans, and Charts issued by the Survey:

Catalogue of Charts, Coast Pilots, and Tide Tables. 1907. 230 p.

Catalogue of Charts, Sailing Directions, and Tide Tables of the Philippine Islands. 1906. 17 p.

FOR LIBRARY CATALOGUE CARDS.

U. S. *Coast and geodetic survey.*

. . . Report of the superintendent of the Coast and geodetic survey, showing the progress of the work from July 1, 1906, to June 30, 1907. Washington, Gov't print. off., 1907.

565 p. 7 illus. 2 maps. 29 diags. 2 charts. 9 prog. sketches in pocket, 2 in colors. 30 cm.

At head of title: Department of Commerce and labor.

7 appendices: nos. 3–7 also issued separately.

Contents of appendices: 1. Details of field operations. 2. Details of office operations. 3. The earth movements in the California earthquake of 1906. By John F. Hayford and A. L. Baldwin. 4. Six primary bases measured with steel and invar tapes. By Owen B. French. 5. Results of magnetic observations made by the Coast and geodetic survey between July 1, 1906, and June 30, 1907. By R. L. Faris. 6. Manual of Tides, Part V: Currents, shallow-water tides, meteorological tides, and miscellaneous matters. By Rollin A. Harris. 7. Long wire drag. By N. H. Heck.

SLIPS FOR LIST AND CATALOGUE.

LIST ENTRY.

1907.

Report of the superintendent of the Coast and geodetic survey, showing the progress of the work from July 1, 1906, to June 30, 1907. Washington, Gov't print. off., 1907.

565 p. 7 illus. 2 maps. 29 diags. 7 charts. 9 prog. sketches in pocket, 2 in colors. 30 cm.

At head of title: Department of commerce and labor.

7 appendices; nos. 3-7 also issued separately.

APPENDICES.

1. Details of field operations. p. 21-54.
2. Details of office operations. p. 55-66.
3. The earth movements in the California earthquake of 1906. By John F. Hayford and A. L. Baldwin. p. 67-104.
   2 maps in colors.
4. Six primary bases measured with steel and invar tapes. By Owen B. French. p. 105-156.
5. Results of magnetic observations made by the Coast and geodetic survey between July 1, 1906, and June 30, 1907. By R. L. Faris. p. 157-230.
6. Manual of Tides. Part V. Currents, shallow-water tides, meteorological tides, and miscellaneous matters. By Rollin A. Harris. p. 231-546.
   22 diag. 7 charts.
7. Long wire drag. By N. H. Heck. p. 547-561.
   7 diag. 7 illus.

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(And Baldwin, A. L.) The earth movements in the California earthquake of 1906. Rept., 1907, app. 3, p. 67–104.

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Base measures.

UNITED STATES. French, O. B. Six primary bases measured with steel and invar tapes. Rept., 1907, app. 4, p. 105-156.

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French, O. B. Six primary bases measured with steel and invar tapes. Rept., 1907, app. 4, p. 105–156.

Tapes.

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Tides.

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Heck, Nicholas Hunter.

Long wire drag. Rept., 1907, app. 7, p. 547–561.

Harbor sweep.

Heck, N. H. Long wire drag. Rept., 1907, app. 7, p. 547–561.

Channel sweep.

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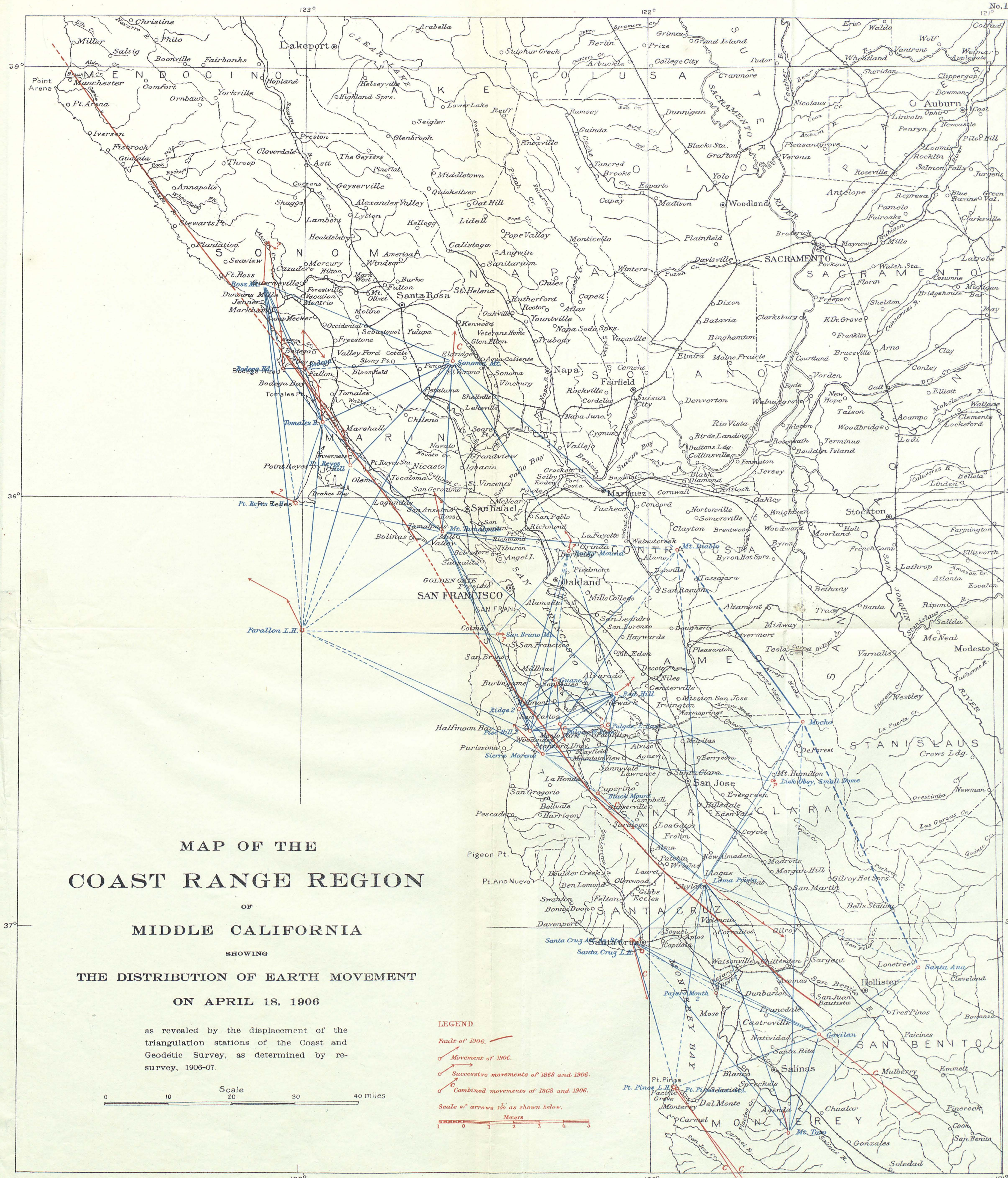
No.1


MAP OF THE
COAST RANGE REGION
OF
MIDDLE CALIFORNIA
SHOWING
THE DISTRIBUTION OF EARTH MOVEMENT
ON APRIL 18, 1906
as revealed by the displacement of the triangulation stations of the Coast and Geodetic Survey, as determined by re-survey, 1906-07.
Scale
0 10 20 30 40 miles
LEGEND
Fault of 1906.
Movement of 1906.
Successive movements of 1868 and 1906.
Combined movements of 1868 and 1906.
Scale of arrows 1/100 as shown below.
Meters
1 0 1 2 3 4 5
123°
122°
121°
39°
38°
37°
SAN FRANCISCO
SACRAMENTO
Oakland
San Jose
Santa Rosa
Stockton
Salinas
Hollister
Modesto
Monterey
Santa Cruz
Farallon L.H.
Mt. Diablo
Mt. Tamalpais
Mt. Hamilton
Mt. Toro
Point Reyes
Halfmoon Bay
MONTEREY BAY
MENDOCINO
SONOMA
NAPA
MARIN
SOLANO
YOLO
COLUSA
LAKE
SUTTER
PLACER
CONTRA COSTA
ALAMEDA
SAN MATEO
SANTA CLARA
SANTA CRUZ
SAN BENITO
STANISLAUS
SAN JOAQUIN
THE NORRIS PETERS CO., WASHINGTON, D. C.

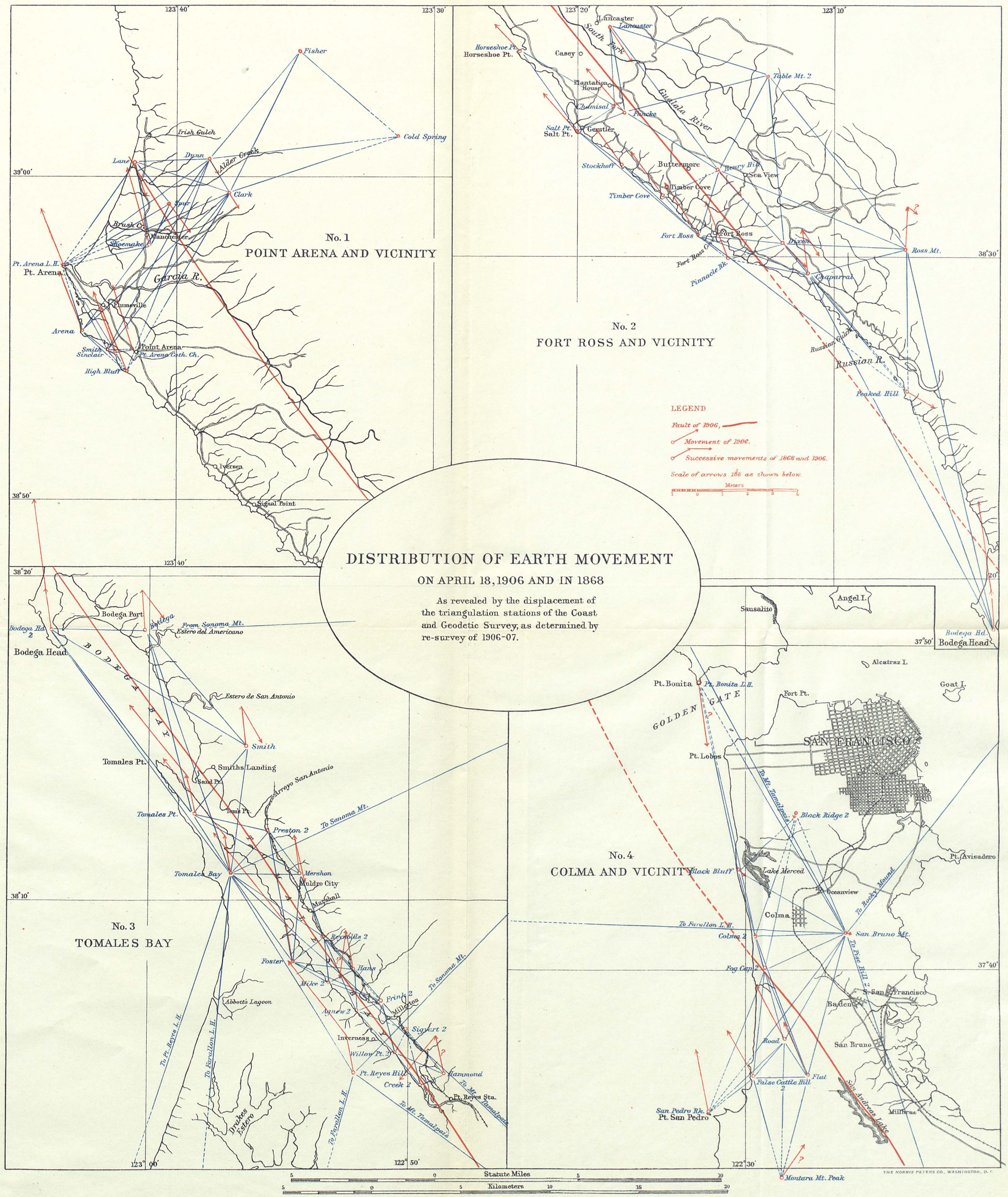

DISTRIBUTION OF EARTH MOVEMENT
ON APRIL 18, 1906 AND IN 1868
As revealed by the displacement of the triangulation stations of the Coast and Geodetic Survey, as determined by re-survey of 1906-07.
No. 1
POINT ARENA AND VICINITY
No. 2
FORT ROSS AND VICINITY
No. 3
TOMALES BAY
No. 4
COLMA AND VICINITY
LEGEND
Fault of 1906,
Movement of 1906.
Successive movements of 1868 and 1906.
Scale of arrows 100 as shown below.
Meters
Statute Miles
Kilometers
SAN FRANCISCO
GOLDEN GATE
Bodega Bay
Tomales Bay
Garcia R.
Gualala River
Russian R.
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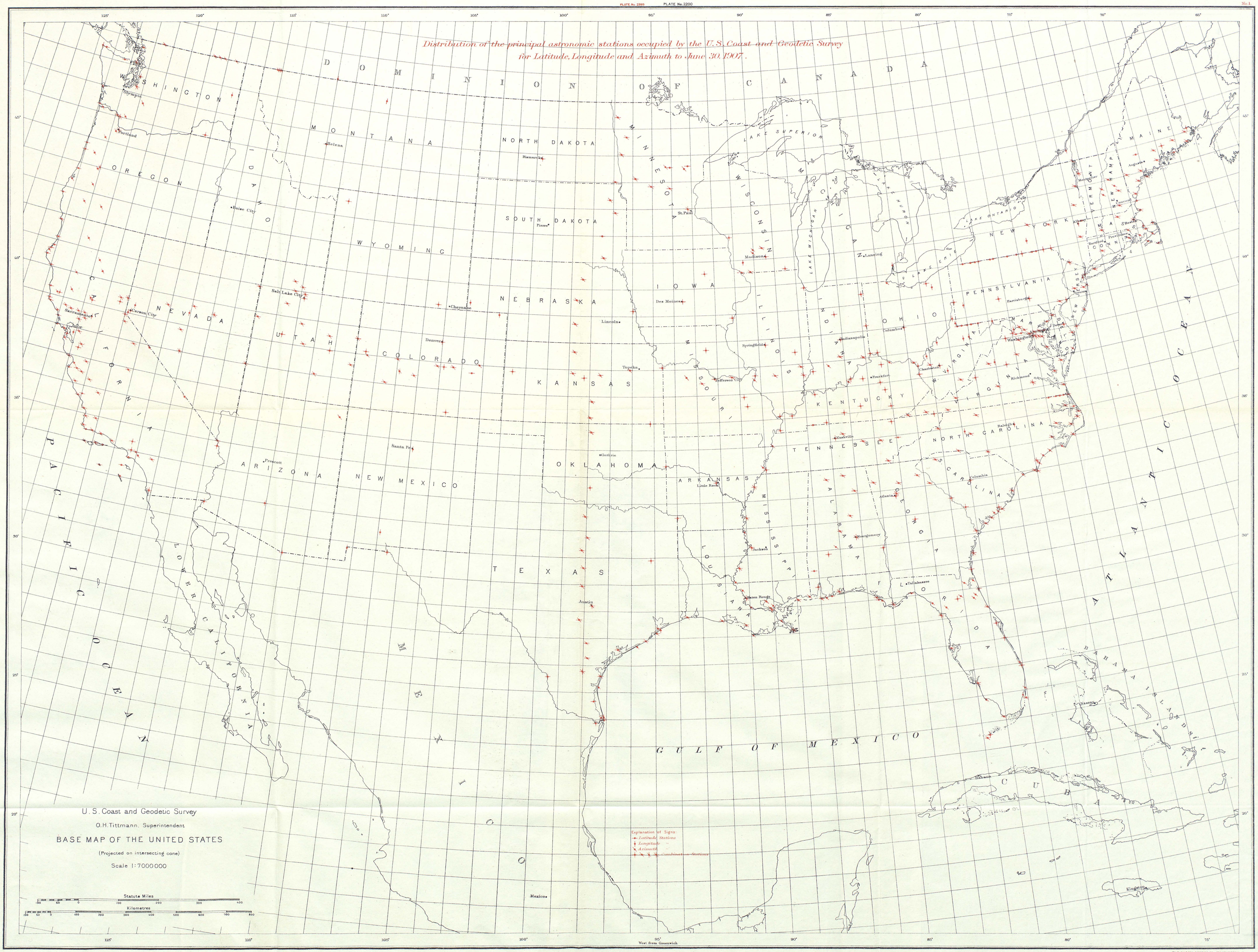
PLATE No. 2399 PLATE No. 2200 No. 1



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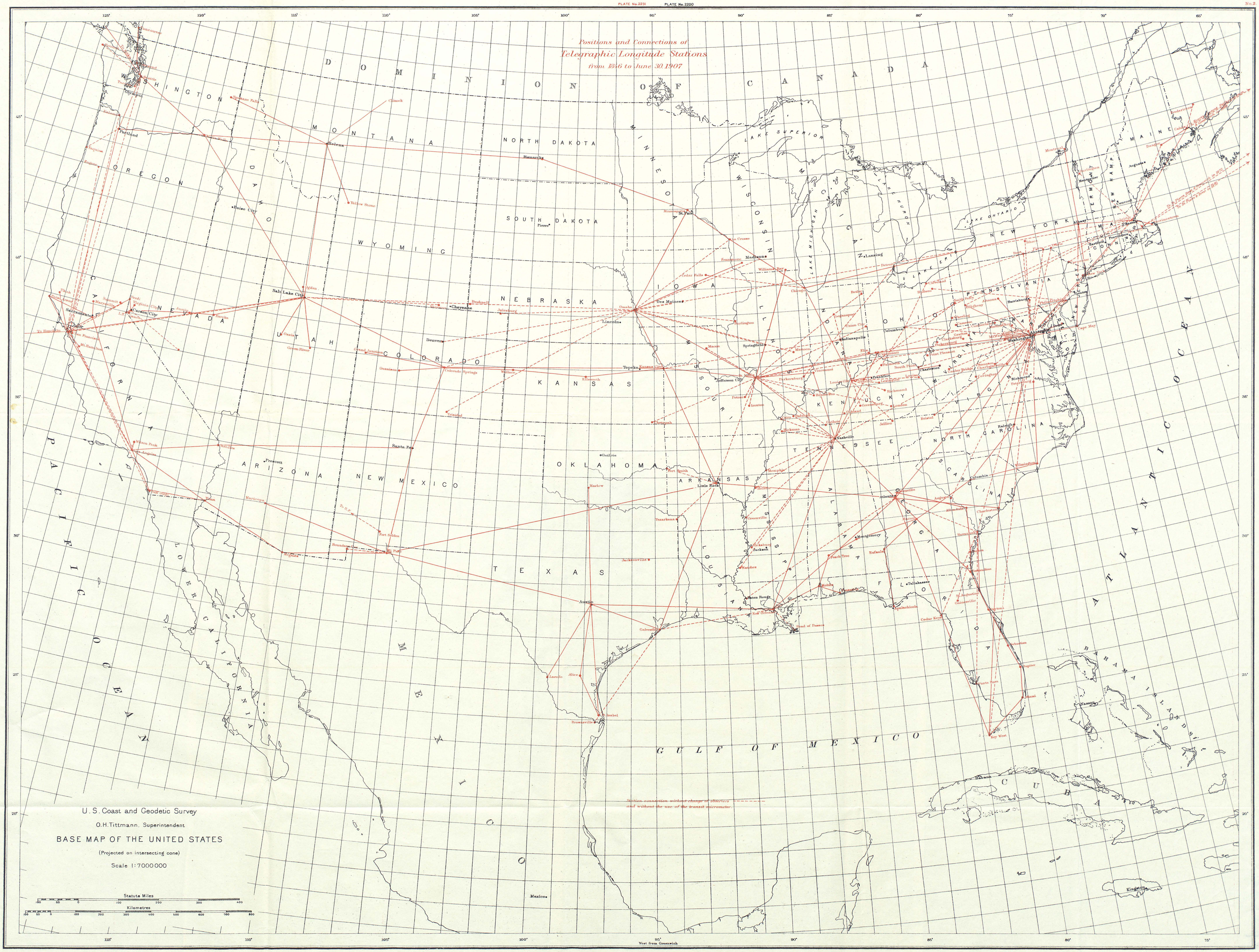

THE NORRIS PETERS CO., WASHINGTON, D. C.

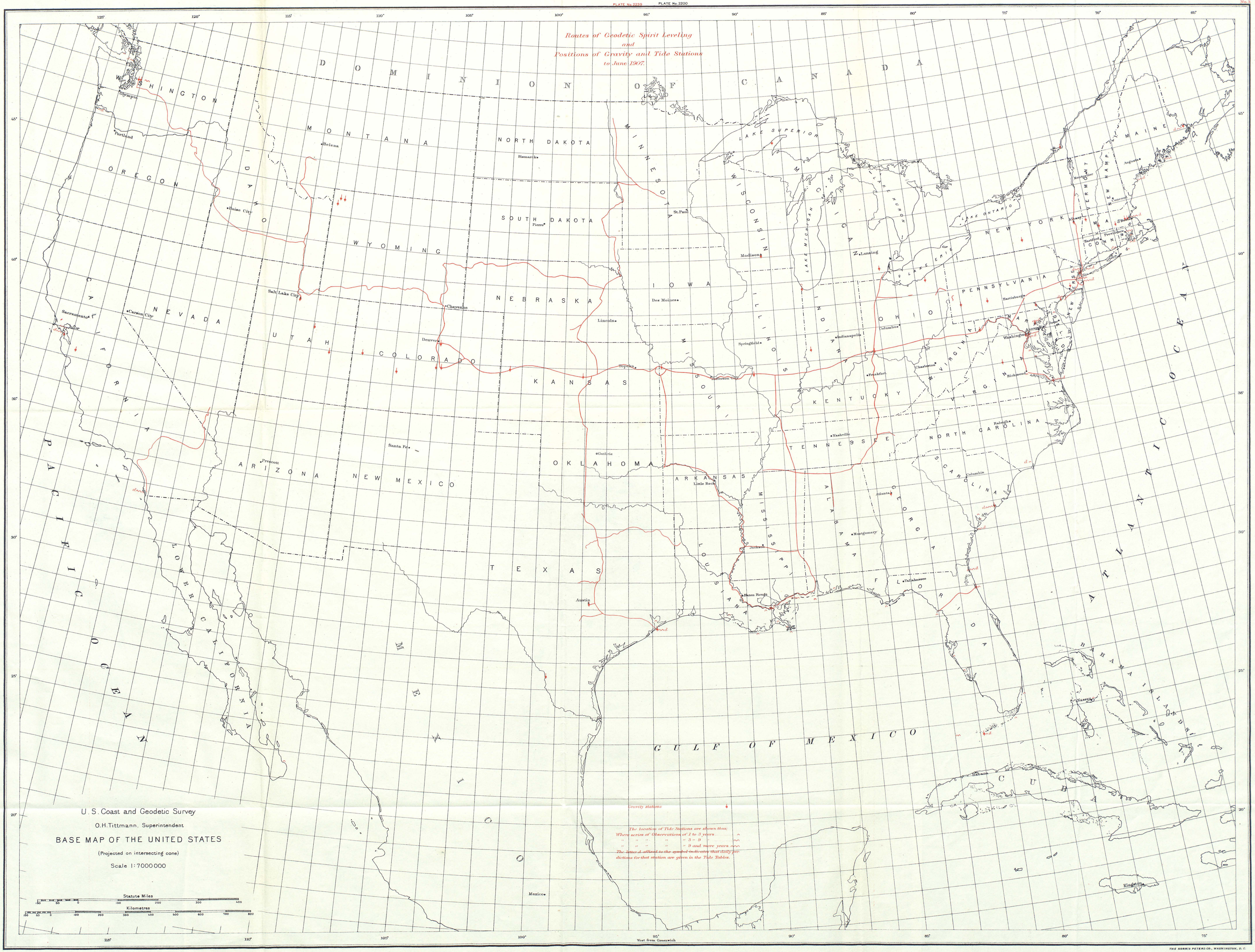

PLATE No. 2239
PLATE No. 2200
Routes of Geodetic Spirit Leveling
and
Positions of Gravity and Tide Stations
to June 1907.
DOMINION OF CANADA
GULF OF MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
MEXICO
CUBA
Gravity stations
The location of Tide Stations are shown thus;
Where series of Observations of 1 to 3 years
" " " " " 3 " 9 "
" " " " " 9 and more years
The letter d affixed to the symbol indicates that daily predictions for that station are given in the Tide Tables.
U. S. Coast and Geodetic Survey
O. H. Tittmann, Superintendent
BASE MAP OF THE UNITED STATES
(Projected on intersecting cone)
Scale 1:7000000
Statute Miles
Kilometres
West from Greenwich
THE NORRIS PETERS CO., WASHINGTON, D. C.

PLATE No. 2233 PLATE No. 2200 No. 4

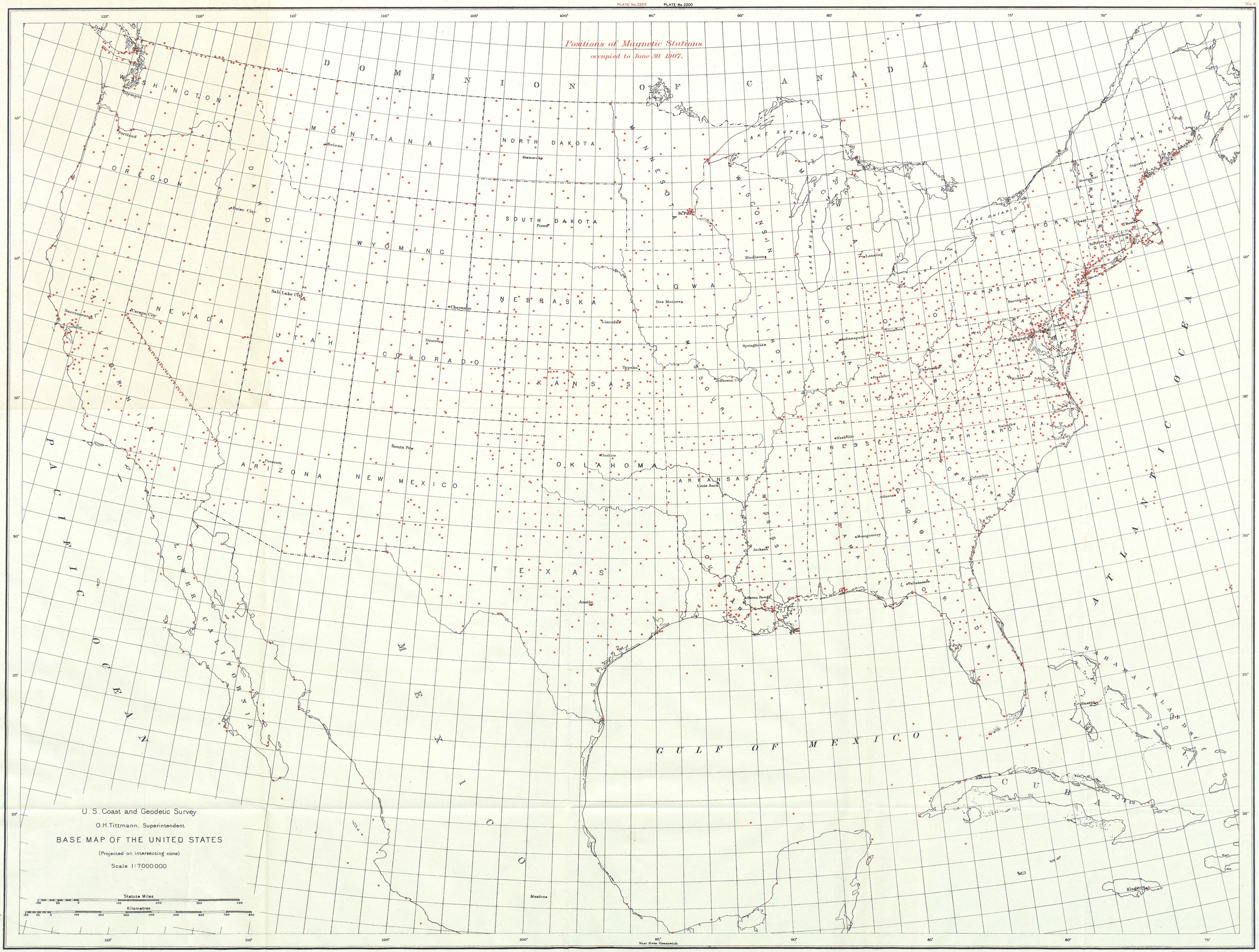

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PLATE No. 1654

THE NORRIS PETERS CO., WASHINGTON, D. C.

PLATE No. 1655

PLATE No. 1655

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ETCHED PLATE No. 2988

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GENERAL PROGRESS SKETCH

D.

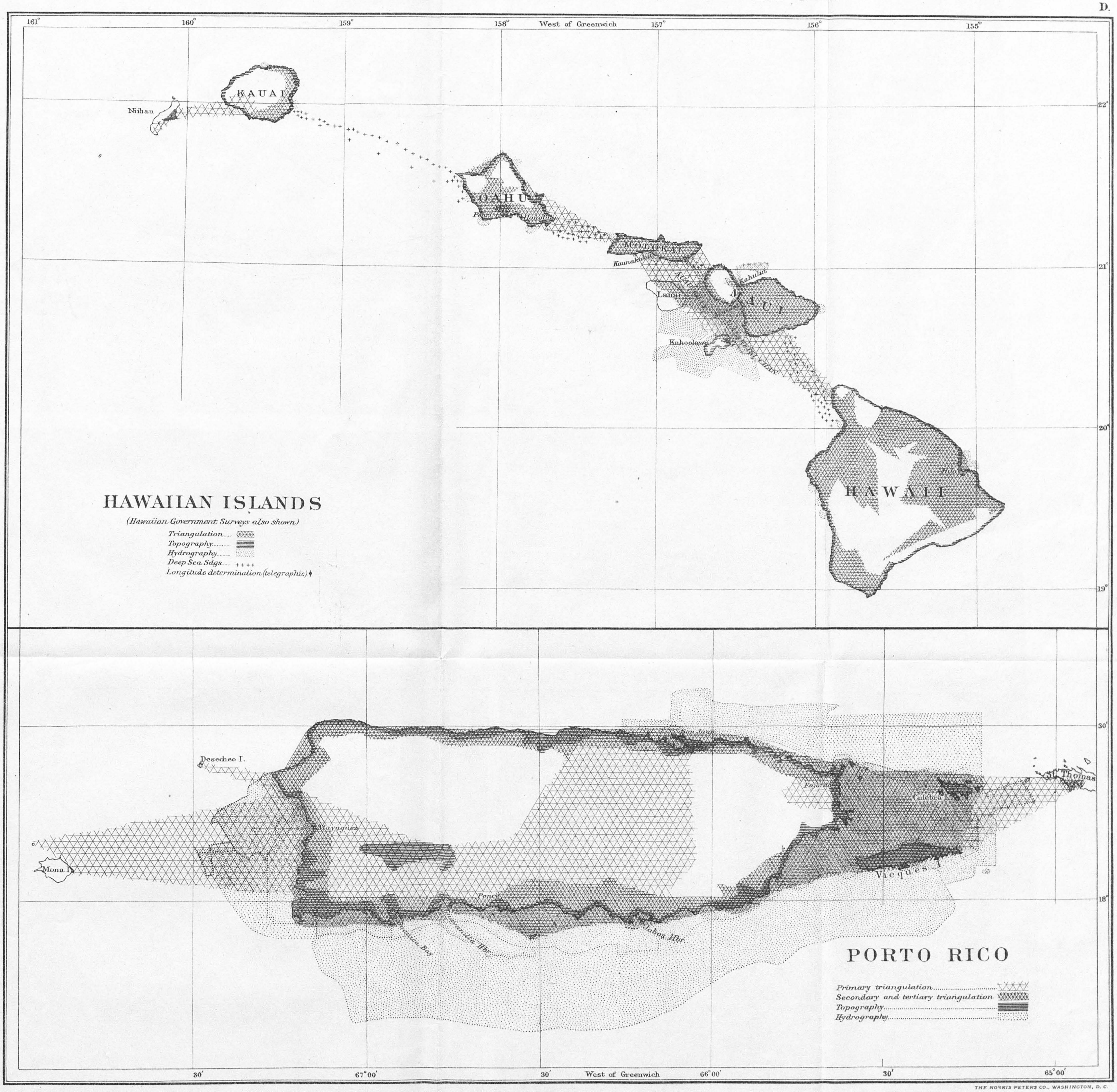

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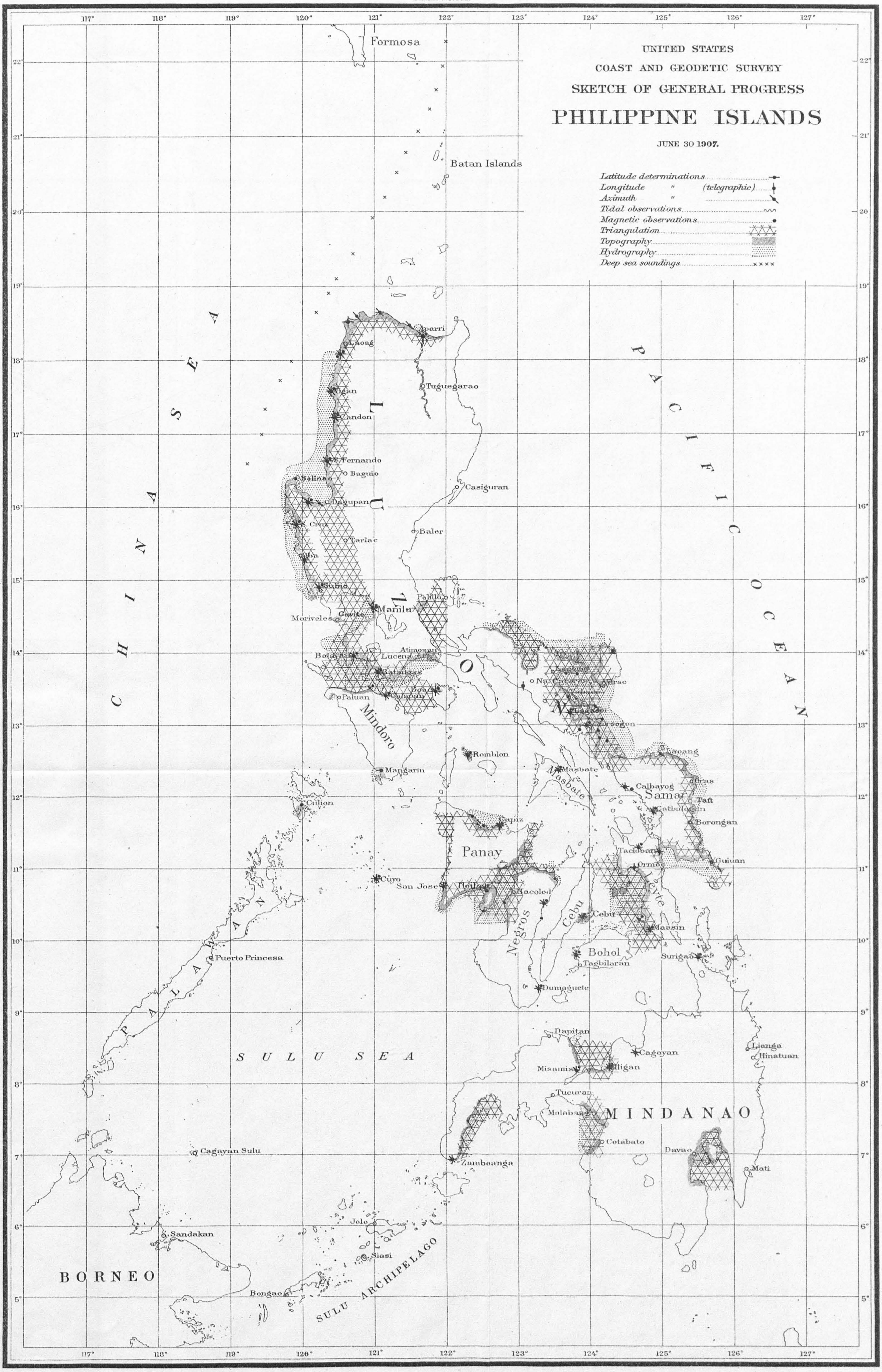
PLATE No. 2949



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Mercator projection $\frac{1}{5000000}$ *in lat. 13° N.*