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REPORT OF THE SUPERINTENDENT

OF THE

UNITED STATES COAST SURVEY

SHOWING

THE PROGRESS OF THE WORK

FOR THE

FISCAL YEAR ENDING WITH

JUNE, 1877.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1880.

National Oceanic and Atmospheric Administration

Annual Report of the Superintendent of the Coast Survey

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LETTER

OF

THE ACTING SECRETARY OF THE TREASURY,

TRANSMITTING, IN OBEDIENCE TO LAW,

THE ANNUAL REPORT OF THE SUPERINTENDENT OF THE UNITED STATES COAST SURVEY FOR THE YEAR ENDING JUNE 30, 1877.

JANUARY 17, 1878.—Ordered to lie on the table and be printed.

TREASURY DEPARTMENT, *December* 26, 1877.

SIR: In accordance with section 4690, United States Revised Statutes, I have the honor to transmit herewith, for the information of the Senate, a report addressed to this department by Carlile P. Patterson, Superintendent of the United States Coast Survey, showing the progress made in the survey of the Atlantic, Gulf, and Pacific coasts during the year ending June 30, 1877.

Very respectfully,

JOHN B. HAWLEY,
Acting Secretary.

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

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REPORT.

COAST SURVEY OFFICE,
Washington, D. C., December 20, 1877.

SIR: I have the honor to report herewith the progress made in the survey of the Atlantic, Gulf, and Pacific coasts of the United States during the year ending June 30, 1877. The allotment of parties is shown in geographical order in the Appendix No. 1, which mentions the localities and the class of work done in each.

With the reduced appropriation it was inexpedient to retain all the force heretofore employed in field-work and hydrography, but the advance made in the work has been commensurate with the means, and the results are highly satisfactory. In one or another of its branches work has been continued in each of the sea-board States of the Union, exclusive of the determination of geographical points in several of the interior States. But this distribution, wide as it has been, left untouched much work designated in special calls that could not be met for want of means. It has been necessary to balance closely between requirements so as to meet as many as possible with the limited amount which would not suffice for all. This condition has been a subject of special regret. After reducing the force and fixed expenses to the lowest limit consistent with efficiency the amount left for field-operations was inadequate to maintain constant activity. As already explained in a separate communication addressed to the department, the cost of placing a party in the field, and the cost of taking it out of the field, is the same in amount whether the working season be long or short. Frequently it has been necessary to discharge hands after a short season, and when a small additional sum would have told largely on the progress of the work without increasing the unavoidable expenses.

In the course of the year all parts of the Atlantic coast were swept by gales of unusual force, and storms were uncommonly frequent in the Gulf of Mexico. The vessels used in the service are generally small, and of necessity subject to all the hazards of the sea, but it is gratifying to record that in the past season, although several were in great peril, no vessel belonging to the Survey has been lost. Of the only three instances that stand in the records of former years as sad exceptions, one in 1846 involved loss of life, including the commander, and part of his crew, and damage to the vessel. By a collision off the coast of New Jersey, in 1860, one of our steamers was sunk and lost with twenty of the crew. In 1851 a small steamer intended for hydrographic work on the western coast was shattered in a hurricane off the coast of Patagonia, but since that date no vessel employed in the survey has been damaged in any storm beyond the reach of repairs. In October, 1876, one of the schooners was injured by a heavy gale on the coast of Maine, and another by a violent storm near Sandy Hook in the following December. The incidents in these cases will be more particularly referred to in describing the work in which the parties were then engaged. In Indian River, Florida, in October, 1876, the small vessel there employed was saved only by great efforts, though the violence of the hurricane was such as to carry away all the signals that had been erected, and, by the lashing of the waves, even the ground that held most of them. The steamer engaged in sounding along the eastern coast of Florida encountered heavy storms, and upwards of twenty gales are noted in the records of the hydrographic party that passed the season in running lines of soundings in the Gulf of Mexico.

As no year has passed without a recurrence of severe storms along our Atlantic sea-board, the meteorological conditions which precede and attend them have been judged as subjects of inquiry likely to yield information of great importance in the interests of navigation. The operations of laws recognized as general in regard to the motions of the atmosphere have been ably discussed by Mr. William Ferrel, of the Coast Survey, and the inference is ready that however or wherever the cyclones here referred to may arise, the exceptional disturbance must soon become subject to some general law, or at least be modified by such law. The great range of storms of this character adds to the probability of the inference. The inquiry is new, the end is important, and so far as the subject has been pursued there is no reason to doubt that the discussion will develop principles which may yield knowledge in advance respecting the direction of storms and their rate of motion. The leading part of Mr. Ferrel's discussion was given in the Appendix (No. 20) of my report for the year 1875.

Another subject of interest to navigators, and of which the study has been unavoidably postponed, was entered upon in June last. The tidal-currents of the open sea were then for the first time observed with success, and their characteristics recorded at stations on which soundings gave depths of more than one hundred fathoms. The great importance of results already derived from these observations will be explained under a separate head before closing the introductory part of this report.

Of scarcely less consequence than the soundings on charts, which result from the labors of the hydrographic parties, are the compasses denoting the variation of the magnetic needle. In fact the course at sea is paramount in importance when the navigator is not in the vicinity of rocks or shoals. But at sea only approximate results can be had, and observations to the degree of exactness requisite for determining the laws controlling the variation of the compass cannot be made; hence, of necessity, the knowledge needful for developing its peculiarities has depended entirely upon observations made on land. These, moreover, must record the magnetic conditions at many points, and if practicable the stations should be distributed over the entire continent. Our extensive coasts are traversed at different angles by the curves of equal magnetic declination, and to project the lines out to sea, the curves on land must be determined with precision.

The variation of the compass claimed attention at the outset of the survey, and no opportunity has been lost for acquiring information on the subject. All known records of magnetic variation near the Atlantic coast since the year 1649, and of the variation stated subsequently for other points as settlements spread over the continent of North America, have been carefully collated and used for discussion. While some of the early notes are now known to have been much in error, others were found to be less so. All observations recorded within the last forty years and accepted for discussion in the Office of the Coast Survey are trustworthy. When consistent with each other in respect of date and measure of variation, even the early and imperfect observations become important in a series, being confirmed by the law that has been deduced in recent years from observations of which the validity is unquestionable. From these last it is well known that the compass-needle pointed truly to the north in the year 1875 in the immediate vicinity of Cape Fear; and that about the year 1800 the same was true at some point about one hundred and seventy-five miles distant, in a straight line, or near Chincoteague, on the coast of Virginia, where the compass-needle now points three degrees and three-quarters west of north. These general facts and others concerning the varying rate of change in the deviation of the needle at various localities, as developed by successive discussions within the last twenty years at the Coast Survey Office, have been made known in several of the annual reports.

In a system of lines passing through places on a map of the United States, at which places the compass had the same variation, little, much, or nothing in the year 1875, the line marked zero, and along which there was no variation of the compass-needle in that year, would pass from the east end of Lake Superior across the continent in a southeast direction, and, as before stated, would cross the coast at Cape Fear. North of that cape, lines marking successive degrees of westerly variation would converge in passing inland from the coast. South of Cape Fear, and so on westward to San Francisco and then northward to and beyond Sitka, in Alaska, the successive lines would mark easterly variation, and the lines themselves would converge in passing towards the magnetic pole in British America. As the line of no variation shifted from Chincoteague southward to Cape Fear in seventy-five years and is still passing to the southward, it will be readily seen that the entire system of lines marking westerly and easterly variation along the Atlantic coast was correspondingly shifted, and that they are all passing southward.

But on the Pacific coast the lines of easterly variation are also passing southward, just as westerly lines do on the Atlantic coast, and consistently it is noticeable that one of the lines passing through Mexico, and along which the variation is easterly, has remained for some years without change. Assistant Hilgard suggests that if the stability of the variation along that line continues northward to the magnetic pole, the fact that everywhere east and west of it the variation is increasing, would seem to imply a southerly movement of the magnetic pole itself. At present that pole is near the Arctic circle in a region near the meridian of Omaha.

From this condition it results for the Atlantic coast that wherever the variation is westerly, the westerly variation is increasing, and as the easterly variation is diminishing on the coast of our Southern States, that on lines expressing but little easterly variation the variation must soon become westerly. On the Pacific coast, however, at all points above the peninsula of Lower California the easterly variation is still increasing. In the determination of the magnetic elements the hydrographic parties cannot co-operate. By the field-parties and in former years, as incidental to the work in which they were engaged, the variation of the magnetic needle has been ascertained at upwards of four hundred stations. The results are of great value and were procured without any cost as additional to that of the field-work which was at the same time in hand. Already their discussion has served for generalizing the lines of equal magnetic variation and for pointing out positions at which observations will bear systematically towards greater accuracy in drawing the series of lines for successive years in the future. At the close of June an observer was assigned to this special duty, and with suitable instruments the summer was passed in occupying stations which had been previously indicated. The details of the work will be given in my next annual report.

Disputes about land-boundaries frequently involve questions in regard to the compass-bearings in earlier times. For some years inquiries of that kind have been referred to the Coast Survey Office, and the needed information is promptly given. The calls even from interior States are increasing in frequency. It is therefore fortunate that, in addition to records of the variation gathered from the incidental labors of the field-parties, and which have yielded much information in regard to the secular change between certain dates, early means were taken for ascertaining the laws that govern the earth's magnetism. For their successive study it is requisite to keep up, at a few selected places, continuous observations of the phenomena, and this is most conveniently done by automatic registration. Such observations are maintained in the British Dominions at certain points in both hemispheres. On the part of the Coast Survey they were formerly made in Washington City in co-operation with the Smithsonian Institution, but before the series was far advanced an emergency arose for moving the apparatus to Key West, where observations were continued during six years, a period which is the least for deriving the laws that govern at any given locality. The particulars concerning the Key West station were given at length in Appendix No. 9 of my annual report for the year 1874.

At a point far distant the magnetographs formerly used at Key West were again put in operation within the year. The new station is at Madison, Wis. In pursuance of an arrangement with the authorities of the State University a suitable underground building was established by that institution. The instruments are to be maintained in running order at the expense of the Coast Survey in accordance with terms arranged by Assistant Hilgard with the authorities. Assistant C. A. Schott has been charged with the duty of securing efficiency in the operation of the instruments. To that end he will in the present fiscal year personally visit the station, adjust the instruments, and determine their scale values. The readings of the photographic traces, their tabulation, and the computations and discussions connected with them will also be in his care. The magnetic observatory will be in the local charge of Prof. J. E. Davies, of the State University of Wisconsin. As forming part of the establishment at Madison, the differential observations near there will be checked and supplemented annually by observations of the absolute measure of the declination, the dip, and the intensity of the magnetic force.

It is in contemplation, when means are available, to establish three similar observatories, one to the westward of Madison and two upon the western coast. Many advantages would result from the simultaneous study of magnetic observations made with delicate instruments at widely distant places.

In Appendix No. 7 will be found the particulars connected with the establishment of the magnetic observatory at Madison.

As usual a brief statement will be given of the operations of the fiscal year preceding that for which estimates were presented in October last.

The work done in the year ending June 30, 1877, has included hydrography of the sea-coast of Maine, near Mount Desert Island, and soundings in Eggemoggin Reach; tidal observations at the entrance of Penobscot Bay; topography of the shores of the Penobscot from Hampden to Bangor; soundings near the entrance of Saco River, Me.; triangulation in the vicinity of Mount Washington, N. H.; tidal observations at Boston, and off the coast; tidal currents observed in the Gulf of Maine; the triangulation of Taunton River, Mass.; tidal observations at Providence, R. I.; topography of the vicinity of New Haven, Conn.; primary triangulation across the Hudson River near Albany; tidal observations at Governor's Island, Brooklyn, and Sandy Hook; observations with the pendulum at New York City; supplementary soundings in Gedney's Channel; triangulation in Northern New Jersey; the hydrography of Barnegat Bay, including Tom's River, N. J.; sailing-notes for navigation between Sandy Hook and Cape May, and for Delaware Bay and River; triangulation in Eastern Pennsylvania; sailing-notes for the coast of Maryland and Virginia, and for the estuaries of Chesapeake Bay; determination of the positions of life-saving stations between Cape Henlopen and Cape Charles, Va., for insertion on charts; special shore-line survey and hydrography of the harbor of Baltimore City for United States Commissioners; determination of the magnetic elements at Washington City; surveys in the vicinity of Smith's Island, Chesapeake Bay, for the Boundary Commission of Maryland and Virginia; topography of the shores of the James River, Va., from City Point upward to Kingsland Creek, and of the northeastern approaches to Norfolk; tidal observations at Fortress Monroe; selection of station-points in West Virginia for geodetic work; primary triangulation along the Blue Ridge in Virginia and North Carolina; hydrographic examination between Hatteras and Oregon Inlet, and of the Frying-Pan Shoals, N. C.; soundings in Ocracoke Inlet, and hydrography extended in Pamplico Sound, Currituck Sound, and East Lake, N. C., and in North Landing River, Va.; latitude and azimuth determined at Long Shoal Point and at Hog Island, N. C.; hydrography completed in Core Sound and Bogue Sound, N. C.; topography of the vicinity of Cape Fear River, at Wilmington, N. C.; primary triangulation across the boundary between North Carolina and South Carolina; examination of harbors and sounds for sailing-notes between Cape Fear and Saint Mary's River, Ga.; tidal observations at Fernandina, Fla.; survey of Saint John's River, Fla., from Jacksonville southward to Hogarth's Bay; hydrography of the coast approaches between Matanzas Inlet and Mosquito Inlet, Fla.; survey of the coast and sea-water channels near Cape Cañaveral, with parts of the Banana River and Indian River; topography and hydrography of the western coast of Florida from Cedar Keys northward to Horseshoe Point; hydrography of the Gulf coast from Pine Point westward to Choctawhatchee, including Saint Andrew's Bay and its approaches; determination of points by triangulation in Kentucky, between Cumberland Gap and Lancaster Court-House; measurement of base-line and selection of points in Tennessee for triangulation between Knoxville and Nashville; triangulation in the northwestern part of Alabama; hydrographic development of the Gulf of Mexico by numerous lines of deep sea-soundings and temperature observations; topography of the shores of Barataria Bay, La., and extension of the triangulation towards the Mississippi River; special hydrographic survey of Cubitt's Gap and from thence to the Head of the Passes, Mississippi River, and of Southwest Pass; detailed survey of the shores and waters of that river between Bonnet Carré and Point Houmas; height of the water recorded regularly at New Orleans with a tide-gauge; reconnaissance for geodetic points in Illinois and through Missouri westward towards the Wasatch Mountains; points determined in the vicinity of Madison, Wis., and establishment of a permanent magnetic observatory in connection with the university at that place; and on the coast of Texas, the triangulation of Laguna Madre from Corpus Christi Bay southward to Baffin's Bay.

On the Pacific coast of the United States, beginning at the southern boundary of California, the work of the year included reconnaissance for triangulation-points between San Diego and Santa Barbara; topography of the western part of Santa Catalina Island; inspection of field-parties near the shores of Santa Barbara Channel; connection of Anacapa and Santa Barbara Island, by triangulation, with stations on the main coast of California; hydrography of the approaches to San Miguel and Santa Rosa Island; supplementary soundings in the vicinity of Santa Monica, Cal.; inshore hydrography eastward of Point Concepcion, and lines of soundings across the Santa

Barbara Channel; topography of the coast north of Point Concepcion towards Point Arguello; reconnaissance for triangulation between Los Angeles and Point Arguello; tidal observations at Fort Point and Saucelito, San Francisco Bay; geodetic measurements, and determinations of latitude and azimuth at Mount Diablo and Mount Helena; reconnaissance for geodetic points between the Sierra Nevada and Salt Lake City; topography of the coast of California from Timber Gulch northward to Stewart's Point Landing; reconnaissance for triangulation points in the coast-range of mountains north of Mount Ross and Sulphur Peak; hydrography of the coast of Oregon from False Tillamook northward to Columbia River entrance; topography of the shores and soundings in the Columbia River between Cathlamet and Cottonwood Island; tidal observations at Astoria and at Port Townshend, W. T.; erection of signals for triangulation across the waters of Washington Sound and the Strait of Fuca; additional soundings along the shores of Whidbey Island and Admiralty Inlet, W. T.; topography of the shores of Admiralty Inlet, and Colvos Passage from Point Orchard south to the entrance of Commencement Bay; inspection of topographical work in this section; and, as yet in progress, the hydrography of Commencement Bay, W. T.

The compilation has been kept steadily in hand of sailing-notes and other maritime data pertaining to the Coast Pilot for navigation along the sea-board of California, Oregon, and Washington Territory; and also for the Coast Pilot of Alaska.

Progress commensurate with the field-work has been made in the work of the Coast Survey Office, which comprises the computations of all geodetic, trigonometric, tidal, and magnetic observations, including the arrangement for publication of the records and results; the drawing of hydrographic charts from the records of soundings; the reduction of the original topographical and hydrographic maps for publication; the engraving, electrotyping, printing, and issue of the same, as well as the maintenance of the instruments used in the survey. Tide-tables of the principal ports of the United States for the year 1878 have been published; the drawing of sixty-one charts has been in progress, of which number twenty-eight have been completed, including sixteen charts for publication by photolithography; nine new copper-plate engravings have been begun; one hundred and nine engraved plates have received additions, and twenty-one have been completed; an aggregate of eighteen thousand eight hundred and forty-two copies of charts has been issued; two thousand eight hundred and thirty copies of the Coast Survey reports have been distributed; and the second volume of the Atlantic Coast Pilot, comprising the coast from Boston to New York, has been in preparation, and will be published before the close of the year.

ESTIMATES.

The aggregate of the following estimates which were submitted to the department in October last, although greater than the amount appropriated for the current year, is urgently needed. Resurveys of most important localities, as Long Island Sound, New York Harbor entrance, Delaware Bay and River, and others, in all of which great changes have occurred since the charts were issued, call for a sum in addition to the amount required to maintain the regular progress of the survey of the coast.

The estimates for continuing the survey of the Atlantic and Gulf coast of the United States, during the year ending June 30, 1879, are intended to provide for the following progress:

FIELD-WORK.—To continue the topography of the western shore and islands of Passamaquoddy Bay and its estuaries; of the coast east of Penobscot Bay, towards Narraguagus Bay, and of the shores of the Penobscot, near Bangor; for the determination of heights at some of the principal trigonometrical points between Boston and the Saint Croix, and of co-efficients of refraction; to complete the hydrography of Penobscot Bay and River, of Isle au Haut Bay, Blue Hill Bay and Frenchman's Bay, and continue soundings in the coast approaches, eastward of Penobscot Bay; to continue a topographical and hydrographic survey of Portsmouth Harbor; to make such additional triangulation as may be requisite for that and other surveys on the eastern coast, and determine the position of new light-houses between Eastport, Me., and New York; to continue soundings along the coast of Maine, and other off-shore hydrography between Cape Cod and Manan; make special examination for the sailing lines for charts; to continue the observations of sea and tidal currents in the Gulf of Maine; to continue tidal observations, and to make such astronomical and magnetic observations as may be required; to continue such topographical and hydrographic resurveys of the coast between Cape Cod and New York as may be found necessary; to continue the survey of the Connecticut River, from its mouth to Hartford; to make such examination as may be required in New York Harbor, and such surveys in its vicinity as may be found necessary, including a topographical and hydrographic survey of the south coast of Long Island; to make at this port, observations on tides and currents; to extend the plane-table survey of the Hudson River above Haverstraw; to continue the triangulation between the Hudson River and Lake Champlain; to make the requisite astronomical observations; to continue the topographical and hydrographic surveys of the coast of New Jersey, and of Delaware Bay and River; to connect the Atlantic triangulation with that of Chesapeake Bay, near the boundary line between Maryland and Virginia; to complete the detailed survey of James River, Va., including the hydrography, and continue the plane-table survey of the Potomac River; to continue southward the main triangulation along the Blue Ridge, parallel with the coast, including astronomical and magnetic observations; to continue the supplementary hydrography between Cape Henlopen, Del., and Cape Henry, Va., and in Chesapeake Bay, and also the tidal observations; to measure base-lines of verification and determine azimuths for the coast triangulation south of Cape Lookout; to make the astronomical and magnetic observations requisite; to continue the off-shore hydrography between Cape Henry and Cape Fear; to continue the hydrography of Pamplico Sound and its rivers, and that of Bogue Sound, and sound the entrance to Cape Fear River, and continue the topography of its shores to Wilmington; to extend northward the primary triangulation parallel to the coast in Alabama; to continue the topographical and hydrographic survey of rivers near the coast of South Carolina and Georgia; to determine azimuths for the triangulation of the coast of South Carolina and Georgia; to continue the detailed survey of the sea islands and water passages between Charleston and Savannah, and to make tidal observations; to continue the off-shore hydrography between Cape Fear, N. C., and the Saint John's River, Fla.; to continue southward from Cape Cañaveral the triangulation, topography, and hydrography of the eastern coast of Florida, including Indian River; to continue the triangulation, topography, and hydrography of the Saint John's River; to make the requisite astronomical observations; to continue hydrography off the eastern coast of Florida, from Mosquito Inlet to the southward; to continue soundings and observations for sea-temperatures in such parts of the Gulf Stream as may be deemed advisable, between the west end of Cuba and Nova Scotia, and dredging along the coast, within the same limits, in conjunction with the United States Commission on Fish and Fisheries; to continue the astronomical and magnetic observations requisite between Cape Florida and Pensacola; to complete the hydrography of Charlotte Harbor, and the triangulation, topography, and hydrography of the western coast of Florida between Cedar Keys and Tampa Bay, and between Tampa Bay and Charlotte Harbor; to continue the same classes of work to the southward of Charlotte Harbor; to run lines of soundings and make observations of sea-temperatures in the Gulf of Mexico, and develop the hydrography of the Gulf coast included in field operations; to connect the trigonometrical survey of the Mississippi River at New Orleans with that of Lake Borgne and Lake Pontchartrain, and continue the trigonometrical, topographical, and hydrographic survey of Lakes Pontchartrain and Maurepas, and of the Mississippi River, above New Orleans, to the head of ship navigation; to determine geographical positions, and make the astronomical and magnetic observations requisite; to extend the triangulation, topography, and hydrography of Louisiana westward of the Mississippi delta, and continue the hydrography of the Gulf of Mexico between the mouth of the Mississippi and Galveston, Tex.; to continue the triangulation, topography, and hydrography of the coast of Texas westward between Sabine Pass and Galveston, and between Corpus Christi and the Rio Grande; to measure a base-line of verification, and make the astronomical and magnetic observations requisite between Sabine Pass and the Rio Grande; to continue the hydrography of the approaches to the coast of Texas; to continue the triangulation connecting the surveys of the Atlantic and Pacific coasts, and to furnish points for State surveys; to continue the determination of the positions of new light-houses and life-saving stations along the coast between New York and the Rio Grande; to continue the field-work for the description and verification of the work for the Coast Pilot; to continue the organized system of magnetic observations required for a complete magnetic survey, and to run lines of levels connecting points in the main triangulations with the sea-level.

OFFICE-WORK.—To compute results from the field operations executed along the Atlantic and Gulf coasts, including astronomical, geodetic, geographical, magnetic, and tidal work; to continue the publication of the Coast Pilot for the Atlantic and Gulf coasts; to prepare the predictions of tides for the year 1879; to continue the reproduction of the original topographical maps, and to plot the hydrographic surveys; to continue the drawing and engraving of the general chart of the coast from Quoddy Head to Cape Cod, to complete the engraving of the western part of this chart; to continue the drawing of coast charts 1 and 2, coast of Maine between the Saint Croix River and Petit Manan Light; to continue the drawing and engraving of chart No. 3, which includes Frenchman's Bay, Mount Desert Island, Blue Hill Bay, Isle au Haut Bay, and their approaches; also local charts of Mount Desert Island, Eggemoggin Beach, and Penobscot Bay east; to complete engraving the chart of Lake Champlain; to continue the drawing and engraving of a new chart of Long Island Sound, and of charts No. 22 and No. 23, between Barnegat and Cape May; to make additions to the charts and sketches between New York and Cape Henry; to continue the drawing and engraving of a new chart of Delaware Bay and River, and to complete that of James River; to continue the drawing and engraving of the general chart of the coast between Cape Henry and Cape Lookout, and of charts No. 38, No. 39, No. 42, No. 45, No. 46, and No. 47, showing parts of the coast between Cape Henry and Cape Lookout, including Pamplico Sound; to finish the engraving of the Atlantic coast sailing-chart, No. II, from Cape Hatteras to Key West; to continue the engraving of the general charts of the coast between Cape Romain and Cape Cañaveral, and of charts No. 51 and No. 52 between Cape Fear and Winyah Bay; to continue the engraving of a new chart of Georgetown Harbor, S. C., and to make additions to the charts between Cape Henry and the Saint Mary's River; to continue the drawing and engraving of charts No. 59 and No. 60 from Saint Augustine to Cape Cañaveral, and to make additions to the charts of the coast between Saint Mary's River and Cape Florida; to continue the drawing and engraving of charts No. 81, No. 82, No. 83, No. 84, No. 85, and No. 86, showing the Gulf coast between Cedar Keys and Pensacola entrance, and to complete the charts of Tampa Bay; to engrave the chart of Saint Andrew's Bay; to complete the engraving of charts No. 92, No. 93, and No. 95, showing Isle au Breton Sound and the Mississippi River, between New Orleans and the Gulf of Mexico, and the general chart showing the sea approaches to the Mississippi River; to publish by photolithography on a large scale the maps of the Mississippi River, showing its levees above New Orleans to Point Houmas; to continue the drawing and engraving of the general chart of the coast of Louisiana and Texas from Atchafalaya Bay to Galveston; to continue the drawing and engraving of that between Galveston and the Rio Grande, and to complete chart No. 110, showing Corpus Christi Bay; for material for drawing, engraving, map-printing, for electrotyping, photographing, for instruments and apparatus.

Total for the Atlantic and Gulf coasts, involving work in twenty-nine States, will require $425,000.

The estimates for continuing the survey of the Pacific coast of the United States are intended to provide for the following progress:

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

OFFICE-WORK.—To make the computations from observations recorded in the field, including astronomical, geodetic, geographical, magnetic, and tidal observations; to continue the publication of the Coast Pilot of the Pacific coast; to prepare tidal predictions for 1879; to continue the reproduction of the original topographical maps, and to plot the hydrographic surveys; to draw and engrave the additions on the general chart of the Pacific coast of the United States; to continue the drawing and engraving of the charts of the coast from San Diego to Point Concepcion, No. 1, No. 2, and No. 3; to continue the engraving of a new chart of San Francisco entrance and harbor from resurveys; to continue the drawing and engraving of charts of the coast from Point Arena to Cape Mendocino, No. 8, of that from Cape Mendocino to Saint George's Reef, No. 9, and of that from Saint George's Reef to the Umpquah River, No. 10, Shoalwater Bay, Puget, and Washington Sounds; to complete the drawing and engraving of the chart of Columbia River to Kalama, and to continue that of the local harbor charts of the coast, with those of the northwestern coast; for material for drawing, engraving, map-printing, for electrotyping, photographing, and for instruments and apparatus.

Total for the Pacific coast, involving work in five States and Territories, will require $275,000.

For repairs and maintenance of the complement of vessels used in the Coast Survey will require $50,000.

For continuing the publication of the observations made in the progress of the Coast Survey will require $10,000.

For general expenses of all the work, rent, fuel; for transportation of instruments, maps, and charts; miscellaneous office expenses, and for the purchase of new instruments, books, maps, and charts, will require $40,000.

At the Treasury Department it was deemed inexpedient at this time to vary considerably in estimates for work above the amounts given in recent appropriations, although larger appropriations had been made in previous years. Accordingly, in November, the estimates for continuing the work of the survey during the next fiscal year were reduced to an amount equal to the appropriation for the year ending June 30 1877. The reduced estimates were transmitted to the department with the following remarks:

"The estimates submitted in October are such as, in my judgment, after full consideration of the necessities of the work and its economical progress, would best conduce to a completion of the survey in a reasonable period of time. As the work is to be confined to certain limits, and the organization of the force is thorough, the more rapidly it is executed the greater the economy, the less the total cost, and the more quickly will the public have use of the results.

"Eighty per cent. of the amount of the estimates exceeding the appropriation for this year would apply directly to field-work, and would yield as results not less than two and a half times the amount obtained from the present appropriation. If the cost of placing a party in the field is $500, and the cost of keeping it at work is $500 per month, withdrawing it from the field at a cost of $500 gives an aggregate of $1,500 in one month. Adding to this an additional $1,500 quadruples the amount of field-work by merely doubling the expenditure. Upon these grounds my estimates were submitted in October.

"The appropriation for the current year proves to be entirely inadequate for the work without a radical change in the organization, and tends to loss in economy, and delay in the completion of charts of the coasts. I have therefore, after personal explanation, with your consent and direction, reduced the estimates from the amounts submitted in October to the amounts which were appropriated for the year ending June 30, 1877, after a most careful examination of the work by a subcommittee of the Committee on Appropriations of the House of Representatives, at the head of both of which was the present Speaker. Even the amount then appropriated was a great reduction from previous appropriations."

SEA-CURRENTS.

In compiling data for the Coast Pilot the want of information concerning the currents along the outside coast has been, more than ever before, pressed upon my attention. To obtain such information by systematic inquiry has always been a purpose recognized by the Coast Survey, but from the want of suitable vessels, the estimates for which, submitted during several successive years, were thrown out of the appropriation by Congress until 1876, it has been postponed from time to time.

The weather suitable for making good observations far out at sea, or in dangerous proximity to unsheltered shores, it was feared, would be passed before the vessel could reach the destined station; or it would be consumed in the observations themselves, and replaced by a storm, with an anchorage too near a lee shore. I have long been convinced that a staunch and carefully equipped vessel ought to ride safely at anchor anywhere along our coasts in depths less than one thousand fathoms, at the proper season, and that the difficulties were exaggerated.

Quiet weather and smooth water are not infrequent at any season, but they are of short duration, and it is only by patient waiting—not in *port* but upon the spot where the work is to be executed, through all states of the weather—that success can be assured.

When at last, in the appropriation for 1875–'76, Congress included the special sum necessary for the purpose, I had the little schooner Drift constructed, with every requirement of a good sea-boat, and when equipped sent her to sea under command of Acting Master Robert Platt, U. S. N., Assistant Coast Survey, with instructions to lie out at anchor on stations in the Gulf of Maine, in depths varying from thirty to one hundred and forty fathoms, till the particular project of work which I had arranged should be completed; returning to port only for supplies.

I am happy to say that Acting Master Platt, seconded very earnestly and efficiently by Ensign J. P. Underwood, has successfully begun this important work, and his early observations (only hastily examined as yet) give promise that the completed series will be far more important as aids to navigation, and far more interesting as an addition to our scientific knowledge, than I had anticipated.

The completion of the soundings in the Gulf of Maine had brought out upon the chart the extent and limits of the shoals lying between Nantucket and Cape Sable, which form, in effect, a bar or *sill* at the entrance to the great tidal basin between Massachusetts and Nova Scotia; and Prof. Henry Mitchell, Assistant Coast Survey, who has special direction of this work, as also that of the general physical hydrography of the Coast Survey, had been able to complete, from the tidal information of the various ports, how much flux and reflux of the sea, *in the average*, must occur at the bar or sill we have named; but how the *velocities* making up the average discharges over the sill disposed themselves among the shoals and channels, or how their exact directions or their times of recurrence should be stated, could only be made known by actual observation.

If we draw a straight line from Sankaty Head Light (Nantucket Island) to Seal Island Light, off the southwest point of Nova Scotia, we find, in a distance of two hundred and eighteen miles, the greatest depth one hundred and forty-five fathoms and the average seventy-eight, giving a section of six hundred and twenty-two million square feet. This line lies across the entrance to the Gulf, but it is within the *bar*. If, with this line as chord, an arc of a circle of one hundred and thirty-four and a half miles radius be described, we have a distance of two hundred and fifty-two miles, in which the average depth is but forty-two fathoms, giving for the section three hundred and eighty-six million square feet, a reduction of thirty-eight per cent. from that of the chord, notwithstanding the greater length. It was this arc, suggested by Professor Mitchell as the sill of the Gulf, that I designed to have gauged. Acting Master Platt's stations, eight in number, will be occupied for periods varying from thirteen to ninety-two hours, with observations at less than half-hour intervals. The stations are as near this arc and as near the proper relative distances upon it as could be expected of a sailing-vessel. I have no doubt we shall be able to issue tables, very shortly, by which the navigator may ascertain the velocity and direction of the current on any date and at any hour that he may find himself on this bar or sill.

In the course of the observations many incidents occurred to impress the officers of the Drift with the importance of their work, among others, the following: Wishing to go from one station to another which lay to windward, the party arranged their time of leaving and their tacks so as to *lee bow* the tidal current and thus make it do duty in their favor, at the same time observing that a brig, which occasionally came into view, was, from ignorance of the direction of the tidal current, working on an opposite rule and making no progress whatever; and long after reaching their station—indeed, for a period of thirty-six hours—they observed the brig returning again and again to her original position, when she should, with the knowledge that every sailor on the Drift already possessed, have been a hundred miles away on her true course. These incidents occurred in the neighborhood of George's Shoal, the most formidable danger in the track of our northeastern coast commerce, marked at that very time by the projecting top-masts of a vessel whose hull lay buried in the sands below, and whose crew had probably perished.

Acting Master Platt reports the existence or recurrence of many violent tide-rips, which will now receive, for the first time, definite location. He will also, in addition to the sea-current stations along the comparatively shallow arc of the Gulf, occupy current-stations along the outer coast of Cape Cod and between Cape Cod and Cape Ann, so as to complete the information required for the approaches to the harbors of Boston and Salem, Gloucester, &c.

To Prof. H. Mitchell has been assigned the work of discussing and obtaining final results from the observations made by Acting Master Platt.

CENTENNIAL EXHIBITION.

Among special attractions that distinguished the International Exhibition, at Philadelphia, in 1876, from preceding representations of the same kind, was the exhibit on the part of the United States Government of objects pertaining to the operations and results of its Executive Departments. It is now gratifying to record that the presentation suggestive of the resources and of the value of many practical operations in public work was in itself an imposing exhibition, even when surrounded by the splendors and profusion which illustrated the industries and luxuries of all the nations of the earth.

The requisite authority and provision in part for the governmental exhibit were granted by Congress early in 1875, and when the time approached for opening the Exhibition a government building erected in the Centennial grounds was partly filled by representative contributions from all the departments excepting the Treasury. The space in the building and the sum allotted to that department for incidental expenses were found to be inadequate, and at a late day it remained doubtful whether any exhibit could be made by the Coast Survey or other branches of service under the charge of the Secretary of the Treasury. Hence, although further provision was accorded in space and means shortly before the opening, only limited preparations at this office could be authorized or completed, the date which restricted the forwarding of articles being then near at hand. Richard D. Cutts, Assistant in the Survey, who had been one of the United States Commissioners sent to the Vienna Exposition, made the arrangements needful at the Coast Survey Office and at Philadelphia. The articles deemed most suitable for the occasion were selected, a descriptive catalogue was made, and within the space allotted in the government building that officer designated the position which each of the objects was to occupy on its arrival from Washington. By the unremitting exertions of General Cutts, and the activity of the mechanicians who accompanied the packages to Philadelphia, the various articles were in their assigned positions and ready for inspection on the 10th of May, the opening day of the Centennial Exhibition.

In the space allotted to the Coast Survey were arranged for convenient examination:

I. Characteristic specimens of instruments and apparatus employed in the geodetic, astronomical, topographical, and hydrographic operations of the survey, also for recording the tides and magnetic variation, and illustrative of the order, character, and precision of the field-work, and adjunct operations.

II. Results of the field and hydrographic operations as embodied in three hundred of the charts and sketches of the Atlantic, Gulf, and Pacific coasts of the United States, published for the benefit of commerce and navigation.

III. Reports and other publications in which the methods adopted in the field and at the office are described and discussed, and which have been published for the advancement of science.

IV. A complete set of the standard weights and measures of the United States, including also those of the metric system, and of the balances and comparators used in their adjustment at the Office of the Coast Survey.

The descriptive catalogue, preceded by a short historical sketch of the organization of the survey, will be published in the general report of the Centennial Board on behalf of the Executive Departments.

On the 1st of July, 1876, when all the details connected with the Coast Survey exhibit at Philadelphia, and the accounts for the expenditures incident to the arrangement of the articles were adjusted, General Cutts resumed field-work, further mention of which will be made under the head of Section II in this report. He was succeeded at Philadelphia by Assistant George W. Dean, who remained in charge of the Coast Survey property there until the close of the Centennial Exhibition.

Notwithstanding the uncertainty at the outset and consequent restriction in the time needful for preparation, the expression of intelligent visitors was that this exhibit of articles sent from the office showed evidence of earlyand steady foresight in regard to the requirements of commerce and navigation. Several of the most eminent scientific men of Europe after being at Philadelphia passed on to Washington, and in visits at the office cordially recognized its exemplification and results as worthy of a nation which is second to none in most of the practical appliances of life.

OBITUARY.

Since the close of the year, the labors of which will be detailed in this report, the field record has been marked by the untimely loss of one of the most talented and energetic of the assistants. Franklin Pierce Webber died in his tent near Woodville, Ala., on the morning of July 25, 1877, in the forty-first year of his age. Through life he had been of robust constitution, and was in the prime of useful powers when seized with remittent fever, which proved fatal in the course of ten days. We deplore the sad event, therefore, as a loss somewhat exceptional in the mortuary record of the service.

Our deceased associate was a grandson of a former president of Harvard College. His father, an officer of the Army, was in early manhood an intimate friend of the eminent citizen who afterwards became President of the United States. Of a lineage so honorable, Assistant Webber ably sustained his own degree. He entered the service of the Coast Survey at the age of seventeen, and even then manifested special aptitude as a computer and astronomical observer. Being by nature methodical and very discreet, he was soon assigned to field-work, and in after years steadily evinced sound judgment and energy in prosecuting the coast triangulation. Subsequently he conducted some important hydrographic surveys, and thus his name is intimately associated with several classes of work on the Atlantic coast and Gulf of Mexico.

In 1873 Mr. Webber was entrusted with the geodetic operations going westward from the Atlanta base-line towards the Mississippi River. In that responsible work he overcame natural difficulties that to many would have seemed insuperable.

His own personal exertions in the field doubtless induced the disorder which terminated fatally. He was earnest, loyal, and sincere towards his associates, and manifested the same sterling qualities in the conscientious performance of all his public duties.

PART II.

Under the heads of sections, beginning at the northeastern boundary on Passamaquoddy Bay, and following the Atlantic coast and Gulf of Mexico to the Rio Grande, separate statements will now be given of the work done in each locality to which a party was assigned in the course of the year ending June 30, 1877. The notices will be arranged in geographical order going southward, but for the Pacific coast the most southern locality will be mentioned first, and all others in geographical order going northward.

In details relating to the transportation required by field and hydrographic parties, including also the outfit and repair of vessels, the service has had during the year the able co-operation of Commander Edward P. Lull, U. S. N., as hydrographic inspector of the Coast Survey. All original sheets marked with soundings are verified under his direction in advance of their acceptance in the office as materials for charts. Commander Lull was assisted by Lieut. H. E. Nichols, U. S. N., until the 16th of April, when that officer was assigned by the Navy Department to service in the Mediterranean. In August he was replaced by Lieut. W. H. Parker, jr., U. S. N.

To the experience of Commander Lull in surveying, his professional skill, readiness in conference, and vigilance in regard to expenditures for outfits and repairs of vessels, I am indebted for relief from much anxious care and labor in hydrographic details.

SECTION I.

ATLANTIC COAST OF MAINE, NEW HAMPSHIRE, MASSACHUSETTS, AND RHODE ISLAND, INCLUDING SEAPORTS, BAYS, AND RIVERS.—(SKETCHES NOS. 2 AND 3.)

Coast hydrography off Mount Desert Island, Me.—For extending the coast hydrography to the northward and eastward of Isle au Haut a party was detailed in June of the present year to work under the charge of Lieut. J. F. Moser, U. S. N., Assistant Coast Survey, in the steamer Endeavor. After providing lumber for signals, the vessel left Rockland on the 26th, and at the close of the fiscal year the party was engaged in a general examination of the site of work. The projection sent to Lieutenant Moser will in the course of the summer be filled with soundings recorded in the sea approaches to Mount Desert Island, and as pertaining to the work of the present fiscal year the details will be given in my next annual report. Lieutenant Moser is aided in this section by Masters J. B. Murdock and F. E. Greene, U. S. N. Hydrographic operations by the same party will be subjects of mention under Sections II and IV in this report.

Hydrography of Eggemoggin Reach, Me.—In the work of previous seasons the hydrography of Eggemoggin Reach had been extended from its northern entrance in a direction southward and eastward nearly to the mouth of Benjamin River, in the vicinity of the town of Sedgwick. For completing the work, Lieut. J. M. Hawley, U. S. N., Assistant Coast Survey, sailed from Boston on the 24th of July, 1876, with his party in the schooner Earnest. A few days after a tide-gauge was set up on Chatto's Island, Centre Harbor, and by the close of the month the party was employed in erecting signals along the shores of the reach. The steam-launch Sagadahock, after slight repairs at Bangor, ultimately joined the party, and was used for hydrographic service. Soundings were begun by Lieutenant Hawley on the 7th of August, and the work advanced until the middle of September with favorable weather. The next fortnight was employed by the party at Northwest Harbor, Deer Isle, in the development of shoal spots which had been partially sounded by Lieutenant Hawley last year. While so engaged a dangerous sunken rock was developed near the middle of the channel between Eagle Island and Bradbury Island. The depth on the rock is eleven feet at mean low water. Directions for avoiding this danger were promptly reported by Lieutenant Hawley. The following are statistics of the work done in Eggemoggin Reach, part of which yet remains to be sounded, and of supplementary hydrography in the vicinity of Northwest Harbor:

Miles run in sounding	329
Angles measured	2,947
Number of soundings	30,279

The work here under notice was still in progress on the 9th of October, when Lieutenant Hawley received directions for sounding a harbor at the lower end of Isle au Haut. The vessel was detained at Brooklin, Me., by fresh gales until the 13th, after which date the incidents which resulted in great damage to the schooner and imminent peril to her officers and crew will be separately mentioned under the next head.

Head Harbor, coast of Maine.—In the plan of work for last year were included directions for developing the waters at the south end of Isle au Haut, and the party sent to that vicinity was accordingly furnished with a projection for plotting the soundings intended in Head Harbor. But owing to delays by bad weather at the general working ground the party was constrained to return at the close of the season without entering upon the hydrography at the south end of Isle au Haut.

Early in September of the present year urgent request was made by a corporation interested in the shipment of ice for the information needful for passing vessels in and out of Head Harbor. The schooner Earnest, then in service near by with the party of Lieutenant Hawley, was in consequence assigned to make the soundings. On the morning of October 14 the vessel got under way, stood out of Brooklin Harbor with fresh wind from the southeast, and at half past ten was at anchor in Head Harbor, which is entirely open to the sea from south around to west. The afternoon was spent in setting up a tide-gauge and in erecting and determining the positions of signals, as usual, in advance of running lines of soundings. Snow fell to the depth of three inches, and the wind was strong from the northeast. At eight o'clock in the evening of the 15th the wind backed to northwest and increased in force. As the schooner had a high hill for a lee, no uneasiness was felt on board, but close watch was kept upon the anchor-chains. Up to that hour the vessel had not dragged from either of the two anchors. In the course of the next hour, or about nine o'clock at night, the wind suddenly shifted to west-southwest, and blew a heavy gale directly from seaward into the harbor. The schooner dragged, struck, and swung broadside to the shore. Lieutenant Hawley promptly hove up the port anchor, in lieu of the chain bent on a five-inch hawser, and had the anchor carried well out to windward. By that expedient the Earnest was hauled out, and, being upon a lee shore in a harbor too narrow to work in, the starboard anchor was raised and sent out with fifteen fathoms of chain in hopes that both anchors might hold in the new position. But as the wind hauled to southward and westward the sea increased rapidly, and in about fifteen minutes the vessel commenced thumping under the starboard quarter upon a rocky bottom. Perceiving that this unfortunate condition was due to the fall of the tide, Lieutenant Hawley immediately gave orders to heave in on the hawser and starboard anchor, and the Earnest was again clear of the rocks. Presently the starboard anchor came home, but had quickly bent to it the other end of the hawser, and the anchor was taken out and dropped well over towards the opposite shore.

After midnight the sea was too heavy to admit of sending out chains, but the vessel still held by her hawsers. Lieutenant Hawley for additional security made a long line of the fore and main sheets and peak halliards, and had one end of it fastened to the western shore. The vessel then showed about an equal strain on each of the three fastenings by which she was held. As the tide was falling rapidly the precaution was taken to draw the vessel towards deep water by occasional pulls on the lines, and that expedient was effective until three o'clock in the morning of the 16th. But in the course of the next half hour, sea and wind increasing, the starboard hawser parted, the schooner swung around broadside to the wind, parted the shore line, and dashed violently on the rocks, at the same time bringing home the port anchor. All resources bearing on the safety of the vessel being exhausted, the officers and crew left the schooner. By the force of the sea the gig was dashed into small pieces on the rocks.

Notwithstanding the cold and the excessive labor which all had endured for many hours, another line was made fast to the port quarter of the vessel and hauled taut, in hope that the schooner might float when the tide (about ten feet) was again high. But as water appeared in the hold, Lieutenant Hawley ordered the movable property to be taken ashore. This was done by the exertions of Masters Richard Mitchell, G. C. Hanus, and A. H. Cobb, U. S. N., who were faithfully seconded by every man in the crew of the vessel.

Lieut. H. E. Nichols, U. S. N., assistant in the Coast Survey Hydrographic Division, was at

Head Harbor as soon as possible after the disaster and co-operated with Lieutenant Hawley and his officers in relieving the vessel. Subsequently it was found that the schooner had lost her keel, garboard streaks, and well logs. In that condition, however, the vessel was raised and beached at Head Harbor, and being subsequently filled with empty casks at low tide, was at high tide of November 14 successfully floated to Belfast, where temporary repairs were made, in order to secure the vessel for the winter. The Earnest was subsequently repaired and thoroughly refitted at Belfast, and during June of the present year was used for prosecuting hydrographic work in the approaches to Penobscot Bay.

When the mishap occurred at Head Harbor Mr. William E. Woodall, of Baltimore, the builder of the vessel, immediately proceeded at his own cost and, on viewing the schooner, offered advice and assistance for her recovery.

The Earnest having been built in composite style, iron frames and beams with wood planking, a style unknown to seamen on the coast of Maine, the knowledge of the constructor was of great use in relieving the vessel from her perilous situation. Great interest had been excited in regard to the ability of any composite vessel to withstand severe trials of strength, and this question was about to be solved. When taken out of the water at Belfast astonishment was expressed by seamen and ship-builders at the small amount of damage to the hull of the Earnest. The declaration was general that if the vessel had been entirely constructed with wood scantling, she must inevitably have gone to pieces on the rocky bottom of Head Harbor. As the composite style of building was adopted for the Coast Survey service after careful consideration, the issue of the severe test to which the Earnest was subjected has been at least some offset as against the cost of subsequent repairs. The refitting at Belfast was done by builders who had no concern whatever in the construction of the vessel.

For the disinterested action of Mr. Woodall, who declined reimbursement even for his traveling expenses, I take pleasure in recording here the acknowledgment of my obligations.

Tidal observations.—At North Haven, on the coast of Maine, the series of tidal and meteorological observations which were commenced in January, 1870, have been continued during the present year by Mr. J. G. Spaulding. The self-registering tide-gauge there in use is of the best construction and is furnished with heating apparatus to prevent the formation of ice near the float. By the care and attention of the observer interruptions in the series have been generally avoided. As usual, the record has been kept up by means of a staff-gauge when it has been necessary to stop the self-registering apparatus for cleaning or for repairs. The series at North Haven is, so far, one of the best on record.

Topography of the Penobscot River, Me.—The survey of the Penobscot was resumed early in August, 1876, by Assistant A. W. Longfellow, and has been extended along the west bank from Hampden up to Bangor and on the east bank from Orrington to Brewer Village. Mr. C. H. Van Orden was attached to the plane-table party as temporary aid. Among the details mapped are the line of railroad within working limits on the east side of the river, and on the west side the terminus of the Maine Central Railroad at the city of Bangor. County roads within the same limits were traced and mapped, as were also the surface features of the ground and improvements in their vicinity. The work was continued until the 25th of October. The part of the Penobscot remaining to be surveyed lies between the work done this season and the dam which limits the flow of the tide at a point about one mile above Bangor. A summary of statistics given in the field report shows, in addition to the aggregate of about twenty miles of shore-line traced in the preliminary survey of 1867, the following particulars:

Shore-line surveyed (miles)	12
Streams and brooks (miles)	8½
Roads (miles)	19
Area of detailed topography (square miles)	7½

The survey of the Penobscot will be resumed hereafter in the immediate vicinity of Bangor.

Hydrography, Saco River entrance, Me.—For the supplementary soundings needful in the approaches to Saco River a party was detailed early in September, 1876, to work under the charge of Assistant F. F. Nes. After establishing a tide-station and erecting signals, soundings were extended beyond previous limits abreast of Ferry Beach, to include the vicinity of Eagle Island

and Ram Island, on the north side of the entrance to the Saco, and also to the southward from the shore-line of Fletcher's Neck beyond the Hussey's Rock buoy. The weather was generally unfavorable, but at intervals the hydrography was continued until the 28th of October. The statistics of soundings are:

Miles run in sounding	34
Angles measured	396
Number of soundings	2,643

Unusually cold weather in the latter part of October made it impracticable to continue the soundings desirable in the approaches to the Saco.

Triangulation in New Hampshire.—This work has been further advanced by the occupation of two primary stations to the southward and westward of Mount Washington.

Prof. E. T. Quimby took the field early in June, 1876, established his party on the summit of Whiteface Mountain, in the town of Waterville, and was there engaged until August. The party was then transferred to Mount Lafayette. Unfavorable weather hindered the observations at both stations, but the angular measurements at Mount Lafayette were completed by the end of September.

In addition to careful measurements on primary signals, numerous secondary and tertiary objects were observed on from the stations occupied by Professor Quimby.

The summer months of 1876 are noted in the field-records of this party as unprecedented in the mountain region of New Hampshire for heat, drought, haze, and forest fires, all tending to retard the progress of work. During twenty consecutive days in August no outlying signals could be seen from Mount Lafayette. The observations of this season by Professor Quimby for connecting Mount Washington with the State scheme of triangulation were all directed to the iron chimney of the new hotel as a signal. The statistics of the season are:

Stations occupied	2
Angles observed, principal	27
Angles observed, secondary, &c	51
Angular measurements, horizontal	1,271
Angular measurements, vertical	1,032

The work here under notice falls in a quadrilateral, of which the points yet to be occupied are Mount Washington and, southeast of that peak, a mountain known as *Kearsarge*, in Carroll County, New Hampshire.

When the position of the last-mentioned mountain was determined approximately in 1851 by angular measurement from adjacent stations, the name of the station so determined was entered in the Coast Survey record of the triangulation as "*Pequauket*," a designation then warranted by occasional use in the county, and adopted rather than the name *Kearsarge*, as being conveniently distinctive in the record. It was known to the observers that one of the mountains in Merrimac County had been called *Kearsarge* for many years, and that it had probably borne no other name.

Whether or not the mountain in Merrimac was the first so named in New Hampshire, the fact has been brought to light by reference to the records of the official surveys that the mountain in Carroll County was known by the name *Kearsarge* in 1784, and probably earlier; and it is com monly so designated at this day. Old records, examined in the course of the research, show also that the name "*Pequauket*" applied about two hundred years ago, not to the mountain, but to a plain near its base, which plain was the site of one of the early settlements of New England. The use of the name "*Pequauket*" served in the Coast Survey record to distinguish in 1851 the station in Carroll County from the mountain (subsequently occupied with the theodolite) in Merrimac, but copies of early maps now on file in the Coast Survey Office prove that up to the year 1816 the mountain in Carroll was known only as "*Kearsarge*," and close inquiry shows that persons of great age and yet living have passed their lives near by without hearing any other name applied to it. The name "*Pigwackett*," as applied to a mountain upwards of three thousand feet high, appears first on the map published by Philip Carrigain in 1816. He thereon inserted the name as "*Pig-wackett, formerly Kiarsarge*." But map publishers since the year 1816 have, with few exceptions, restored the name "*Kearsarge*" as attaching to the mountain in Carroll.

As the printed records of the Coast Survey must become part of the permanent matter used for reference in the future, it seems proper to enter therein the names of the two mountains of New Hampshire so that the record may conform with the usage which has been most general in past years. The mountain in Carroll will therefore be designated in the Coast Survey record "*Kearsarge North*," and the mountain in Merrimac "*Kearsarge South*."

While prosecuting field-work in New Hampshire, Professor Quimby has had the advantage of direct correspondence with Assistant Richard D. Cutts, whose knowledge and experience have become the sources of valuable suggestions for securing success in triangulation.

Tidal observations.—Until the middle of February, when the recorder died, the tidal and meteorological observations were kept up at the Charlestown navy-yard, near Boston. The observer, Mr. H. Howland, a clerk on the receiving-ship, had been some time in bad health, but until his death had the occasional aid of friends in maintaining the tidal records. The series of observations at this station was closed on the 19th of February and discontinued. A very complete series of observations of high and low water had been recorded at the same station for a period of nineteen years. For predicting the tides the results have already become available by discussion in the office.

Since the year 1872 a self-registering tide-gauge of improved construction has been in use at Providence, R. I., the observations being maintained at the expense of the city. During four years the tidal registers and the forms furnished for tabulating have been regularly sent to the Coast Survey Office as an equivalent for the use of the apparatus. The observations thus recorded will materially aid in the investigation of the tides of Narragansett Bay.

Tidal currents, Gulf of Maine.—For the purpose of recording observations on the tidal currents between Nantucket and Cape Sable, the schooner Drift was refitted, and left New York early in June with a party under charge of Acting Master Robert Platt, U. S. N., Assistant Coast Survey. At Hyannis, Assistant Henry Mitchell joined the party for conference, and suggested in detail the methods for securing and recording the desired observations. On a chart stations were marked at which the vessel was to be anchored while currents in the vicinity were observed. At the first station, to the eastward of Nantucket, the Drift was anchored on the morning of the 6th of June in sixty fathoms of water. The day was passed in recording observations, and the record for the station was completed on the following day, showing the rate of current at the surface and downward to a depth of thirty fathoms. The density of the water was also noted and recorded. Acting Master Platt remarked that the flood-tide, *swell*, or *sea* showed distinctly just before the last of the ebb. "These swells begin and increase until about three-quarter flood; then the sea becomes more quiet, and at high tide they become regular. As the ebb-tide makes, the swell begins to go down and at about three-quarter ebb it becomes quite smooth."

North of Nantucket other current stations will be occupied in the course of the summer. The work then executed will be mentioned in further detail in my next annual report. Ensigns Albert Mertz and J. P. Underwood are attached to the party in the schooner Drift.

In October and November, 1876, repeated attempts were made by the party in the schooner Drift to observe for currents in the Gulf of Maine, but the weather was then too boisterous to admit of keeping the vessel at anchor for a period sufficient for completing observations at either of the intended stations. At the end of November the Drift returned to New York.

Triangulation of Taunton River, Mass.—In a preceding season the triangulation of this river was extended from the head of Narragansett Bay upwards to North Dighton. Subsequently the detailed topographical survey was carried as far up as Weir Village. To provide for completing the survey to the head of navigation, a party was sent to determine points intermediate between Dighton and the city of Taunton, and from the city eastward to include the manufacturing village known as Squaw-betty. For this work Assistant A. M. Harrison took the field on the 14th of August, 1876, aided by Mr. C. H. Sinclair, and during part of the season also by Mr. W. C. Hodgkins.

The banks of the river being thickly settled and affording no prominent hills, special care was exercised in the selection of points that would be intervisible without interfering with the numerous patches of forest trees, orchards, or tree-borders of roads. By the courtesy of residents, the roofs of a number of houses were marked with signals and subsequently occupied as stations with the theodolite by the use of a platform so contrived as to be easily removed from one and mounted on another house-top. Ground-stations were marked as usual to insure identification if the point should be needed at any future time. Of the fifty-two stations at which angles were measured, fifteen were on houses. The triangulation was completed on the 28th of November, and the work comprises the following in statistics:

Signals erected	54
Stations occupied	5
Angles measured	320
Observations with theodolite	5,668

Before leaving the vicinity of Taunton River, Mr. Harrison traced and added to the plane-table survey of the previous season several miles of the line of the Old Colony Railroad, to make the road appear continuous on the sheets above Fall River, the parts omitted in the survey being somewhat beyond the limit adopted for the detailed topography.

In preceding seasons most of the topographical details of the shores of Narragansett Bay were mapped by Assistant Harrison. Soon after the completion of that work Prof. N. S. Shaler, of Harvard College, made a special study of the geology of this part of the coast, and in doing so relied on the results of the plane-table survey. He thus refers to the advantage which the topographical representation afforded for his researches: "So perfectly has the topographer caught the expression of the surface of the country, that by studying the map of Aquidneck or Rhode Island, I have been able to determine the position of geological *faults* and the general character and dip of the rock even before visiting the localities, and at points where the uneducated eye would perceive no variety in the character of the surface. Most of the satisfaction and success which I have had in my work is due to the excellence of the plane-table survey."

SECTION II.

ATLANTIC COAST, AND SEAPORTS OF CONNECTICUT, NEW YORK, NEW JERSEY, PENNSYLVANIA, AND DELAWARE, INCLUDING BAYS AND RIVERS. (SKETCHES NOS. 4 AND 5.)

Topography of the vicinity of New Haven, Conn.—The detailed survey of the vicinity of New Haven has been extended by parties working under the charge of Assistant R. M. Bache. For the purposes of the plane-table work twenty-six points were determined by triangulation. On the eastern side of the harbor the details of topography were filled in to include the vicinity of Lake Saltonstall. From West Haven, on the opposite side of the harbor, the plane-table work was continued northward to the limit reached in other parts of the survey. Field operations were discontinued late in November, 1876, but were resumed at the opening of spring. The survey was steadily prosecuted until the end of the fiscal year, and is yet in progress. At the end of June the statistics of work added to the previous survey were:

Shore-line of rivers and creeks (miles)	77
Road (miles)	123
Area of topography (square miles)	39

An aggregate of about forty miles was run in lines traced with the spirit-level.

Pendulum experiments.—The work which has been prosecuted by Assistant C. S. Peirce was resumed at New York on the 1st of February, 1877. For determining the flexure of the pendulum stand numerous measures were made during February and March. Experiments with the automatic relay were then commenced, and the force of gravity was ascertained on the Repsold stand. These operations were continued until the middle of May, and similar experiments were made upon another form of support.

Subassistant Edwin Smith, under the direction of Mr. Peirce, commenced time observations early in March, and these were repeated on thirty-one nights preceding the end of June. In April a very extensive series of measures of the length of the pendulum was made, and at intervals these were repeated in May and June. At the same time optical measures of wave-lengths were recorded in good weather for the determination of a standard of length.

In the latter part of the fiscal year Assistant Peirce made a full set of experiments with the pendulum, uniform with a set which he had made in Europe for ascertaining the force of gravity. Of the operations here noticed further mention will be made in my next annual report.

Triangulation.—At the opening of the fiscal year Assistant Richard D. Cutts relinquished the charge of the Coast Survey exhibit which he had arranged as part of the International Exposition at Philadelphia, and early in July, 1876, resumed field-work in this section. At South Adams he found that the residents of that vicinity had opened a road to the summit of Greylock Mountain, and thus his party was enabled to proceed at once to the primary station which would have been occupied last season if facilities for reaching it had then existed. A temporary observatory was set up, the instruments were mounted, and camp was pitched on the summit of Greylock by the 12th of July. Between that date and September 9 the requisite horizontal and vertical angles were measured. Heliotropes were employed at Mount Tom, on Monadnock, on Greenwich Hill, on Helderberg, and at Prospect Mountain. The lines to these several stations vary from 38 to 62 miles in their distances from Greylock.

During August the work was retarded by causes that are somewhat common in other districts in that month, but which especially affected the atmosphere in the valley of the Hudson. A drought prevailed, and consequently continuous haze, and the smoke from furnaces at Troy and elsewhere along the river became, to an unusual degree, a hinderance to progress in recording the observations. The heliotropes could be seen only after a north or northwest wind or a rain storm from the west, the effect of which was to clear the air of the valley.

From Greylock, Assistant Cutts transferred his party to Helderberg, a summit 1,824 feet above tide, and about seventeen miles westward of Albany. Observations were begun at that station in the middle of September and were concluded on the 15th of November. In cloudy weather, generally, the heliotropes proved ineffective, but under clouds the atmosphere occasionally became such as to bring into view the distant signal-poles, when, at the same time, the heliotropes could not be seen. To the westward observations were made on the signal of a station in Otsego County, about thirty-six miles distant from Helderberg.

Assistant Cutts was aided in the field by Mr. J. F. Pratt. The following are statistics of the triangulation:

Primary stations occupied	2
Horizontal angles measured	26
Number of observations	1,317
Vertical angles measured	14
Number of measurements	415

In reference to means for ascertaining the heights of the triangulation-points above the sea, Assistant Cutts remarks in his report:

"As it was very desirable that the leveling should start from a correct base, connected directly with tidewater, the altitude above mean tide of the station-mark on Mount Rafinesque was determined, in the course of the season, by a line of spirit-levels forward and back. By means of this base, the heights of Monadnock and Mount Tom, of the primary triangulation to the eastward, could be checked, and the heights of stations in the interior of the country could be determined with unusual accuracy. The spirit-leveling up the Hudson River, by the Coast Survey, as far as Stuyvesant's Landing, was accepted as correct. From the bench-mark at the Landing to the bench-mark at Lansingburg the leveling done by Mr. R. H. Talcott (the mean of three separate and close lines of levels) for the improvement of the Hudson River was accepted as equally correct; and from the bench-mark at Lansingburg to the station-mark on Mount Rafinesque, the leveling was done under my direction by George R. Talcott, an experienced observer."

The original records of this work, and of the triangulation, have been duplicated and deposited in the office, with abstracts of angles and computations showing the lengths of triangle-sides, the heights of stations above mean tide, and the resulting values of the coefficient of refraction.

While at this station, and generally during the season, Assistant Cutts maintained correspondence with the several observers who have been accepted for the work of determining geodetic points in the States of the Union in which geological or other surveys are now in progress. His readiness and large experience in the field have been specially useful to the acting assistants in New Hampshire, New Jersey, Pennsylvania, Kentucky, Tennessee, and Wisconsin, who, being professors in colleges, need only the information which cannot be gained except by many years of observation and traversing all varieties of country through which triangulation has been prosecuted. Mr. Cutts has discussed the character of the work, so far as done in the States, with reference to the standard of accuracy deemed requisite for the operations of the Coast Survey, and, by his knowledge of the requirements, has secured the unity so desirable in regard to plan and method for the work already executed in the States, and upon which must ultimately be based the detailed surveys of their areas.

Tidal observations.—The series of tidal observations at Governor's Island, in New York Harbor, has been kept up by Mr. R. T. Bassett. Hot water is used freely during severe weather in winter, as without that expedient the continuity of observations could not be maintained. This series was begun on the 12th of December, 1852, but for several years immediately following, on account of frequent stoppages in cold weather, observations were omitted during winter. High and low waters were, however, recorded for those periods by a box-gauge on the Brooklyn side of the harbor. In 1861 winter observations were again resumed, and, with some unavoidable interruptions, they have been kept up to the present time. The apparatus in use is of the old form, and without recent improvements, but the experience of the observer has enabled him to furnish good records of the tides. The same observer makes day observations at Hamilton Avenue Ferry wharf, in Brooklyn, for comparison with the series at Governor's Island.

The series of tidal observations started with a self-registering gauge at Sandy Hook, in October, 1875, has been kept up by Mr. J. W. Banford, at the station on one of the wharves of the New Jersey Southern Railroad. The observer having charge of the depot, and with a party of hands subject to his direction, is well furnished with facilities for keeping the tidal apparatus in order. Good observations have been returned, though at times the surface of the sea becomes quite rough. At this station the tides are greatly affected by winds, as must be the case in the immediate vicinity of the open sea. The position occupied by the tide-gauge seems to be as near the ocean as it is practicable to maintain the apparatus in steady operation at the entrance of New York Bay. A continuous series of observations at this station is very desirable.

Verification.—In November, 1876, my attention was called to a supposed decrease of depth near Buoy No. 2, in Gedney's Channel, entrance to New York Harbor. The schooner Drift having shortly afterwards returned to New York, directions were given to Acting Master Robert Platt, U. S. N., to examine the locality in question. For that purpose the vessel was got under way on the morning of the 7th of December, and soon after came to anchor near the railroad wharf at Sandy Hook, to note the condition of the self-registering tide-gauge before beginning the soundings needful in Gedney's Channel. The Drift remained comfortably at her anchorage during the night of the 7th, although the breeze was strong from the westward. Next morning the wind was quite fresh from the northwest, but as it moderated at 9 a. m. the vessel proceeded to the working-ground and recorded soundings near Buoy No. 2 until two o'clock in the afternoon, when the wind began to blow hard. As the weather at the same time became very cold, Acting Master Platt recalled the sounding-boat, and returned to his anchorage inside of Sandy Hook. At midnight the barometer did not indicate much change, but the temperature had sunk to 20° above zero. The wind at that time was from the southeast, with snow-squalls. The vessel was held by two anchors, and when the land could be seen good ranges were taken, and it was not deemed necessary to change the position. Early next morning the wind suddenly shifted to northward and westward, making Sandy Hook a lee shore. In half an hour the anchorage was swept by a hurricane, the barometer sunk rapidly and the thermometer stood at 10°. The sea became very rough, the schooner shipped much water, and ice formed thick and fast on the deck. Presently the vessel began to strike the bottom at every heavy swell of the sea. Signals were made to several tug-boats that lay near the railroad wharf, and though one of them instantly moved towards the Drift, the attempt to reach her was twice unsuccessful. In a third effort a second tug joined, and by hard work passed a hawser on board the schooner. The Drift was then towed in near the railroad wharf.

Three schooners and a steamboat were thrown on the beach by the hurricane; the damage sustained by the Drift was inconsiderable. At the opening of the season the vessel was refitted, and has since been in service in the Gulf of Maine.

Acting Master Platt's report on the incidents attending the hurricane encountered in Raritan Bay, states that the officers, Acting Ensign George Glass and Mates L. F. Lee and J. A. Smith, and the crew of the Drift behaved with great spirit and energy notwithstanding the extreme cold to which all were subjected.

Triangulation in New Jersey.—At the end of July, 1876, field-work was resumed near Caldwell where it was hoped that a station might be found for connecting the primary triangulation which crosses the State of New Jersey with the system of triangles laid out under the direction of Prof. G. H. Cook, to the northward of Morristown. Early in August, Prof. E. A. Bowser commenced the erection of signals at stations which he had previously selected. When requisite, in order to bring others into view, he also put up elevated scaffolds to sustain the theodolite while angular measurements were in progress. Of the stations selected, Goat Hill and Mount Rose were occupied in the course of the season. Under the direction of Professor Bowser, a line of levels was run from a bench-mark near the lock of the Delaware and Raritan Canal feeder, at Lambertsville, up to Goat Hill station, with a view to determine the height of that triangulation-point above mean tide. Field-work was discontinued in January, but was resumed in May of the present year. The observations required at Goat Hill, Mount Rose, and Newtown were completed in the month following—and as the triangulation in Eastern Pennsylvania connects with those stations directly, and thus also with the completed primary triangulation of New Jersey, the length of the triangle sides in Pennsylvania will become readily known by computation. As yet no base-line has been measured in either of the two States. The aggregate statistics of the work of the past fiscal year in New Jersey are:

Stations occupied	2
Angles measured	15
Number of observations	1,251

In the progress of this work Professor Bowser was advised, from time to time, by correspondence with Assistant Richard D. Cutts.

Hydrography of Barnegat Bay, N. J.—The hydrography of Barnegat Bay has been completed by a party working under the direction of Lieut. J. F. Moser, U. S. N., Assistant Coast Survey, with the schooner Bache. In a previous season soundings had been extended from the entrance upward to the vicinity of Tom's River. At that limit the hydrography was resumed by Lieutenant Moser on the 23d of August, 1876, and was carried forward with the schooner as long as was found to be practicable with a vessel of that draught. Subsequently the barge which had been in use while the plane-table survey was in progress proved available for completing the soundings above the mouth of Tom's River. That branch of the bay, and also Mosquito Cove, Kettle Creek, and the lower part of Metitiniconk River, are included amongst the details on the hydrographic sheet. While soundings were in progress a tide-gauge was kept for record at Sea Side Park. Later in the season a second gauge was established in Kettle Creek, and after the middle of September observations were recorded with a third tide-gauge in Tom's River. The hydrography of the bay and its branches was completed by the 5th of October. Some of the points established in the triangulation of Barnegat Bay had been obliterated by the action of the sea, but enough were identified by Lieutenant Moser to suffice for the hydrographic survey. The statistics are:

Miles run in sounding	228
Angles measured	2,206
Number of soundings	25,113

The improvements erected at Sea Side Park since the completion of the plane-table survey were located by Lieutenant Moser and marked on the hydrographic sheet.

Under the head of Section IV notice will be taken of the subsequent work of this party. In both sections Lieutenant Moser was aided by Master J. B. Murdock and Ensign O. W. Lowry, U. S. N.

Coast Pilot.—The work of compiling and preparing for publication the Coast Pilot for the Atlantic coast has been continued by Assistant J. S. Bradford. In October, 1876, with a party in the schooner Palinurus, he examined the coast of New Jersey between Sandy Hook and Delaware Bay. The dangers incident to navigation along the outer coast were carefully noted, and special examinations were made of Little Egg Harbor and Absecon. In proceeding up Delaware Bay search was made for a shoal spot said to have only six feet of water to the westward of Brandywine Shoal, but no danger to navigation was found in the place indicated, nor was its existence known amongst the bay pilots.

The examination of the Delaware was extended as far up as Trenton. As heretofore, views of prominent points on the bay and river were drawn by Mr. John R. Barker, who accompanied the party in the Palinurus. In passing the coast of New Jersey the entrances were sketched as usual for the Coast Pilot, and the views were as soon as practicable etched for printing.

Lieut. Frederick Collins, U. S. N., accompanied the party in the schooner Palinurus, and at the close of work, which will be noticed in the next section of this report, took command of the vessel for duty on the southern coast.

The preparation of the notes compiled for the second volume of the Coast Pilot, including thirteen views drawn in the course of the season, is well advanced and the matter will shortly be in readiness for publication.

Triangulation in Pennsylvania.—Field-work was resumed in this State in the middle of June, 1876, by Prof. L. M. Haupt, and was prosecuted until the 26th of November. The reconnaissance for points of triangulation was continued until the connection of the scheme in Eastern Pennsylvania with the scheme of triangles laid out in New Jersey proved to be entirely satisfactory. By the selection near Allentown of a station intervisible with a summit in the upper part of Bucks County, the system of work was further improved, and to the southward and westward stations were finally chosen for extending the triangulation to the Susquehanna River.

In order to adjust the scheme in its approximate geographical position, Professor Haupt measured a short base in the preceding year and observed for latitude and azimuth, but no site has yet been found suitable for a base on the measurement of which the lengths of the triangle sides will depend. A site in the vicinity of Lonsdale, on the line of the North Pennsylvania Railroad, has been under consideration, and may be available if required for the desired measurement and for connecting properly with the triangulation above Philadelphia. Some of the southern stations in the scheme laid out by Professor Haupt may prove to be intervisible with points occupied in the triangulation of Chesapeake Bay, in which case no base of verification will be required within the present limits of the field-work in Pennsylvania. The statistics of the triangulation are:

Signals erected	8
Tripods	6
Stations occupied	4
Horizontal angles measured	17
Number of observations	1, 337

In addition to the operations of his own party in the northern part of this section, Assistant R. D. Cutts gave close attention to the interests of the field-work in New Jersey and Pennsylvania. In both States the schemes as developed by reconnaissance from time to time were carefully examined, and the conditions essential to the success of the work were made known by the correspondence of Mr. Cutts with the observers.

SECTION III.

ATLANTIC COAST AND BAYS OF MARYLAND AND VIRGINIA, INCLUDING SEAPORTS AND RIVERS.

(SKETCH No. 6.)

Coast Pilot.—In November, 1876, after closing work in Delaware River, Assistant J. S. Bradford, accompanied by Lieut. Frederick Collins, U. S. N., proceeded with the schooner Palinurus southward of Cape Henlopen. The coast approaches and inlets along the seaboard of Delaware and Virginia were examined by Mr. Bradford, and, under his direction, views of special localities were drawn by Mr. J. R. Barker both of the outer coast and of points along the shores of Chesapeake Bay. The weather proved to be exceptionally severe, but work was continued until the 7th of December, when further operations were stopped by the prevalence of ice at the head of the bay. Assistant Bradford, in consequence, returned to Baltimore. The command of the vessel was there transferred to Lieutenant Collins, and preparation was made for continuing examinations and the preparation of sailing directions, etc., below Cape Henry. Mention of the work done by the party in charge of Lieutenant Collins will be made under the head of Sections IV and V, in this report.

Upward of fifty views were drawn by Mr. Barker, of points indicated by Assistant Bradford, along the outer coast and the shores of Chesapeake Bay. During the winter the material collected under his direction was compiled at the office and arranged for publication. In addition to the personal oversight of details relating to the Coast Pilot, Mr. Bradford retained charge of the Engraving Division of the Coast Survey Office until the end of March, when he was relieved by Assistant L. A. Sengteller.

Positions of United States life-saving stations.—Last year the positions of life-saving stations north of the entrance to Delaware Bay were determined by Assistant F. H. Gerdes, and were carefully marked on the original plane-table sheets proper to the localities of the stations. In continuation of the service, Mr. Gerdes proceeded to this section late in September, 1876, and in the following month determined in position the stations at Cape Henlopen and Indian River, on the coast of Delaware; at Green Run Inlet, on the coast of Maryland; and at Chincoteague, Cedar Island, Hog Island, Cobb's Island, and Smith's Island (Cape Charles), on the coast of Virginia.

The inspector of the life-saving stations, Capt. J. H. Merryman, of the United States Revenue Marine, afforded many facilities for the work of this and the preceding year in giving notes of the best routes for reaching the stations and in regard to their approximate positions. With these Assistant Gerdes was enabled to identify the localities by examining the plane table sheets, and, as data for the field operations, tracings were made of the vicinity of each of the stations.

Various methods were used for determining positions. When the locality could be identified on the topographical tracing, angular measurements were recorded, the object in such case being light-houses, old buildings, or sharp and well-defined points in the topography. If no conspicuous object was in view, linear measurements were made, to determine the distance from the station to the nearest objects that had been previously ascertained in position; these, in a few cases, being points used for the coast triangulation. The report of Assistant Gerdes was accompanied by sketches and descriptions of the stations. After his arrival at the office in Washington positions were carefully plotted from the field-notes, and the original topographical sheets were marked to correspond with the positions of the life-saving stations of the fifth district. Assistant Gerdes was aided in the field by Mr. Hugh Caperton.

Baltimore Harbor.—For the special survey of the harbor of Baltimore, for which work means were appropriated by the legislature of the State of Maryland, a careful triangulation was made by Assistant J. W. Donn, in July and August, 1876. Subsequently the entire wharf-line was measured carefully as a check and for comparison with the determinations of the plane-table. As usual, the work was done entirely on the ground, the only record being the delineations shown by the topographical sheets. Comparisons were constantly made with the measured lines of the wharves, piers, and docks, and the agreement left nothing to desire in point of accuracy.

"In extending the survey along such parts of the harbor-line as were not occupied by wharves or piers, and which could not be clearly determined otherwise, a leveling instrument was used to mark out the line of mean high water. This plane was ascertained by a series of day and night observations extending through two lunar months. Tide-stations were established at Henderson's wharf, Fell's Point; Woodall's floating dock, Locust Point; Bollman's wharf, Canton; and at Winans' dock, on the Patapsco River front. The series was recorded at the Fell's Point gauge, and, during a calm season, free from winds and abnormal tides, simultaneous observations were made to determine differences of period of maxima of flood and ebb. These differences were found to be less than fifteen minutes, or practicably inappreciable in the limited tidal flow of the harbor, which the mean of one hundred and fifteen tides shows to be 1.16 feet or four-hundredths of a foot less than that established for the station at Fort Carroll."

Soundings were commenced early in October and were continued uninterruptedly until the part of the harbor known as Spring Garden was closed by ice. While the hydrography was in progress, Assistant Donn surveyed the shores of the Patapsco on both sides of the harbor, and mapped the results on a scale of 300 feet to the inch. The space between the head of the basin and the water front of Canton was surveyed on a scale of 150 feet to the inch. On the south shore of the Patapsco the details were mapped from the Long Bridge to the bulkhead at the Marine Hospital. The hydrography represents the depths found between Spring Garden, Ferry Bar, Bush Point, at Brooklyn, and a line extended from the bulkhead of the Marine Hospital to the lower wharf of the Stickney Iron Company, at the Lazaretto. The area of the basin and harbor to Canton was sounded, and plotted on the scale of the topographical sheets that cover the same locality.

During intervals of weather unfavorable for work in the field or afloat, the reductions, computations, and other details pertaining to the work were completed. Assistant Donn closed active operations at Baltimore at the end of the year, and resumed the survey of the James River, Va., as will be mentioned under a separate head in this chapter.

On the 1st of June of the present year the special survey of Baltimore harbor was again taken up at Spring Garden, and along the Patapsco between the drawbridge and Brooklyn, and west of the bridge.

The recorded details show that in the course of the survey seventeen thousand four hundred soundings were made, and that one thousand four hundred and forty-three angles were measured for determining the position of the boat while sounding in midwater. The positions of the ends of the lines were ascertained by means of the plane-table. The principal lines of soundings were run parallel to the meridian, and cross or check lines were run at right angles to them.

Lines of levels were run between the tide-gauges at Henderson's, Bollman's, and Woodall's, but no appreciable difference of planes was detected. The same result was found by recording simultaneous observations of the tides.

The following is an extract from the concluding report of Assistant Donn:

"The kindness and consideration of the mayor of Baltimore, Hon. Ferdinand B. Latrobe, were manifested on many occasions during the progress of the survey. Previous to the conclusion of arrangements with the State comptroller for a supply of funds, and when money was needed to forward the work, the mayor advanced means, which were subsequently replaced from the State appropriation by Hon. Levin Woolford, the State comptroller. As chairman of the harbor board of Baltimore, the mayor issued a request to pilots and captains of vessels to give the right of way throughout the harbor to the sounding-boat while at work, and thus the progress in hydrography was greatly facilitated, as the request of the mayor was generally acceded to."

This elaborate survey is represented by five topographical and five hydrographic sheets, all of which will be in request for the uses of a board constituted by the President of the United States, in May, 1876. As defined in the direction from the President, the duties of the board include "the survey of the harbor of Baltimore City and the adjacent waters, and the establishment of the river and bulkhead lines thereof." The members are, General A. A. Humphreys, Chief of Engineers; the Superintendent of the Coast Survey; and Maj. W. P. Craighill, Corps of Engineers.

Magnetic observations.—The usual annual observations for the determination of magnetic declination, dip, and intensity were recorded by Assistant Charles A. Schott, on the 14th, 15th, and 16th of June, 1877, at a station on Capitol Hill, in Washington City, intermediate between the

Capitol and the station at which observations had been regularly made in preceding years, and which was of necessity abandoned when the ground on which it stood was required for buildings. At the two sites, the magnetic dip and intensity are very nearly the same, but declination at the new station is affected by differential local disturbance, although the position is only nine hundred and fifty feet northwest of the old station, which was first established in the year 1866.

Boundary between Maryland and Virginia.—Mention was made in my last annual report of the assignment of Mr. Charles Junken for the topographical survey of such parts of Smith's Island in Chesapeake Bay as might be deemed requisite by the boundary commissioners of Maryland and Virginia, when the members, who were present at Crisfield early in July, 1876, were in conference respecting the dividing line between the two States. In accordance with their request Mr. Junken made a complete map of the island south of Mister's Thoroughfare, and another showing parts of the country west of Pocomoke River, in the vicinity of the boundary. Maryland was represented at Crisfield conference by the Hon. Isaac D. Jones, and Virginia by the Hon. R. T. Daniel and Hon. William J. Robertson. The special requests of each member of the commission in respect of measurements between indicated points were complied with. Mr. Junken also endeavored to identify the outlines of tracts of land on Smith's Island, described in deeds of 1685 and 1693, in which reference is made to the dividing line between the States. Early in January of the present year, when the arbitrators on the disputed part of the boundary were about to enter upon their duties, and in accordance with application made by their chairman, Hon. J. S. Black, several backed copies of the engraved chart which represents Chesapeake Bay, eastward from the mouth of the Potomac River, were furnished for the use of the board. One of the sheets, duly certified as being a copy of those retained by the board, and marked correspondingly with the line indicated by the arbitrators, was returned by them, and is now on file in this office. If the division line thereon marked is accepted by the two States, the sheet will be of interest as showing the settlement of a dispute of very long standing in regard to State limits.

Topography of James River, Va.—This work was resumed early in February, 1877, by Assistant J. W. Donn, whose party had been previously engaged in the special survey of Baltimore Harbor, as stated under a preceding head.

Between Westover and points near Richmond signals had been set up early in 1876, and some of the stations were partially occupied before the party was recalled from the section, on account of danger to the vessel from running ice in the river Fortunately the points remained without disturbance and were available for the uses of the plane-table party. Resuming work at City Point, Assistant Donn occupied in succession all the stations with the theodolite, and perfected the triangulation of the river to Richmond. Subsequently the shore-lines were traced and the usual margin in topographical details was mapped, including the lower parts of creeks, or branches of the main river as far up as Kingsland Creek, or within nine miles of the city.

One of the features delineated on the topographical sheet of this season is the Dutch Gap Canal, in reference to which Mr. Donn observes:

"Important changes in the hydrography of the river have followed the opening and deepening of the canal both below and above that work. The great bend of the river, cut off by the severance of Farrar's Neck, has shoaled, and at the western curve a bar is forming that will render navigation difficult or impossible at no distant day. At the present time the large steamers of the Old Dominion Line pass around the bend when the currents through the gap make its passage difficult for vessels of considerable length. Above the gap the changes are slight, except where obstructions were placed during the war."

Field-work was closed below Richmond on the 25th of May. The statistics are:

Stations occupied	23
Number of theodolite observations	2,556
Shore-line surveyed (miles)	87
Roads (miles)	85
Streams (miles)	50
Area of topography (square miles)	34½

After the return of the schooner Scoresby with the party, to Baltimore, Assistant Donn resumed work in the special survey of that harbor, of which notice has already been taken in this chapter.

Norfolk Harbor, Va.—Mention was made in last year's report of a physical survey executed for, and partly at the expense of, the harbor commissioners of Norfolk and Portsmouth, Va. Since the completion of the field-work of this survey much labor has been necessary to reduce the data to proper form for easy reference and use; and the Coast Survey has, at the request of the United States advisory board to the aforesaid commission, furnished the necessary computers without charge.

To give the utmost simplicity to the results of the current observations they have been tabulated so as to present in each case three observed and two derived elements. The observed elements are width, depth, and velocity; the derived data are mid-area and mid-volume. The observed elements when plotted develop two curves, one of which is the perimeter, the other the transverse curve of velocities—the former actually existing as the profile of the cross-section, and the latter no less real. If, for instance, standing at a height above the stream, one were to strew floats across from shore to shore, he would see them begin immediately to bend from the straight line, those at the axis of the stream moving faster than those near the shore, etc., so that after the lapse of our unit of time the floats would lie in a curve—and this is the transverse curve of velocities above mentioned. This curve of forces is seen to be related to the curve of depth, and if the bottom is yielding, the profile of the section is seen to be that which the forces have impressed upon it; in other words the channel is in a general way the mold of the forces grouped within it.

This statement of the general case loses somewhat its simplicity of meaning when tidal harbors are in question, because then successive groups of forces in opposite directions alternately appear; but the proposition holds. The depth excavated in a muddy bottom is a measure of the highest scouring power; and where ebb and flood streams are respectively compared with the profile of the section it is generally found that the stronger current is that which has left its furrow. Usually the ebb stream is the stronger, but not in every section and not even in every part of the same section.

The practical bearing of these studies lies in the use of their results as guides in the laying down of port-warden lines or lines beyond which no encroachments can be authorized. Such lines have too often been drawn upon the authority of legislative committees or commissions without any stated reasons, and have as often been abrogated upon as good authority and equally without stated reasons. A physical objection to the further projection of a wharf, while it may be inadequate as against the development of great commercial advantages, is exceedingly valuable as weight in the scale when rival commercial interests are balanced, because the whole community are taxed in the violation of a natural law, and will not permit it to be done with impunity.

The determinations of mid-area and mid-volume as guides in the projection of harbor-lines were introduced by Mr. Mitchell of the Coast Survey, and are regarded as furnishing better criteria than the lines of equal depths (submerged contours) and the lines of equal velocity (isodynamic lines), although these elements are still considered of great value.

In alluvial channels that are not in process of change he finds then two elements coincident, and therefore concludes that to bring the banks of a channel into a state of repose, the tendency of all constructions must be towards pushing together the axes of sectional area and discharge.

The tables containing the data from the physical survey above referred to were prepared by Mr. John B. Weir, aid in the Coast Survey, who, having made the original observations in the field under my instructions, was deemed the most reliable computer for reducing the results.

Topography eastward of Norfolk, Va.—For extending the plane-table survey in this quarter Assistant C. M. Bache took the field on the 1st of October, 1876, with a projection made to receive the topographical details found between the eastern branch of Norfolk Harbor and the south side of Chesapeake Bay. The ground passed over presents no elevations, but is much intersected by tide-water creeks with numerous branches. Eastward the plane-table survey was extended to Kempville. The upper waters of Tanner's Creek were traced, as also Broad Creek and other water-courses found between it and the beach, together with the line of canal that joins Tanner's Creek and Little Creek. All the roads within the limits of the plane-table sheet were traced and mapped.

Assistant Bache continued his field-work until the 19th of June and then stored his camp equipage at a station convenient for resuming the survey hereafter. The topographical statistics are:

Shore-line surveys (miles)	76½
Roads (miles)	90½
Area of topography (square miles)	35

Tidal observations.—The observations at Fortress Monroe have been kept up by Mr. W. J. Bodell, with a self-registering gauge of the improved form. Previous to 1873 much difficulty in maintaining the series was experienced with the use of an ordinary pendulum clock, for giving motion to the apparatus, by reason of the jars caused when steamers touched at the wharf. A very decided improvement in the record was gained by substituting a clock with balance-wheel and lever escapement, and clocks of that kind are now employed for all stations subject to disturbance.

The tide-gauge at Fortress Monroe is furnished with an enameled wrought-iron float-box, to obviate the difficulties noticed in regard to that part of the self-registering apparatus at this and other stations.

Reconnaissance.—In September, 1876, Assistant S. C. McCorkle resumed the examination for stations of triangulation to connect the primary work in the Shenandoah Valley with points on the Ohio River, across Western Virginia. The region of the Kanawha River was traversed, but no suitable point east of the Elk was found for extending the scheme of triangulation westward.

In reference to the country west of Charleston, the field report represents that the topography presents natural difficulties to progress in triangulation. "Continuous ranges of hills and peaks, varying but little in height, and all, or nearly all, heavily wooded, are met in going westward. Every promising peak was visited, and it seems probable that lines of ordinary length for primary work can be observed only from elevated scaffolds." Toward the Ohio, the prospect seemed even less favorable for long lines between intervisible stations.

The reconnaissance was continued until the end of November.

Mr. McCorkle, on his return from this section, filed descriptive notes of the region about Table Rock Mountain and Gibson Knob, in Kanawha County; of Pigeon, or Middle Creek Mountain, in Lincoln County; of Lick Creek Mountain, in Putnam County; of Rich Knob, in Cabell County; and near the Ohio River, of Williams' Knob, in Wayne County. These notes include the approximate bearings of outlying points; mention of the character of each station; and the roads and directions for reaching the points mentioned in the list.

SECTION IV.

ATLANTIC COAST AND SOUNDS OF NORTH CAROLINA, INCLUDING SEAPORTS AND RIVERS.—(SKETCHES NOS. 7 AND 8.)

Primary triangulation in Virginia and North Carolina.—At the opening of the present fiscal year, Assistant A. T. Mosman was engaged with his party at Flat Top (Peaks of Otter) in extending the triangulation southward along the eastern slope of the Blue Ridge. Rain prevailed at that station in July, 1876, and the weather proved to be very hazy in August; but the measurement of horizontal angles at Flat Top was finally completed on the 2d of September.

Buffalo Mountain, lying to the southward and westward, was next occupied with the theodolite, and, under more favorable conditions of the atmosphere, the work requisite there was finished on the 16th of October.

The camp was then transferred by Mr. Mosman across the Blue Ridge to Moore's Mountain, in North Carolina. The necessity for determinations of latitude and azimuth at this station involved much labor in the transfer of the instruments to the top of the mountain and in mounting them suitably on stone piers. These requisite preliminaries occupied the party until the 6th of November, 1876, and a few days after the astronomical observations were begun. Generally, the weather was such as to favor the observations that were recorded at night for latitude and azimuth, and to retard the measurement of horizontal angles; which last-mentioned work was continued at Moore's Mountain until the 27th of December. Immediately afterward heavy snow-storms made the roads impassable for ten days, but as soon as practicable the instruments used at the astronomical station were safely stored at the foot of the mountain.

Of the three primary points here noticed, Flat Top Mountain is about four thousand feet high. Buffalo Mountain has nearly the same elevation. The height of the station on Moore's Mountain is upwards of fifteen hundred feet. From each of the points vertical angles were measured to determine the relative heights of outlying stations; and, as usual, horizontal angles were recorded to determine the lines of direction to subsidiary objects that could be recognized by the observers while they were engaged at the primary stations.

One of the lines of sight included in the operations of the triangulation party of this season is eighty-two miles long, and another, leading from the same station, is sixty-nine miles in length. From his station on Buffalo Mountain, Assistant Mosman exchanged signals with Assistant Boutelle, who, in recent years, has advanced the primary triangulation to the northward and eastward from the base-line near Atlanta, Ga. Nine nights were employed at Moore's Mountain for determinations of the latitude and azimuth. For difference of heights, ninety-eight sets of observations, including seven hundred and thirty-seven measurements with the micrometer, were recorded by Assistant Mosman and the two recorders in the party, Messrs. J. B. Baylor and W. B. Fairfield. Twenty volumes, containing field-notes of the work at the three primary stations, have been duplicated and placed in the office. The statistics of the triangulation are:

Stations occupied	4
Primary signals observed on	29
Number of observations	2, 610

Two hundred and fifty-two observations were recorded in addition, giving the direction of subsidiary objects from the primary stations.

In April, 1877, Assistant Mosman reorganized his party, and again occupied Moore's Mountain, at which station observations were completed by the end of May. The instruments were then moved and set up at Cahas station, where observations were in progress at the end of the fiscal year. The measurements requisite at that point were concluded on the 13th of July, and the statistics are embodied in the synopsis already given.

The expediency of employing, in connection with astronomical azimuth measures, a collimator placed near the theodolite while it is in use for measuring horizontal angles at the geodetic stations, or for using a transit instrument to serve both for the determination of azimuth and as collimator has for some years been under consideration in the office, and from time to time the method has been urged on the attention of some experienced observers, but has not yet been brought into general use in field-work. In November and December last, Assistant Mosman put the suggestions into practice at Moore's Mountain, using for the azimuth determination the 48-inch transit No. 8 of $2\frac{1}{4}$-inch aperture, fitted with an eye-piece micrometer-screw. The instrument was mounted in the meridian of the geodetic station on a solid pier, with a rock foundation, and only seven and a half feet distant from the theodolite which was in use for measuring the horizontal angles of the triangulation.

Merely as an additional test in details of the method, and for the alignment of the transit, Mr. Mosman directed the theodolite and transit on an ordinary distant azimuth mark, both instruments being previously adjusted for collimation, and moved the transit till its center wire was bisected by the cross in the theodolite, but, as he remarks, if full assurance of stability in regard to the transit can be had, the azimuth mark may be dispensed with by observing for azimuth with the transit at a time as near as possible to the observations for horizontal angles, and collimating the two instruments without delay.

By the method employed at Moore's station, Mr. Mosman reduced not only the direction to the azimuth mark but also the line of collimation of the transit itself, to every line of the triangulation, and thus obtained two results for azimuth, one on the mark in the usual way, and the other on the transit itself. He further remarks:

"Now, if the transit remained *stable*, by making the proper correction for its azimuthal deviation, a second result is obtained, and by comparing mean results from all the observations of azimuth during the night, reduced to any station by the theodolite, in all the twenty-three different positions used, we have a test of the amount of change in the direction of the transit."

The two azimuthal results proved fairly accordant, the difference being $0''.36$ as found by Assistant C. A. Schott, chief of the computing division, but in this case a theodolite was used that required a large number of positions of circle on account of the graduation, as stated by the observer.

Under the head of Section X mention will be made of the determination by Assistant Davidson of azimuth by means of a second telescope used as a collimator. In such case the collimator is not of necessity placed in the meridian of the geodetic station, as when properly adjusted it becomes a complete substitute for the distant azimuth mark heretofore used by observers in the field.

The principle relied on in substituting for the distant mark a collimator, whether that be a plain telescope, a transit instrument, or merely an object lens supplied with focal threads, and provided that its stability can be insured, is the fact that the cross-threads become the best and most convenient reference mark for azimuth that could by any possibility be procured.

Coast Pilot.—As already mentioned under a preceding head in Section III, the special examinations and compilation of sailing notes and descriptions for the Coast Pilot were continued after January, 1877, by Lieut. Frederick Collins, U. S. N., Assistant in the Coast Survey, with a party in the schooner Palinurus. From Baltimore that officer proceeded directly to the coast of Georgia, and afterwards along the coast of South Carolina, and was there engaged until the 17th of June, as will be mentioned in more detail under the head of Section V. In this section Lieutenant Collins subsequently examined the coast from Hatteras to Oregon Inlet. At the end of the fiscal year the vessel returned to Baltimore and was refitted for service in Section III. Masters Francis Winslow and A. H. Cobb efficiently aided in the work of the season.

Hydrography.—In five localities of this section the hydrography has been extended by Lieut. Richard Wainwright, U. S. N., Assistant in the Coast Survey, with a party in the steamer Arago. Between the 2d of November, 1876, and the 12th of March following, the work was advanced in the northern part of Pamplico Sound. With a separate projection the vessel then proceeded to Ocracoke Inlet, and was there employed until the 12th of April. The remainder of that month was occupied in sounding East Lake, one of the branches of Albemarle Sound. Hydrographic work was begun by the party in Currituck Sound on the 4th of May and completed in July, after which additional soundings were made in North Landing River. The aggregate statistics of the hydrography are:

Miles run in sounding	1,250
Angles measured	7,481
Number of soundings	87,678

Lieutenant Wainwright was ably assisted in the work of the season by Masters W. P. Ray and F. H. Lefavor, U. S. N.

Latitude and azimuth.—For the determination of azimuth at stations of the triangulation of Pamplico Sound, N. C., a party in the schooner Caswell was organized in July, 1876, to work under the charge of Subassistant Edwin Smith. The vessel left Norfolk on the 1st of August, but being delayed by head winds was unable to reach the station at Hog Island until the 7th of that month. The observations made between that date and the 28th of August were:

"Twenty-nine observations of thirteen stars on seven nights, to determine the rates and corrections of the chronometers. Sixty-seven observations of sixteen pairs of stars were made on seven nights to determine the latitude of the station. Fourteen sets of observations of six measures each were made on four nights for the azimuth of the line from Hog Island to Ocracoke Light."

"At this station observing was attended with many difficulties. The island is marsh, covered with a dense growth of reeds, below the roots of which the mud is very soft. During a fresh easterly wind the trembling of the island caused by the beating of the waves can be distinctly noticed. A solid foundation in such a place being impossible, a small tripod was set up and a platform built around it, with bearings fifteen and twenty feet from the tripod. On the platform the observer moved about with great care, so as not to disturb the instrument, but all other persons on the island were required to remain as quiet as possible. In this manner the time and latitude observations were recorded with good results."

At Hog Island the azimuth observations were made from the top of the tripod signal, which was occupied for the triangulation in 1873. As the telescope was more than fifty feet above the ground, azimuth observations could be recorded only when the nights were calm; but by using all precautions against disturbance, Subassistant Smith obtained results which have proved satisfactory.

The astronomical party was transferred to the station at Long Shoal Point on the 1st of September, and there the work was completed on the 22d of that month.

"Thirty-four observations of twenty-two stars were made on seven nights for corrections and rates of the chronometers; sixty-nine observations of sixteen pairs of stars were recorded on five nights to determine the latitude of the station, and eighteen sets of observations of six measures each were recorded on five nights for determining the azimuth of the line from Long Shoal Point to Sandy Point. In addition, sixteen sets of six measures each were made on five days of the angle formed by lines to Sandy Point and Gull Island, for obtaining the azimuth of the line from Long Shoal Point to Gull Island.

"The island on which the triangulation point is located is an oyster-reef covered with sand. When the instruments were set up the foundation was good, but during the storm of September 16 and 17 the water washed over the entire surface of the island."

The schooner Caswell returned to Norfolk, and was laid up at that port on the 27th of September. After completing the computations incident to his astronomical work in this section, Subassistant Smith was assigned to duty connected with pendulum observations.

Mr. Charles Tappan efficiently aided in the astronomical observations at stations in Pamplico Sound.

Hydrography of Core Sound, N. C.—For completing the survey of Core Sound, a party was organized by Lieut. J. F. Moser, U. S. N., Assistant in the Coast Survey, on board the steamer Fathomer, and reached the working ground in the middle of December, 1876. Operations were begun immediately, but were frequently interrupted by the unusual severity of the weather. At one time during the stay of the party the sound was frozen over from bank to bank, and on several occasions the work was prosecuted in open boats while the temperature was only 35° Fahrenheit. Having identified the station-marks of the triangulation adjacent to his work, Lieutenant Moser carefully replaced them, and secured, by additional marks, such points as seemed to be in danger of displacement, by setting in the ground heavy cedar stubs with the usual center mark.

Harbor Island Bar had been sounded in a previous season, but a new channel having broken through during the heavy gale of September, 1876, the bar was resurveyed by the party in the Fathomer. From that limit, after connecting properly with the work in Pamplico Sound, Lieutenant Moser extended the hydrography southward to Piney Point, on the south side of Nelson's Bay. Late in February, the work was there joined with the hydrography of the lower part of the sound, which had been executed in the previous season.

Lieutenant Moser states, in his concluding report, that he was ably seconded in all the operations of the season by Master J. B. Murdock, U. S. N., and Ensign O. W. Lowry, U. S. N., who were attached to the party in the Fathomer.

The statistics of the work done in Core Sound are:

Miles run in sounding	377
Angles measured	2, 932
Number of casts of the lead	36, 607

Of the body of water developed by the work in Core Sound, Lieutenant Moser remarks as follows: "Between Harbor Island Bar and Piney Point there is no periodical tide; the wind alone causes all appreciable changes of level. A northerly wind banks the water up into Core Sound, causing high water, and *vice versa*."

After completing the survey here under notice, the steamer Fathomer was passed to the southward of Beaufort, N. C., for service, which will be mentioned under the next head.

Hydrography of Bogue Sound, N. C.—For the completion of soundings in the inland water-passage west of Beaufort, N. C., the party of Lieutenant Moser was transferred from Core Sound, where it had been employed with the steamer Fathomer until the close of February, 1877. In Bogue Sound, hydrographic work was resumed on the 15th of March, and, with slight interruptions, was continued until the 21st of April, when soundings were completed. The hydrography is comprised between Mill Point and Bogue Inlet. In regard to the tides of Bogue Sound, Lieutenant Moser remarks:

"The tides are received from Beaufort Inlet as far as Broad Creek with height and velocity varying with the distance from the entrance. Between Broad Creek and Fresh Water Point the tides meet, and to the westward of Fresh Water Point the tide from Bogue Inlet is received. A southwest wind causes a low tide; a northeast wind makes a high tide."

Master Murdock, U. S. N., assisted in the hydrographic work in Bogue Sound. The statistics are:

Miles run in sounding	235
Angles measured	1,980
Number of soundings	24,338

Previous to entering upon duty in this section, the party of Lieutenant Moser had been employed in a survey which has been mentioned under the head of Section II.

Topography of Cape Fear River, N. C.—With his party in the schooner Caswell, Assistant C. T. Iardella reached Wilmington, N. C., on the 28th of January, and without delay took up the plane-table survey of the banks of the Cape Fear River a few miles above that city. The Northeast Branch and Brunswick River were traced, and the adjacent details were mapped. The survey includes Eagle Island, the river banks on both sides of the island, and the banks of the Cape Fear to points about two miles below the junction of Brunswick River. Beyond the rice-fields that occupy most of the area of Eagle Island, and nearly all the ground bordering the rivers, the roads were traced and represented as usual, with other surface details found within about three miles of the water-line.

Master G. C. Hanus, U. S. N., was attached to the party in the Caswell, and assisted in the field-work. The statistics are as follows:

Shore-line surveyed (miles)	21
Roads and railroads (miles)	115
Creeks (miles)	103
Dikes (miles)	44
Area of topography (square miles)	79

Field-work was closed for the season on the 10th of July. The schooner then returned to Baltimore.

SECTION V.

ATLANTIC COAST, AND SEA-WATER CHANNELS OF SOUTH CAROLINA AND GEORGIA, INCLUDING SOUNDS, HARBORS, AND RIVERS.—(SKETCHES Nos. 8, 9, AND 10.)

Primary triangulation.—For extending the primary triangulation through South Carolina in a direction northward and eastward from the Atlanta base, the party of Assistant C. O. Boutelle again took the field in June, 1876, near Spartanburg, in the northern part of that State. Upon the roof of Wofford College an observing tripod and scaffold had been erected by permission of the collegiate authorities, and thus was established the only point suitable in that region for conducting the primary triangulation across the boundary into North Carolina. The high signal at Wofford having been observed on last year from three of the stations then occupied, one of the observers of the party was sent to adjust the several signals, and arrange for their security while observations were in progress at the station on the college. Mr. H. W. Blair erected a signal at the primary station Benn, and also on Mount Mitchell, or the "Black Dome," in North Carolina, the recorded barometric height of which is 6,707 feet above the level of the sea. By angular measurements made in the course of the season the position of that mountain was approximately determined. At Wofford observations were commenced on the 6th of July, 1876, with the 20-inch theodolite, the instrument being on a platform, ninety-eight feet above the ground on which the college building stands. From that height the signal on King's Mountain was clearly visible over the intervening ridge. The measurement of horizontal angles was completed on the 7th of August. Additional observations were made in order to free the results from the effect of any want of stability in the structure which supported the theodolite, and from the effect of heat on the brick walls that sustained the temporary scaffolding. While observing vertical angles one person watched the level while another recorded, neither of them moving until the entry was complete.

Wofford station was marked by burying four stone posts in the college grounds, two of them south and two east of the station point. Deep diagonal grooves are cut in the heads of the posts, and lines drawn through the intersection of the diagonals will meet at the station, on the site of the college, if the building should ever be removed. For many courtesies during the occupancy of the station the party was indebted to the president of the college, Prof. J. H. Carlisle, and also to the Rev. Dr. Whiteford Smith, and Professor Du Pre. At this station six primary signals were observed on, and for approximate position and elevation, twenty-two subsidiary objects. After closing observations the instruments were transferred to Hogback Mountain, where angular measurements were begun on the 16th of August. The weather proving exceptionally favorable, all requisite observations were completed by the 2d of September. At this station the signal on Mount Mitchell, which is probably the highest summit in the United States east of the Rocky Mountains, was well seen and carefully observed on, as were also seven primary signals of the triangulation, and for approximate position and elevation forty-four subsidiary objects, including many of the highest mountains in North Carolina. The station on Hogback Mountain is marked by five stone posts, the positions of which are carefully described in the records.

In order to improve the scheme of triangulation, Assistant Boutelle deferred operations at King's Mountain, and passed on to Young's Mountain, in hope of finding it practicable as a station visible from King's and from other primary points. At Young's an observing scaffold fifty feet high was erected, and when the theodolite was in place all the signals connecting with it were in view. Horizontal and vertical observations were completed at that station on the 11th of November. Eight primary points and thirteen subsidiary objects were observed on. Assistant Mosman then at Buffalo Mountain exchanged signals with the party on Young's Mountain. The distance between the two primary stations is nearly seventy-four miles. Five stone posts were set in the usual manner to mark the triangulation point at Young's. Azimuth observations were made upon Polaris as heretofore.

For latitude forty-two pairs of stars were observed in two sets, one being observed by Mr. Blair, the other by Mr. J. B. Boutelle.

Having transferred his party to King's Mountain, Assistant Boutelle commenced observations there on the 26th of November, but bad weather frequently recurred after that date, and in the month following, signals only forty miles distant could rarely be seen. As a consequence the measurement of horizontal angles could not be completed before the close of the working season. During the dull weather, however, arrangements were made for determining the latitude. By the two aids, forty pairs of stars were observed in two sets, between the 4th and 14th of December. Azimuth observations were deferred, as no good image of the star could be obtained in the mercurial horizon, the narrow rocky crest at the station point being jarred by the winter winds. On the 24th of December snow fell on King's Mountain to the depth of a foot. Storm succeeded storm, and the party was detained at the summit, the elevation of which is 1,700 feet, until the 6th of January. In the course of the winter the records and computations of the work were completed and sent to the office.

Assistant Boutelle resumed field-work on the 30th of April, 1877. After adjusting and securing the signals to be observed on, the camp was again pitched on King's Mountain, but it became almost immediately necessary to remove the instruments and equipage. Fire, carelessly left by bee-hunters, started at the southwest base of King's Mountain, and rapidly swept towards the summit, bringing into jeopardy the persons of the party and the property in their care. This unusual condition of danger continued for three days and nights, but by constant exertion all loss was finally averted. During thirty consecutive days ending with the 7th of June no rain fell, and the mountain was enveloped in smoke and haze. Distant signals could not be seen, but the night observations were less hindered. A good azimuth was obtained between May 26 and the 2d of June; thirty-three series were observed. The azimuth here noticed gives a connected chain of azimuths at each end of a series of geodetic lines extending from the Atlanta base to Moore's Mountain, in North Carolina, a distance of more than three hundred miles. This sweep of triangulation skirts the southern and eastern flank of great mountain masses that attain their maximum height in Western North Carolina. The azimuths, as noticed by Assistant Boutelle, are a fine exhibit of systematic local deflections of the force of gravity, or, as more commonly stated, of the direction of the plumb-line. He states the results for each of seven astronomical azimuths, and the discrepancy of ten seconds between the most southern and most northern of the series he ascribes to local deflections. Dividing into three groups, the first and last showing two azimuths each, and the middle one three azimuthal results, he observes "that the mean of each group is *larger* than the preceding, showing a steady twist of the geodetic curve or north meridian towards the west (in the direction of the mountain masses), as the observations go easterly. It will be noticed that the first group (azimuths at the base and at Sawnee station) have the mountain masses bearing northeast of them; that the middle group (azimuths at Currahee, Paris, and King) would be affected about equally; while the two azimuths of the third group (Young and Moore's) have the masses bearing southwest of them, with the center of the area nearly at the same distance from a point midway from Young station to Moore station, and from Sawnee station to the Atlanta base."

At the southwestern stations the smaller azimuths, as compared with a mean of all the azimuths referred to one line, which is about midway in the chain of quadrilaterals, indicate that the zenith is deflected to the westward, whereas at the northeastern stations the azimuths being greater indicate that the zenith is deflected to the eastward. These facts seem to be accounted for by the local attractions of the mountain masses to the westward of the system of triangulation that follows the Blue Ridge from Virginia to Georgia. When the field-work is complete, these and like deflections in the observed latitudes and longitudes will be thoroughly discussed in the computing division of the office.

Having previously provided magnesium lamps, Assistant Boutelle made arrangements early in June for using them for the measurement of horizontal angles, the record of which had been much delayed at King's Mountain, and frequently at other stations. Mr. Blair having rejoined the party was sent to the station on Wofford College. The magnesium lamp was adjusted there for the direction to King's Mountain, thirty-nine miles distant, and was readily observed on by Mr. Boutelle through the telescope of the theodolite. On the 19th of June Mr. Blair showed signals with the same lamp from Paris Mountain, nearly sixty-five miles distant. The light was always seen through the telescope at King's, and during periods of greatest brilliancy was visible to the naked eye. The difficulty generally found in regard to steady delivery was so far remedied by Mr. Blair that during the last half hour of his operations on Paris Mountain the lamp was intrusted to the heliotroper, who succeeded well in showing a signal with the lamp. At both stations the magnesium ribbon was burned in the focus of an eight-inch paraboloid reflector, and the clock was adjusted to deliver the ribbon at the rate of fifteen inches per minute.

The measurements of horizontal and vertical angles on the outlying primary stations, and subsidiary objects in view from King's Mountain, were completed on the 27th of June. Assistant Boutelle then removed the instruments to the mountain station Benn in North Carolina, and in July resumed operations, of which notice will be taken in my next annual report. At the close of the fiscal year Mr. Blair was detached from this party and assigned to duty in Section VIII.

The statistics of the work of this section are:

Stations occupied	5
Primary signals observed on	16
Angles measured	26
Number of observations	6,677

Coast Pilot.—After refitting the schooner Palinurus at Baltimore, Lieut. Frederick Collins, U. S. N., Assistant in the Coast Survey, sailed from that port on the 28th of January. At Fernandina, Fla., the work needful at harbor entrances, in tests for sailing-lines, was begun early in the following month, and along the coast of Georgia was continued until the 15th of May.

A close examination was made of all the harbors and anchorages from Savannah southward, including Wassaw, Ossabaw, Saint Catharine's, Sapelo, Doboy, Altamaha, Saint Simon's, Saint Andrew's, and Cumberland Sounds, together with all the rivers and inlets connected with them. Sailing-directions for all the harbors, as well as for navigation coastwise, were duly prepared, and all dangers and obstructions to navigation were carefully described. The shores of Long Bay, between Cape Fear and Cape Romain, were also described, and a thorough examination was made of Cape Fear River and Frying Pan Shoals.

Subsequent work by the party in the schooner Palinurus has been mentioned under the head of Section IV.

Lieutenant Collins was ably assisted by Masters F. Winslow and A. H. Cobb, U. S. N. The work in this section occupied the party until the 17th of June. After returning to Baltimore, the vessel was refitted for service in Chesapeake Bay.

SECTION VI.

ATLANTIC AND GULF COAST OF THE FLORIDA PENINSULA, INCLUDING THE REEFS AND KEYS AND THE SEAPORTS AND RIVERS.—(SKETCHES NOS. 11, 12, AND 13.)

Tidal observations at Fernandina, Fla.—In previous reports, the purpose of establishing a tidal station on the coast of the South Atlantic States was mentioned, and provision was made accordingly by the construction of a self-registering gauge of improved form. Fernandina had been decided upon at the opening of the fiscal year, but the arrangements requisite for commencing the record of observations at the station were not then complete. The new gauge was therefore sent to Philadelphia, and appeared in the Centennial Exhibition, with other instruments and apparatus belonging to the Coast Survey.

Early in March last, Mr. R. S. Avery, of the Tidal Division of the office, having previously packed and shipped the tide-gauge for Fernandina, proceeded to that port, and on arrival called upon the Hon. D. L. Yulee, whose wharf, at the foot of Beech street, was found to be specially favorable as a site for the tidal station. With characteristic courtesy, a place was assigned for the structure and all needful assistance in its erection was tendered by Mr. Yulee.

After the erection of the tide-house and the establishment of the gauge inside, Mr. Avery securely placed three bench-marks on Beech street. One of these, at the intersection of Second street, coincides with the top of a piece of hard-burnt drain-pipe, about three feet long, set upright in the ground; another was made by setting upright in the ground, near one of the piers of the verandah of the Egmont Hotel, near its southwest corner, a cut block of granite; and for the third, copper nails were driven, at the level of the top of the granite block, into the trunk of a water-oak tree which stands two hundred and twenty feet westerly from the second, or granite bench-mark. Apart from the self-registering gauge, and separate from each other, two tide-staffs were set up in places convenient for observing. These, as at other self-registering stations, will serve for recording during any emergency that may require the repair or removal of the self-registering apparatus. From the several bench-marks, Mr. Avery carefully leveled to each of the tide-gauges and recorded the height of each bench-mark above the zero of the gauge.

When the meteorological instruments were securely fixed in place, Mr. H. W. Bache, as observer, took charge of the station. The tidal rolls since received from Fernandina give promise of good results and regularity in the series of tidal and meteorological observations.

Survey of the Saint John's River, Fla.—In the field-operations of the preceding year the shore-lines of the Saint John's had been traced by Assistant H. G. Ogden, from Jacksonville as far southward as Mandarin Point. The work would have been resumed early in the fiscal year, but for the prevalence of yellow fever in the vicinity during the summer of 1876. In the middle of September, however, the party was again at Jacksonville, and without delay the steamer Hitchcock was moved to the vicinity of Mandarin Point. Old signals were repaired and new ones set up along both banks of the Saint John's, and at the close of October the soundings had been extended from Jacksonville to Buckley's Bluff. McGirt's Creek, which enters the river on the western side, a few miles south of Jacksonville, was surveyed and sounded in connection with the work done in this part of the Saint John's. In the course of the month of November the topographical survey of the banks of the river was brought to Buckley's Bluff. The triangulation was resumed at Mandarin Point in December, and thence on until near the close of the season the several branches of work advanced together. At the end of May the plane-table survey had been extended to Patricio Point; the hydrography was brought to the same limit early in June, and by the close of the fiscal year the triangulation had been carried as far south as Tocoi, or about ten miles beyond the limits of work on the plane-table and hydrographic sheets. Among the topographical details mapped this season are the wharf-lines of the city of Jacksonville, McGirt's Creek and its branches, Doctor's Lake, Julington Creek, Black Creek, and Governor's Creek. Generally all fixed objects found within a mile of the shore-line are represented on the plane-table sheets. Two villages, Mandarin and Green Cove Springs, appear, and a much larger aggregate in roads than is usual within the same limits in southern sections. The soundings made in the river will be plotted as soon as possible. In reference to the channel, Assistant Ogden remarks that the hydrographic work of this season developed only one middle ground, and that the channel, as far as sounded, is clear from a point about one mile south of Jacksonville. The middle ground here mentioned is a narrow ridge lying north and south with only about four feet of water on it at low tide. The channels on either side have a depth of two fathoms or more, and the chart will probably show a channel of good width without obstruction between the middle ground and Hogarth's Bay. As being somewhat exceptional in river beds, Mr. Ogden notes also that a number of deep holes were developed by the soundings. Twenty-nine miles of the course of the Saint John's will be represented by the resulting sheets of the season.

Master A. C. Dillingham, U. S. N., was attached to the party in the steamer Hitchcock, and assisted in the hydrographic work. The statistics of the survey are:

Signals erected	41
Stations occupied	22
Angles measured	256
Number of observations	4,476
Shore-line surveyed (miles)	88
Creeks (miles)	61
Roads (miles)	158
Area of topography (square miles)	62½
Miles run with soundings	696
Angles measured with sextant	4,864
Casts of the lead	68,201

Under the direction of Assistant Ogden the triangulation-points were chiefly occupied by Sub-assistant W. I. Vinal, who also kept up the records and computations as the work advanced in the field.

Hydrography, east coast of Florida.—For extending the coast hydrography between Matanzas Inlet and Mosquito Inlet, Lieut. Commander J. C. Kennett, U. S. N., Assistant in the Coast Survey, was furnished with a projection from the office, and sailed from Norfolk with his party, in the steamer Bache, on the 24th of September, 1876. As soon as practicable, signals were set up along the coast between the intended limits of work, but these preliminaries were interrupted by the hurricane of October. At intervals, soundings were recorded in the course of the winter, but the weather was generally unfavorable for operations afloat. Many signals cast down by storms were several times replaced.

While the hydrography was in progress, the tides were observed at Saint Augustine and also at a station on the north side of Mosquito Inlet.

The lines of soundings run between the two inlets extend from the coast to seaward, several of them going to a depth of thirty fathoms. In a future season these will be crossed by lines parallel with the shore-line. The work was discontinued on the 24th of May. A summary of statistics appended to the report of Lieutenant-Commander Kennett is as follows:

Miles run in sounding	428
Angles measured	619
Number of soundings	4,557

The steamer Bache returned from this section early in June. Of the officers attached to the vessel, Lieut. Washburn Maynard and Masters W. F. Low and S. H. May were transferred to the steamer Fathomer. Lieut. W. I. Moore, U. S. N., remained in charge of the steamer Bache, at Washington, D. C.

Survey of the vicinity of Cape Cañaveral, Fla.—Previous to the opening of the fiscal year 1876–'77, work done by the party of Assistant Charles Hosmer had extended southward the detailed survey of the eastern coast of Florida to a limit about nine miles above Cape Cañaveral. Arrangements were made for resuming work at the opening of the fiscal year, but the prevalence of yellow fever on several routes to Jacksonville, and the difficulty of finding means of transportation between the Saint John's and Indian Rivers, caused delay, so that operations could not be resumed until the middle of September. Subassistant Joseph Hergesheimer, with the party in the sloop Steadfast, set up signals needed for the triangulation on the outer coast and along the shores of Banana River abreast of Cape Cañaveral, and was joined by Assistant Hosmer on the 19th of October.

The night of that day and morning of the 20th were marked in the record of the season by a terrific hurricane, which destroyed all the signals and greatly imperiled the lives of the party and the safety of the vessel.

Field-work was resumed on the 23d of October and was continued until the 11th of the following May, when the detailed survey had been advanced to points twenty-four miles south of Cape Cañaveral. Besides the outer coast, both shores of Banana River were mapped with the plane-table; also the shores of New Found Harbor; and a sketch was made of Indian River corresponding with the limits of the survey below Cape Cañaveral. The lower parts of Banana River and Indian River were developed by soundings.

It will be seen by the statistics that, notwithstanding frequent interruptions by stormy weather, good progress was made by the party. South of Merritt's Island, towards which point the survey will be advanced when again taken up, the principal difficulty will be to obtain the requisite transportation for supplies from Titusville to the field of work. After laying up the sloop Steadfast and housing the boats, the party was disbanded. The following are statistics of the field-work:

Signals erected	54
Stations occupied	37
Angles measured	293
Number of observations	4,128
Shore-line surveyed (miles)	223
Roads (miles)	23
Area of topography (square miles)	88
Miles run in sounding	280
Angles measured	1,254
Casts of the lead	23,776

Sixty-eight points were determined by triangulation for use in the plane-table survey.

During the summer of the present year Assistant Hosmer was engaged on the coast of Section I, as will be further mentioned in my next annual report. Subassistant Hergesheimer was at the same time employed in Section II.

SECTION VII.

GULF COASTS AND SOUNDS OF WESTERN FLORIDA, INCLUDING THE PORTS AND RIVERS.
(SKETCH No. 14.)

Survey north and south of Cedar Keys, Fla.—The survey of the western coast of the Florida peninsula has been advanced by extending the triangulation southward from Horseshoe Point to Cedar Keys, and from thence eastward to the mouth of Waccasassa River. The topographical survey and hydrography have been completed within the same limits. Assistant F. W. Perkins resumed work in this section with his party on board the schooner Ready, on the 3d of October, 1876, and closed work in July of the present year, after the measurement of a test base on Daughtry's Island in Cedar Keys Harbor.

In passing along to the southward from Saint Mark's a material change was noticed in the characteristics of the coast on nearing the Suwanee River. "The shore-line is more broken and is fringed with innumerable islands and keys. A series of reefs runs nearly parallel with the coast, and outside of the reefs the Gulf bottom is very irregular. Deep channels run in different directions, and shoals of considerable extent rise abruptly to the surface from deep water. The almost unbroken line of reefs that commences about two miles northwest of the Suwanee River stretches to Cedar Keys, a distance of about twelve miles, and forms a considerable bay of shoal water. Directly off the eastern mouth of the river the reef has gained about ten feet to seaward in the course of the past year, and although this is probably more than the average growth, the fact that the oysters are all dead in the river slope, while those in the outer slope are alive, seems to show that for the present a steady change is going on in that direction."

The lines of soundings were extended from the shore-line about ten miles into the waters of the Gulf of Mexico. The results show that neither labor nor pains have been spared in the development of shoals and channels.

On reaching the vicinity of Cedar Keys from the westward, Assistant Perkins connected his work with the survey made some years ago of that locality, and then joining on the eastward extended the work of the year so as to include part of Waccasassa Bay and its approaches. The details of the field-work serve for the delineation of thirty-two miles of the coast above and below Cedar Keys. A synopsis of statistics is appended:

Signals erected	19
Stations occupied	24
Points determined	40
Number of angular measurements	3, 104
Shore-line surveyed (miles)	204
Creeks (miles)	48
Roads (miles)	7
Area of topography (square miles)	70
Miles run in sounding	1, 222
Angles measured	6, 062
Number of soundings	80, 869

On closing work for the season the schooner Ready and a small steam-launch used in the hydrography were laid up at Apalachicola.

Hydrography of Saint Andrew's Bay and the Gulf Coast of Florida.—Lieut. R. D. Hitchcock, U. S. N., Assistant in the Coast Survey, with his party in the steamer Gedney, arrived at Pensacola on the 20th of November, 1876. Before taking up work to the eastward, for which projections had been made, some additional lines of soundings were run for developing the approaches to the bar of Pensacola entrance. After their completion signals were set up along the beach east of Choctawhatchee for a distance of seventy miles. This part of the work involved much labor, and the necessity of moving from point to point, during several months, along the beach, as lumber could nowhere be brought to the shore from the interior. Preparations for sounding were finally completed early in April, and either of the numerous signals which had been put in position could be seen in clear weather for at least ten miles off shore, in the Gulf of Mexico. Much bad weather occurred in the course of the winter, tending to retard the hydrography, but all favorable intervals were employed in sounding until the close of the season. In March and April many of the signals were totally destroyed by heavy gales which swept the coast with unusual severity, many houses at Pensacola being at the same time unroofed. The fifty-four signals required for sounding in Saint Andrew's Bay were made entirely of trees cut by the party.

Until the 1st of June the steamer was engaged, with a steam-launch in company, in running lines of soundings normal to the coast between Choctawhatchee and Saint Andrew's entrance, depths being recorded out to a distance of ten miles from the beach. The hydrography along the coast was extended so as to include the approaches to Saint Andrew's Bay, the waters of which were developed by soundings in the latter part of the season. In reference to it Lieutenant Hitchcock says:

"Saint Andrew's Bay is a most beautiful sheet of water, and everything about it is pleasing to the eye. It abounds in fish of all kinds, and oysters. Large quantities of pompano, Spanish mackerel, blue fish, red fish, grouper, sea trout, and mullet are taken. Oysters found in the eastern part of the bay are eaten at all times of the year, but those of the north and west parts only during the winter months.

"During summer the shores of the bay are resorted to by families from Northern Florida and Southern Georgia, who thus avoid the intense heat of the interior, and the so-called *swamp fever*, a fatal disease that prevails in hot weather at places only sixty miles from the Gulf coast. Saint Andrew's Bay is said to be one of the healthiest places along the Gulf of Mexico. The climate in winter is delightful, and in summer, though the air is always warm, the wind blows almost constantly from some southerly direction during the day, and by this wind the temperature is kept down."

To the westward of the general limits of his hydrographic work, Lieutenant Hitchcock developed off Santa Rosa Island some depressions in which the depth of water is seventeen fathoms, or considerably greater than the average depth along that part of the Gulf coast.

While soundings were in progress the tides were observed at the wharf near Fort Pickens, and for the hydrography of Saint Andrew's Bay, at three points on its shores. Upwards of sixteen thousand observations were recorded. Specimens of the bottom, brought up in sounding, were preserved, and the temperatures of the water there and at the surface were recorded.

The currents along the Gulf coast and those of Saint Andrew's Bay were observed in the usual way. The general statistics of the work are:

Miles run with soundings	2,240
Angles measured	9,399
Number of soundings	53,826

The steamer Gedney returned from this section in August.

Lieutenant Hitchcock was assisted in the hydrographic operations of the season by Lieut. J. N. Hemphill, U. S. N., and by Masters John Hubbard, F. G. C. Salter, and J. L. Hunsicker, U. S. N.

Triangulation in Kentucky.—In the work of determining geodetic points in this State for the immediate uses of the geological survey, and for the ultimate uses of the authorities in the construction of a State map, good progress was made in the season of 1876. Prof. William B. Page took the field in the middle of June, and continued work until the 13th of October. Additional ground was examined for extending the triangulation. One of the lines selected for a base was measured approximately and was joined with the nearest stations of the scheme of work in the vicinity of Shelby City. In the range of ninety miles between Cumberland Gap and Lancaster Court-House, three quadrilaterals and two triangles have been laid out. The lines vary in length from fourteen to forty-seven miles, and the altitudes of the stations range between 956 feet and 3,460 feet, as determined by means of the barometer.

In selecting the principal stations at which horizontal angles will be measured with the usual degree of precision, Professor Page noted from each point a number of secondary stations. These being adjusted in the scheme can be occupied in quick succession at any time hereafter, their positions and direction from the primary stations being already known approximately. While going through the district in which the work lies, remarkable discrepancies in existing maps, in regard to topographical features, were apparent. These errors have been the subject of previous mention, and are thus referred to again by Professor Page in his last field report:

"To give an idea of the inaccuracy of the best existing maps of the State, the sketch of my work, which falls within about twenty-five hundred square miles, was reduced to the proper scale and placed upon the corresponding part of the geological map so as to cover what purports to be the general topography of the same region as given on the geological map. The discrepancies are very striking, but it seems probable that the delineation is most defective in the tract included in reconnaissance. The State geological survey is endeavoring to represent the topography of parts of the State, but is necessarily dependent upon the triangulation for the proper connection of the detached surveys. Mapped in patches and with whatever degree of accuracy, the general result would of course be such as appears in the region between Cumberland Gap and Lancaster, in which the relations in distance between prominent topographical features have not been adjusted by means of a previous triangulation."

The progress of the work in Kentucky and in other States, in regard to the determination of points, has been carefully scanned by Assistant Richard D. Cutts, with whom the several observers communicate directly as they have need of advice in the details of field-work.

Triangulation in Tennessee.—The work of determining points in the State of Tennessee was commenced by Prof. A. H. Buchanan on the 9th of August, 1876, and at favorable intervals was prosecuted until the end of June, 1877, by that observer, with thoroughness, rapidity, and economy. East and west through the region of about one hundred and sixty miles, between Nashville and Knoxville, an excellent scheme of triangulation has been laid out after thorough and patient examination of the country. The ground passed over does not afford good sites for base-lines, but is otherwise favorable for geodetic operations. Near Lebanon Professor Buchanan selected and reported a site of a line that would admit of measurement, and that would also connect readily with the triangulation. This site, as being probably the only one available for the work, was visited by Assistant Richard D. Cutts, near the end of November, 1876, and after careful consideration, and comparison with several other sites pointed out by Professor Buchanan, was adopted. It was then arranged with reference to the measurement of the base in the ensuing summer, that favorable intervals were to be employed in clearing the summits in the vicinity, for connecting the ends by angular measurement with stations of the quadrilateral near Lebanon. This was done at the opening of the present season. Professor Buchanan also placed underground and surface marks, and over them erected signals. For such details Assistant Cutts having given all needful information, and also in regard to clearing and marking the line for actual measurement, returned to other duties in December, and in the following May, after forwarding from the office the six-meter iron contact slide-rods, again repaired to Lebanon. Professor Buchanan had completed all the requisite preliminaries. The hands selected by him, and to be relied on for the movement of the bars, were immediately drilled by Assistant Cutts. The measurement of the line was begun without delay, and went forward to the entire satisfaction of that experienced officer. Arrangements for his own field-party being then in progress, Mr. Cutts proceeded to Section I, leaving the completion of the measurement in charge of Professor Buchanan. The work on the line was closed in June last, giving for the length of the base 7,282.6 meters, or rather more than four and a half miles. All the records of the work have been received, and found to be satisfactory.

Reconnaissance.—When my last annual report closed, Assistant F. P. Webber was in the field with his party south of Huntsville, Ala., and had erected signals on Roe's Mountain and Warnock's Knob, two stations lying westward of the points to which the triangulation had been extended from the base-line near Atlanta, Ga. Difficulties peculiar to this region have been met in the prosecution of field-work, and from the nature of the ground can be only partially overcome.

The mountain ridges being very nearly equal in height, this district presents few of the advantages for triangulation that are to be expected and are generally found in a hilly country. The plan of work calls for a chain of quadrilaterals to go westward across the mountain ranges, and hence obstacles have been encountered of necessity that would not have interposed if the work was to be pushed in the direction of the mountains. After great labor, Assistant Webber selected stations for carrying the triangulation to points westward of Decatur, and in doing so found that it will be necessary to elevate the theodolite above several of the summits to the eastward, where he had selected the positions most favorable for intervisibility between the stations east and west. At Summit a scaffold forty-six feet high was erected. With structures of greater elevation at other stations, openings must be made through the timber of intervening ridges to bring into view the signals at the selected points. At Roe's Mountain a structure was put up sixty-seven feet in height. on the platform of which the theodolite will be placed when that station is occupied.

In September, 1876, Subassistant F. D. Granger was detailed from the party to complete the measurement of horizontal and vertical angles at Gulf Point, where the difficulty of carrying the chain of triangles directly westward first appeared. The main obstacles are the Sand Mountain plateau, ten miles east of Gunter's Mountain, and a ridge to the westward of that triangulation-point.

The party continued in the field until the close of the year, and as far as practicable completed a scheme for three additional quadrilaterals. Under the direction of Assistant Webber the lines of sight on several of the mountain summits were cleared by Mr. J. H. Christian.

In reference to one of the impediments found in arranging for triangulation to the westward, Mr. Webber remarks:

"The work this season has been over the most difficult country we have yet encountered. This includes the Sand Mountain plateau, which stretches south from eighteen to twenty-five miles, and west as far as the State line between Alabama and Mississippi. The plateau is heavily wooded, and it is generally impossible to find any tree on it that will permit an observer to overlook the forest. In the course of reconnaissance the members of the party cleated some of the trees as high up as ninety feet, for observing at that elevation with the prismatic compass. Heliotropes have been posted at almost every station, and the same ground of necessity has been passed over many times in order to arrange the scheme now submitted."

Late in April of the present year the party was again organized, and a signal was erected on Capshaw's Mountain, about twelve miles northwest of Huntsville. A tripod and scaffold thirty feet in height was put on the summit of Wilson's Mountain early in May, and preparations were made for occupying that station.

Triangulation.—At favorable intervals of weather between May 26 and the end of June, horizontal and vertical angles were measured with the theodolite at Wilson's Mountain. In each case twenty-nine objects were observed on, by an aggregate of 1,005 observations. Until the 6th of June, no weather occurred suitable for recording angular measurements, but then and previously the nights were favorable for astronomical observations.

Latitude.—Observations were made during fifteen nights for latitude at Wilson's Mountain. Twenty-six pairs of stars were observed by Assistant Webber, and noted in the record by three hundred and nineteen entries. For time, one hundred and sixty-nine observations were recorded on twenty-two nights.

Azimuth.—During six nights observations were made in the usual manner at Wilson's Mountain. The record contains two hundred and thirteen entries. On the last day of June the instruments and camp equipage were transferred to Gunter's Mountain, the station next in order to be occupied.

During the first fortnight of July, Assistant Webber was in usual health, and exerted himself in clearing some of the lines of sight so as to bring into view, at the summit of Gunter's Mountain, the signals which had been placed at stations adjacent to it. Mr. Granger was engaged in the same duty, but at a distance from the chief of the party, who first returned to camp, after passing two days in the vicinity of Roman's Landing, on the Tennessee River. Mr. Granger reached camp on the 20th, to find that Assistant Webber had been some days seriously ill with remittent fever. For a few days the physician in attendance had some hope of recovery, but Mr. Webber's illness soon after increased. He died in his tent, on Gunter's Mountain, on the morning of the 25th of July. Prof. A. H. Buchanan, who had recently joined the party, Subassistant Granger, and the faithful hands, spared no exertion for the comfort of Mr. Webber during his illness. My sense of his sterling qualities and usefulness has been partly expressed in the obituary notice appended to the introduction to this report. The remains of Assistant Webber were removed to Huntsville, Ala., and placed in a tomb.

SECTION VIII.

GULF COAST AND BAYS OF ALABAMA, AND THE SOUNDS OF MISSISSIPPI AND OF LOUISIANA TO VERMILION BAY, INCLUDING THE PORTS AND RIVERS.—(SKETCH No. 15.)

Deep-sea soundings, Gulf of Mexico.—For continuing hydrographic operations in the Gulf of Mexico, Lieutenant-Commander C. D. Sigsbee, U. S. N., Assistant in the Coast Survey, with his party, in the steamer Blake, left the Delaware Breakwater on the 5th of November, 1876. At intervals of bad weather the vessel was anchored under Cape Lookout, and also at Key West; but on the evening of the 16th of that month, off Cape Romano, a line of soundings in the Gulf was started to run westward. Depths were determined, at intervals of five miles, until soundings showed one hundred fathoms. The position was marked by a buoy, and in its vicinity a series of careful observations were recorded for the temperature of the water at seventeen intervals in depth, including also the surface, where the temperature was 77° Fahrenheit, and bottom of the Gulf, at which the temperature was 57° on the same scale. The difference of 20° was found to be in general conformable at intermediate depths with the law commonly observed in regard to the Gulf waters, but simultaneous observations on the currents at ten fathoms and at twenty-five fathoms revealed their effect in causing variations of temperature at equal depths during the short period of five hours in which the party was engaged near the buoy.

After the buoy was picked up, the steamer again started westward, and the line was extended to a depth of two hundred fathoms. Further on the wire sounding apparatus was used, and gave for depth, at the last station of the line, 1,749 fathoms. This result was obtained in a heavy sea, and very soon after the force of the wind made further operations at that time impracticable. The steamer Blake was then two hundred and fifty-six miles westward of Cape Romano, and the intention was to sound on a line going northward. The sea continued heavy, but, on the morning of the 20th of November, Lieutenant-Commander Sigsbee, when about twenty-seven miles to northward, succeeded in recording a depth of 1,726 fathoms. By using wire, soundings were obtained along this line until the depth was found to be only one hundred fathoms; and thence on, the ordinary rope was employed, as usual. This line of soundings terminated in twelve fathoms near the entrance to Choctawhatchee Bay, on the afternoon of the 22d of November, after a run of two hundred and sixty-nine miles.

In crossing the several lines of soundings run in the previous season broad off into the Gulf from the western coast of Florida peninsula, the depths were found to correspond well. After small but needful repairs to the boiler of the steamer at Pensacola, Lieutenant-Commander Sigsbee started a line of soundings, to go southward, from a position near the mouth of Perdido River, and at the last of twenty-one positions found the depth to be 1,529 fathoms. At the outset the temperature of the air was only 38° Fahrenheit.

"Little trouble was experienced, excepting in the record of water-temperatures. The surface of the water generally showed 60°, but the temperature of the air was generally below 50°. The conditions were such that dependence could not be placed on the minimum side of the water-thermometers unless their indications were below 50°, or whatever the air-temperature might be; nor on the maximum side, unless it read over 60°, or more than the surface-water temperature. When the temperature at any depth was of a degree intermediate between the temperature of the air and that of the surface-water, the reading of the thermometer at that depth was erroneous. To meet this difficulty, the thermometers were kept in warm water until the moment of stopping them on the line when the minimum side had acquired a temperature of about 70°. On hauling in, if the mercury was not touching the needle, the reading of the minimum side was accepted. By this method water-temperatures were recorded with only an occasional break in a series."

The greater part of the line south of Perdido entrance was run while a heavy "norther" prevailed, but however rough the sea, the party on board succeeded, in most cases, in hauling back the heavy sinker which was attached to the sounding-wire. While the "norther" was yet blowing, the course of the vessel was changed to due west at a point one hundred and ten miles to the southward and eastward of the Delta, and depths were found decreasing gradually at thirty-six positions intervening between the point of departure and the meridian of Vermilion Bay. At the western end of this line the course was changed and the steamer passed due north. Soundings were taken on the fifth line, which was terminated in the vicinity of Trinity Shoal, where the Blake was anchored on the 7th of December, to await a clear sky for observations. A gale during the following night made the position of the vessel unsafe, and Lieutenant-Commander Sigsbee was constrained to seek anchorage near Ship Shoal Light-House.

The sixth line of soundings run by the party was commenced in the channel north of Ship Shoal, and was extended eastward to the entrance of Southwest Pass, Mississippi Delta. After recording chronometer observations at Pilot Town the steamer passed up to New Orleans. Under conditions the least unfavorable that offered in the course of several weeks, Lieutenant-Commander Sigsbee left the Southwest Pass on the 31st of December, but soon put back, thus avoiding a gale of extreme violence, and remained at anchor off Pilot Town until the weather cleared.

On the 2d of January the Blake again put to sea and commenced a line of soundings which was extended southward and westward to the meridian of Ship Shoal. The steamer then proceeded to the vicinity of Ship Shoal and there started a line to pass due south, on which soundings were completed on the 4th of January. This line was continued to latitude 27° 11′, and then turned due west, soundings being carried in that direction somewhat to the westward of the meridian of Calcasieu Pass, and along that meridian to the neighborhood of Calcasieu entrance. On the line going westward, although most of the hydrography during the season had been prosecuted in heavy weather, occurred the only cast that was attended with the loss of any wire, and in that instance the loss was due to the drawing of a splice, and not to a break of the wire. The weight of thirty-four pounds used in sounding was in all other cases drawn up with the wire in depths not greater than seven hundred fathoms.

On the night of the 7th of January a line of soundings was run southward from Sabine Pass, and then due west to the approach of Galveston Bar. About sixteen miles south of Sabine Pass the depth, at one cast, showed only four and three-quarter fathoms, at a position comparing tolerably with that marked on some charts as the site of a supposed shoal. On approaching Galveston Bar the steamer encountered a severe "norther," but soundings were continued until the vessel was brought to anchor.

Leaving Galveston with his party on the 24th of January, Lieutenant-Commander Sigsbee developed the Gulf hydrography between Galveston and the mouth of the Rio Grande by eighteen lines of soundings, the courses of which had been previously indicated and marked on the project of work for the season. These lines were so arranged as to cross and verify each other.

The steamer then proceeded to New Orleans, and after taking in a further supply of coal left the Southwest Pass to run southward and westward. Ten miles from the Delta the current was found to be running west at two knots the hour, but five miles further on the current was north-northeast at less than half a knot. Here the approach of a gale from the southward made it expedient to return to the Delta, and on the way back it was noticeable that the rough sea disappeared as the vessel again passed into discolored water. With some difficulty, owing to the fog and unusually strong current, the steamer reached Pilot Town and there remained during a strong gale from the southward and eastward. Leaving Pilot Town on the 4th of March with some prospect of good observations, a line was started southwest so as to cross six other lines of soundings on the run to Sabine Pass. The position of the line was well determined, and the soundings showed the same well-defined depressions that had been reported in connection with previous deep-sea work by the party in the Blake. On this line of fifty-two miles eleven soundings were recorded. The vessel was then turned westward, but had made little way when a northeasterly gale set in. Soundings were however continued in the trough of the sea, all customary data being secured, and good observations were obtained for position, but the vessel was of necessity hove to before reaching the end of the intended line. The wind, after repeated changes, again favoring work, soundings were continued on a line to the northward and westward, and the vessel finally anchored in nine fathoms. Good observations were recorded at the anchorage for the adjustment of soundings. From this position the line was continued to the vicinity of Sabine Pass Light-House. One of the soundings on this stretch gave only three and three-quarter fathoms, there being six and one-half fathoms inshore of it. Lieutenant-Commander Sigsbee states that the position of this shoal is several miles outside of the range of visibility of Sabine Light.

On the 8th of March the steamer left the anchorage off Sabine Pass, and successfully carried a line of soundings direct to Galveston Bar. Continuous bad weather made it impracticable to prosecute further hydrographic work during that month, and, under the necessity of refitting the vessel, Lieutenant-Commander Sigsbee returned to New Orleans. The steamer again left Southwest Pass early in May, and sounded southward and westward to a depth of eight hundred and seventy-five fathoms. Near the termination of this line another was commenced in eleven hundred and seventy-five fathoms, and was continued due south to the Yucatan Bank. Four of the soundings in that run show depths of more than two thousand fathoms.

Leaving Alacran, a line was started in longitude 89° west, and was extended nearly five hundred miles westward to the coast of Mexico, in latitude 23½° north. Fifteen consecutive soundings gave depths of upwards of two thousand fathoms.

Starting off Tampico Bar, on the 18th of May, soundings were recorded on a course due east to the vicinity of Cay Arenas. Another line was then started near the Triangle Islands and was extended due west and finished off Tuspan Bar, Mexico. From thence, after taking in coal, the steamer ran down the coast to a position north of Vera Cruz, and from that station subsequently sounded eastward across the Gulf of Campeche to the Yucatan Bank. Off the mouth of Cazones River Lieutenant-Commander Sigsbee determined the position of a five-fathom bank at about twenty-three miles distance from the anchorage off Tuspan Bar. As seen from the vessel the bottom presented the appearance of coral, but the lead fouled in the attempt to procure a specimen, and was recovered only after considerable labor.

In general the weight used in sounding was left at the bottom in depths greater than one thousand fathoms, but in favorable instances the sinker was brought again on board from depths as great as seventeen hundred fathoms.

In sounding east of Vera Cruz, across the Bay of Campeche, the deepest water found was thirteen hundred and eight fathoms at about a hundred miles from the Mexican coast. This line was closed in twenty-five fathoms on the Yucatan Bank, as before stated. Passing on to Alacran, the steamer was anchored inside of the reef on the 6th of June. After securing observations for positions on the last line of soundings, the Blake started from a position north of Alacran, to run soundings westward along the parallel of 24° 31′ north, the depth at the first position being two thousand and fifteen fathoms. Seventeen consecutive soundings on this line gave upwards of two thousand fathoms. The work was continued westward, and closed near the coast of Mexico in eight fathoms.

On the 12th of June the steamer was again got under way and steamed up the coast to Brazos Santiago. After a short rest at anchorage a line was started off the Laguna Madre and was run with soundings due eastward to the meridian of the Mississippi Delta, and closed at a depth of sixteen hundred and forty-seven fathoms. From this position the Blake started for New Orleans. Good observations for chronometer corrections were obtained at Southwest Pass. Repairs needful to enable the vessel to reach New York were completed at New Orleans as soon as practicable. The steamer left Pilot Town on the 30th of June, and passing south to the latitude of the last-mentioned line of soundings resumed work for extending the line eastward. Soundings were successfully recorded in an easterly run of about two hundred miles, closing in a depth of seventeen hundred and ninety-four fathoms. To the northward and westward another position was chosen in the meridian of Mobile entrance, and from thence a line was run with soundings due south to the Yucatan Bank. The deepest water found was nineteen hundred and eighty fathoms. From the bank, soundings were recorded on a northeast line as far as the twenty-fifth parallel. The usual temperature observations were made, and the last thermometer came up from a depth of eight hundred fathoms. From this position the Blake steamed out of the Gulf and reached New York on the 14th of July.

The reports and records of the work done by the hydrographic party in the steamer Blake show that no pains have been spared for securing precision in respect of position and depth. Success in the development of the hydrography of the Gulf has been mainly due to the intelligent energy of Lieutenant-Commander Sigsbee. Until February last, when continued ill-health constrained him to seek relief, Lieut. J. E. Pillsbury, U. S. N., remained as executive officer on board the Blake. He was replaced by Lieut. S. M. Ackley, U. S. N. Lieut. W. O. Sharrer, U. S. N., and Masters M. F. Wright, W. E. Sewell, and Henry McCrea, U. S. N., have continued in service during the entire season. The statistics are:

Miles run in sounding	6,600
Determinations of position	496
Number of soundings	1,034

The admirable apparatus devised by Lieutenant-Commander Sigsbee for sounding with wire will be described in an appendix, separately published.

By the energy and skill of himself and officers, and the cheerful endurance of his crew, soundings were continued night and day through all weathers. The log of the Blake shows that the vessel rode out more than twenty gales while working in the Gulf. The results include soundings, temperatures, specimens of water from the surface of the sea and at intervals downward, specimens of the bottom, and records of the direction and force of the currents, making an aggregate unequaled in the annals of ocean physics, by results obtained in the same limit of time, by any similar party employed in any nation.

Topography of Barataria Bay, La.—For the survey of Barataria Bay, a base-line had been measured on Grand Isle and a few signals set up in the previous season. Assistant W. H. Dennis reorganized his party in the steamer Barataria on the 1st of October, 1876, and as soon as possible resumed field-work. Signals were erected along the Gulf coast and at points suitable for defining the shore-lines of Barataria Bay, and the waters connecting with it. The stations were occupied in succession with the theodolite, and as soon as practicable the plane-table survey was begun, and was pushed energetically, as shown by the large results in shore-line, until the 27th of June, when the steamer was laid up in Barataria Bayou.

During the winter the weather was unusually bad, and as a consequence the shore-line survey was delayed in progress. The high growth of cane and reeds proved to be a great hinderance in defining the water-line.

Lieut. Kossuth Niles, U. S. N., was in charge of the steamer, and co-operated effectively in the work of the survey, as did also Subassistant Andrew Braid. The statistics of this season are:

Signals erected and determined	56
Observations of horizontal angles	5,952
Shore-line surveyed (miles)	860
Area included in survey (square miles)	256

At the return of the party to this section, the triangulation will be joined with that of the Mississippi River.

Mississippi Delta.—Late in February last arrangements were made for resuming the physical survey of the lower part of the Mississippi, and as heretofore the details of the work were entrusted to Assistant H. L. Marindin. From the outset the survey has been prosecuted in accordance with plans and methods furnished by Prof. Henry Mitchell.

The first operation of the present season was the careful topographical survey of the new lands which have formed outside of Cubitt's Gap. As part of the history of that gap, the field-report mentions that in 1862 it was merely a boat-passage opened in order to give access to oyster beds which lay outside. The cut was made through a strip of marsh, not over four hundred feet wide, that separated the main river from the ocean, about three and a half miles above the head of the Passes. At present, as shown by the survey of the year, the gap is over three thousand feet wide, with depths of water as great as one hundred and thirty feet on the site of the former marsh.

Beyond the gap, new lands created by the deposits of mud from the river extend seaward, forming a subsidiary delta, with something like a circular development over a radial distance of about four miles. The area of dry land there formed since the opening of the gap is three thousand two hundred and nineteen acres, and its average elevation is about one foot above ordinary high-water. The whole is covered with vegetation, mostly reeds, but willows now grow on the parts that were first formed.

Assistant Marindin's topographical sheet shows that the new territory is disposed into broken radial strips and islands with water-spaces twice as great in area as the visible land, but the water-spaces, except in the main pass, are very shallow for the greater part of their courses. The main pass was carefully sounded, as it has been some time in use for light-draught vessels. Mr. Marindin found the outer bar about two miles beyond the limits of the land, or six miles from Cubitt's

Gap. The depth of water on the bar is somewhat less than four feet at low tide. In tracing the shore-lines of the other passes and bayous much difficulty was experienced in passing with small boats. Hence only the main pass of the delta of Cubitt's Gap was developed by soundings.

In the Mississippi River, Mr. Marindin completed soundings between the head of the Passes and the lower side of Cubitt's Gap. The hydrography done there includes the bed of the river for about two miles of its course, and in reference to it Professor Mitchell points out the fact that the river has one-tenth less area of section below than above the gap. It remains to be shown by careful comparison with former surveys whether or not the loss of water through Cubitt's Gap is a probable cause of this relative diminution of section.

In Southwest Pass the party of Assistant Marindin working with the schooner Research extended the hydrographic survey seven miles beyond the limits reached in the preceding season. At nine reaches of the stream, some in the main river and others in Southwest Pass, sections were determined not only by depths but by observing free floats of various draughts for ascertaining the movements of the water. The results of these operations will be given when the computations on which they depend have been completed. Similar data, from the work of the preceding season, seemed to indicate that a general formula would develop the profiles of cross-sections and the transverse curves of velocity, provided that certain coefficients, dependent upon the radius of curvature in the course of the stream, could be ascertained from observations.

Assistant Marindin was efficiently aided by Mr. John B. Weir. In Appendix No. 9 will be found a description of the apparatus employed by the party, and by means of which the currents were determined at four hundred and ninety-six positions under and at the surface of the waters of the Delta. Operations in the physical survey were continued until the 13th of August and included the measurement of thirteen short local base-lines. For the current observations sixteen hundred and ten angles were recorded. The statistics of the shore-line survey and hydrography are:

Signals erected	53
Stations occupied on land	6
Angles observed	5,470
Shore-line surveyed (miles)	127
Number of soundings	15,612

The tides were recorded at two stations while the work was in progress.

Tidal observations.—The height of the water at New Orleans has been regularly recorded at intervals of six hours from January, 1872, to January, 1877, by Mr. G. Faust. Daily fluctuations being small are disregarded, but the changes of level due to annual floods, and intervening dry seasons, and which amount to eleven or twelve feet, are interesting, and as these changes show a considerable approach to regularity in periods, the records are expected to give data for predicting approximately the state of the Mississippi River at New Orleans throughout the year.

Survey of the Mississippi River.—For continuing the detailed survey above Bonnet Carre, the party of Assistant C. H. Boyd was reorganized in October, 1876, on board the steamer Baton Rouge. Triangulation had been carried in the preceding season to Belle Point. From that limit it was extended in the course of the present season as far up the river as Point Houmas, which is about seventy-five miles west of New Orleans. The field-report contains the following remarks:

"The difficulties encountered in this work, besides such as are incident in all regions destitute of natural elevations, are—the twisting of the scheme of triangulation to avoid expensive cuttings through projecting points of cypress swamp; the high levees coming in the middle of quadrilaterals, being sixteen feet, more or less, in height above fields in which the stations fall; and the avoidance of numerous buildings and valuable trees in their vicinity."

The topography was resumed in November. Those lands were first surveyed which had been flooded by the Bonnet Carre crevasse, and which were traced in the spring of 1876. The office has now on file topographical and hydrographic sheets showing the conditions of that locality in April and November of that year. For the detailed work three sheets were projected covering the river to a point near Donaldsonville. These include all surface-features on both sides of the river as far back as the forests, making a belt of about six miles in width. The river-banks are represented as thickly settled, and as presenting the appearance of an almost continuous forest of fruit and ornamental trees. The lands are in sugar, rice, tobacco, and fruit orchards, and fall between the levees and the forest in the aggregate from twelve to sixteen feet, or about four feet to each mile back from the river. Between October, 1876, and the following March, two hydrographic sheets were filled with soundings, including the river between Soniat's Mill and Grandview Reach, the last-named point being about sixteen miles short of the limit reached by the triangulation and plane-table survey. When soundings were discontinued the current had so increased as to render it inexpedient to attempt further work in hydrography. In the various stages of the river while the survey was in progress, during the season, currents were observed at fifteen stations.

Dr. M. F. Bonzano, superintendent of the United States mint at New Orleans, has continued his supervision of the observations for recording the tide or river stand, of which mention has been made in this chapter. In addition to the regular observations, Assistant Boyd kept separate records at four different anchorages of the steamer Baton Rouge while the river was rising. His observations show a difference of about fifteen feet between high and low water at New Orleans, but in the vicinity of Donaldsonville it is said that the difference approaches thirty feet.

Field-work was closed on the 19th of June. The steamer was then laid up between the floating docks at Algiers, and at the end of the month the crew was discharged.

Master Alexander McCrackin, U. S. N., was attached to the party in the Baton Rouge, and rendered cordial, prompt, and energetic assistance during the season. Messrs. C. H. Van Orden and Bion Bradbury served as temporary aids.

Near the close of the season the operations of the party were much crippled by sickness incident to the season. One of the hands died of malarial dysentery in June, and four others were sick when the crew was discharged.

The statistics of the work done this season are:

Signals erected	22
Stations occupied	25
Angles measured	86
Observations with theodolite	5,196
Geographical positions determined	103
Shore-line traced (miles)	73
Roads (miles)	100
Area of topography (square miles)	175
Miles run in sounding	152
Angles measured	1,184
Number of soundings	4,968

Of the lines of sight required for the triangulation, twenty-nine required to be opened by cutting, so as to bring into view the stations to which they led.

The plane-table sheets resulting from the work of the season will represent about forty miles of the course of the Mississippi.

Reconnaissance eastward of Saint Louis, Mo.—For the selection of stations to form a series of quadrilaterals eastward of the triangulation which has been already done in the vicinity of Saint Louis, Assistant G. A. Fairfield reached that city on the 28th of August, 1876, and at once proceeded to the site of the base-line measured in a previous year in Illinois. The signals were yet standing and the surface marks at the ends of the line had not been disturbed. In company with Assistant J. A. Sullivan, the two stations "Clark's Mound" and "Sugar Loaf" were visited. These, as being on the edge of the line of bluffs, at positions north and south of the base-line, must be relied on for extending the triangulation eastward of the base. No available points being in view directly to the eastward, Mr. Fairfield proceeded to Terre Haute by the Vandalia road, and returned to Saint Louis by way of Vincennes and the Southeastern road. The district afforded no position suitable for geodetic purposes.

From Collinsville, Assistant Fairfield started in the middle of September and traversed the country until the 9th of December. Flags placed on trees along lines desirable for extending the work could rarely be seen at the distance required in the scheme of triangulation. Under many disadvantages, among which were the prevalence of smoke in the air, and, later in the season, haze, rain, and snow, a plan of work was marked out to lead eastward of Clark's Mound and Sugar Loaf, but, on account of the lateness of the season, this could not be verified before the approach of winter. In the middle of December Mr. Fairfield returned to the office.

He was again at Saint Louis in April, and after visiting the projected stations, decided that their intervisibility could be ascertained only by lines run with the level. Four stations were thus connected, by an aggregate of sixty-five miles, with the level. In returning to the initial point by a circuit, the error in levelling, as shown by the record, was less than two inches. The field-work was closed in June.

A general examination made by Assistant Fairfield, in advance of taking up field-duty in another section, shows that the stations which he selected in Illinois are not obstructed by intervening ridges, and that they will probably be intervisible from observing scaffolds of ordinary height; but as no appropriation was made for continuing the work after the end of June, the final adjustment of the scheme of triangles has been of necessity deferred.

Triangulation in Missouri.—For extending the geodetic connection between the Atlantic and the Pacific, beyond the limits which had been reached in previous seasons west of Saint Louis, Assistant J. A. Sullivan started from that city early in September, 1876, and in the course of a month made a general reconnaissance of the country westward as far as Pike's Peak. The region in the vicinity of Fort Scott was carefully examined, and ground between that point and Kansas City, with reference to the selection of stations that would be visible from points in western Missouri. From Kansas City Mr. Sullivan proceeded to Denver, in Colorado, and from thence to Pike's Peak, from the summit of which a general examination was made of the contour of the country which had been traversed from the eastward. Subsequently views were obtained by ascending Gray's Peak, Bras Mountain, and Mount Lincoln. Returning by way of Denver City, Mr. Sullivan passed several days of the early part of October in examining a considerable area of the plains near River Bend. Cattle-owners having thorough knowledge of the region were then on an expedition to "round up" their cattle, and it was found advantageous to accompany the party. Much local information was thus noted that would otherwise have involved labor and delay.

After his return to Saint Louis, Mr. Sullivan made suitable arrangements for selecting and marking points for triangulation west of the line to which the work had been carried by Assistant Boyd. From the stations "Gasconade" and "Winter" the ground was examined westward. Two points on the Gasconade River were selected for an additional quadrilateral, and other points in the same direction as far to the west as Jefferson City. Early in January, 1877, the work was discontinued for the season, the roads being then blocked by snow, and the trees so covered with ice that they could not be used as the ordinary means for overlooking the surrounding country. The following is an extract from the report of Assistant Sullivan.

"The region immediately south of the Missouri River, through which this reconnaissance was made, is traversed by the Gasconade and Osage rivers, tributaries of the Missouri, and is hilly and broken in the extreme; a collection of densely-wooded ridges without commanding elevations, and thinly settled. The greater part of the cultivated land is along the small bottoms of the rivers and their numerous small tributaries.

"To avoid felling trees as much as possible, the reconnaissance was carried on by putting up flags of distinguishing colors in trees or the higher points in the region, and endeavoring from the trees to ascertain the intervisibility of these points. In obtaining these results seventeen flags were put up in trees at high points, and avenues were opened on two lines across the tops of intervening ridges."

Early in May of the present year Assistant Sullivan resumed field operations, and continued the reconnaissance to the westward of Gasconade River until the middle of June. In the latter part of that month further examination was made of the country on the line of the Atchison and Santa Fé Railroad, and also along the Union Pacific to Omaha. Mr. Sullivan returned to Washington on the 29th of June. The results of his reconnaissance show that the chief difficulties in passing westward of Saint Louis, and by which the progress of the triangulation has been retarded, will, to a large extent, disappear in the western part of Missouri, and that it will be feasible to lay out a good scheme of triangles for the geodetic connection as far eastward as the

Wasatch Mountains in Utah. But, as no means were appropriated for the work at the last session of Congress, the plan of operations is for the present laid aside.

Triangulation in Wisconsin.—Field-work was resumed in this State by Prof. John E. Davies early in June, 1876, and was continued until the 6th of October. The positions of stations in the vicinity of the base for connecting it with the triangulation having been previously selected, the points were occupied in succession with the theodolite. At station Fitchburg, the angular measurements were made from a scaffold, the outlying stations not being in view from the ground. Much unfavorable weather occurred in June, and the following month was well advanced before the party could be transferred to Blue Mound. Finding that the lines of sight from a scaffold, twenty-six feet high, at the last-named station would pass clear of the dense woods on the adjacent ridges, the structure was put up to avoid the greater expense of opening lines of sight. The erection of that scaffold determined the practicability of advancing the triangulation to the southward and westward by a series of points very favorably situated, and which will be occupied hereafter if means again become available for the geodetic work. Fortunately Professor Davies kept in view the expediency of completing, before the close of the season, the geodetic connection between his astronomical station in the University grounds at Madison, and the base at Spring Green, and that was successfully done, though it was not then doubted that provision would be made for continuing the work. As no appropriation was passed at the last session of Congress, the course pursued by Professor Davies has secured the utmost advantage with the means allotted for his field-operations. The statistics of the work are:

Signals erected	14
Scaffolds and tripods	7
Stations occupied	6
Angles observed	90
Number of observations, horizontal angles	7,510
Number of observations, vertical angles	2,076

Assistant Richard D. Cutts, with whom Professor Davies conferred freely in regard to details, thus remarks on the work done in Wisconsin: "The quadrilaterals are well shaped, the number of measurements of each angle are amply sufficient, and the vertical angles were observed quite closely within the period of least refraction."

SECTION IX.

GULF COAST OF WESTERN LOUISIANA AND OF TEXAS, INCLUDING BAYS AND RIVERS.—(SKETCH No. 16.)

Triangulation of Laguna Madre, Tex.—For this work a general reconnaissance was made in the preceding season by Assistant R. E. Halter, who selected stations for carrying the triangulation southward of Corpus Christi Bay. Having completed his arrangements for resuming field-work, Mr. Halter again proceeded to this section in the latter part of September, 1876. The party was detained upwards of a week at New Orleans in consequence of existing quarantine regulations in the ports of Texas; but finally reached Corpus Christi on the 12th of October. By the close of that month a working camp was established at the north end of Padre Island, and one of the new stations was connected by angular measurements with the concluding line of the triangulation of Corpus Christi Bay. Northers were very frequent during the winter, and the weather was such that the signals were rarely intervisible. At all clear intervals the measurement of horizontal angles was pushed, so that by the middle of April the triangulation had been advanced southward as far as it was found practicable to work from the first-established camp. Mr. Halter then transferred his party to a station twenty miles lower down on the coast, and at the close of the fiscal year was engaged at stations on the shores of Laguna Madre, in the vicinity of the expansion known as Baffin's Bay. The chief impediment to progress is the occasional lessening in the depth of water in the Laguna, dependent upon the direction and force of the winds. The statistics of the triangulation are:

Signals erected	22
Stations occupied	11
Sets of observations (6 repetitions each)	625
Number of observations	7,576

SECTION X.

COAST OF CALIFORNIA, INCLUDING THE BAYS, HARBORS, AND RIVERS.—(SKETCHES NOS. 17, 18, AND 19.)

Coast reconnaissance northwest of San Diego, Cal.—For perfecting the scheme of triangulation partly laid out in the preceding season, Assistant W. E. Greenwell took the field at Santa Barbara on the 1st of September, 1876. Proceeding towards the San Diego boundary, he visited, in succession, the stations which had been selected, and others, to include means for defining the coast-line. Additional points were chosen for extending the triangulation quite across the boundary between the United States and Mexico.

The region embraced in this reconnaissance was found well adapted for plans of triangulation, and, excepting for the labor of reaching the stations and the hardship incident to their occupation, rapid progress could be made with adequate means. From most of the summits visited by Mr. Greenwell the islands off the coast were in view. One of the stations near the San Diego boundary proved to be upwards of 5,000 feet in height. Standing on that summit, the observer had in full view, though one hundred miles distant, the peaks of Santa Catalina Island and of San Clemente Island, the coast-line and mountains, the great Colorado desert and the mountains to the eastward of the desert. Beyond these runs the valley of the Colorado River, respecting which it is noted in the journal of the reconnaissance that a moving volume of smoke was judged as marking the course of a steamer in passing up the river.

At the close of November, Mr. Greenwell had passed over all the ground intervening between Santa Barbara and San Diego. On the return northward, he took the road by way of San Pasqual and Pala, and again explored the region in which Palamar Mountain (4,500 feet high) is a conspicuous point. Previous observations were confirmed, and that station was included in the scheme of triangulation. About two hundred feet below the summit a spring of good water refreshed the party after toiling many hours in the ascent. The scheme was verified by additional tests, and the party passed on to Anaheim, which point was reached late in December.

Of all the stations marked, very few remain in doubt in respect of intervisibility, and desirable conditions are generally fulfilled by the arrangement of the triangles and quadrilaterals. Field-operations in this quarter were discontinued in the middle of January.

Topography of Catalina Island, Cal.—The party of Assistant Stehman Forney was reorganized in the middle of August, 1876, for taking up the topographical survey of Santa Catalina, for which purpose the triangulation had been in part completed in the preceding year. Plane-table work was commenced at the western end of the island, and was prosecuted, at intervals, as far eastward as Goat Harbor on the north and Little Harbor on the south shore. Catalina Harbor and Isthmus Cove were included, and, as usual, the elevations of ground between the shore-lines were represented by contour lines on the topographical sheet.

In addition to the plane-table work, the triangulation was taken up at the limit reached last year, and was extended to the eastern end of the island.

About one-half of the area is shown on the resulting topographical sheet of this season. The shore-line is exceedingly bold, and so difficult of access that its delineation by means of the plane-table would be regarded by many topographers as impracticable. "Santa Catalina Island lies broad off the coast from San Pedro anchorage, at a distance of nineteen miles. The island is twenty-one miles long and has an average breadth of three miles. The highest peak on the island rises to an elevation of 2,110 feet."

During calm weather, boats can land safely at many points both on the north and south shores of the island, and near some of the landings are springs of good water. All are clearly marked on the plane-table sheet. The island is used entirely for grazing, and is said to be the only one of the Santa Barbara group on which the rattlesnake has been found.

The statistics of the triangulation and topography of the season are:

Signals erected	26
Stations occupied	11
Signals, peaks, and headlands observed on	37
Observations for horizontal angles	3,816
Vertical-angle measurements	302
Shore-line surveyed (miles)	34
Roads (miles)	2
Area of topography (square miles)	29½

Inspection of topography.—After examining the topographical features which border the waters of Washington Territory, to which reference will be made under the head of Section XI, Assistant H. L. Whiting returned to San Francisco, and extended a reconnaissance northward along the coast through parts of Mendocino and Humboldt Counties. The dense and enormous timber of that region presents unusual difficulties in field-operations. Characteristic localities were thoroughly examined and described in the final report, which was turned in after his return to the office in December, 1876. That report includes also the results of inspection conducted along the coast of California, and extended to San Diego. The lack of timber and ground-surface contour along the southern coast are remarked on as in contrast with certain parts of the northern coast. All the considerations, practical and economical, that are of account in devising plans for the survey in reference to the ground to be represented, are mentioned in the concluding report of Mr. Whiting. He comments specially on the necessity of aptitude and perception in the topographer who would successfully delineate such coast features as came under his own observation while on reconnaissance.

Triangulation of Santa Barbara Channel.—In September, 1876, the party of Assistant O. H. Tittmann was transferred to Anacapa Island, and immediate preparations were made for occupying the primary station with the theodolite. As a means for the needful supplies of water and provisions, and for visiting the signals requisite on the adjacent islands, the schooner Matinée was employed temporarily. Of three heliotropers engaged for the work, one was stationed on the main at San Pedro primary station, one was placed on Santa Barbara Island, and the third showed signals, when practicable, from a point on San Nicolas Island.

On Anacapa Island fires had been set by sheep-owners to clear the ground of weeds, and during an extended period the resulting dust had not been settled by rain. As a consequence, the condition of the atmosphere was such that the measurement of horizontal angles could not be completed until the 6th of December. So commonly was the view hid in one direction or more that, during the stay of the party, an unbroken series of angles was measured on only one day of the season.

After completing the requisite observations a signal was set up on the highest peak of Anacapa, and approximately determined in position, to furnish a base and direction for the original topographical survey.

Leaving the heliotrope at San Nicolas, Assistant Tittmann next occupied the station on Santa Barbara Island. On the 25th of December he observed on the signals at San Nicolas and Anacapa, and included in the round of angles two topographical stations on Santa Barbara Island for orienting its plane-table survey. The uncertainty of obtaining additional observations being great, Mr. Tittman returned with the schooner to Anacapa on the 28th of December, and next day landed the instruments and equipage on the main at San Buenaventura. Laguna Station, on the main and opposite to Anacapa Island, was next occupied. After closing observations there the party proceeded in the schooner to Santa Catalina Island, and erected signals on the two highest peaks to serve as a base for the determination of points on San Clemente Island. The aid of the party, Mr. D. B. Wainwright, was meanwhile dispatched with the vessel to erect signals on the last-named island, and to measure the angles. The signals were in place on the 6th of March, but owing to the prevalence of fog the observations requisite could not be completed. Assistant Tittmann remained in camp until the 8th of May on Catalina Island, and then closed operations.

The following are statistics of the work:

Signals erected	9
Stations occupied	5
Angles measured	21
Number of observations	1,327

At the close of the fiscal year Assistant Tittmann reported for duty at the office in Washington.

Hydrography near San Miguel and Santa Rosa Island.—The steamer Hassler, with the hydrographic party of Lieut. Commander H. C. Taylor, U. S. N., Assistant in the Coast Survey, left San Francisco in September, 1876, and after completing the supplementary soundings requisite in the vicinity of Santa Monica, resumed hydrographic work near Santa Rosa and San Miguel, of the Santa Barbara group of islands. Four sheets were completed in the course of the season. The approaches to Santa Rosa from the south and from the north, were sounded and plotted on two sheets. A third sheet contains the soundings made in the passage between the two islands, and the fourth shows the character of the approaches from all directions, to the western end of San Miguel. The work was prosecuted afloat until the approach of cold weather, and was discontinued on the 14th of December. In the course of the winter and spring the records were completed and the manuscript charts were sent to the office. The aggregate statistics are:

Miles run with soundings	576
Angles measured	3,759
Number of soundings	10,658

Lieuts. Richard M. Cutts, Richardson Clover, A. B. Wyckoff, and F. J. Drake, U. S. N., assisted in the hydrographic work here under notice. Before entering upon that duty the steamer Hassler was for some time at the disposal of General B. S. Alexander, and officers of the Corps of Engineers, associated with him for the inspection of the harbors between Puget Sound and San Francisco. Lieutenant Commander Taylor's intimate knowledge of the coast enabled the inspecting officers to visit without loss of time ten of the anchorages recognized as harbors. The facilities afforded have been cordially acknowledged by General Alexander.

After retaining command of the steamer Hassler for the period allowed in the regulations of the department, and rendering highly acceptable service in the prosecution of hydrography, Lieutenant Commander Taylor was detached on the 23d of April, and was soon after replaced by Lieut. Commander G. W. Coffin, U. S. N.

Hydrography of Santa Barbara Channel.—On the completion of the steamer McArthur, in December, 1876, Lieut. Frank Courtis, U. S. N., Assistant in the Coast Survey, was assigned to the command, and organized a party for hydrographic work, which was begun early in February of the present year.

To the eastward of Point Concepcion, Lieutenant Courtis joined with inshore work done in a previous year, and extended soundings along the coast fifteen nautical miles to a junction with the hydrography of a preceding season. While this work was in progress, the tides were observed at Gaviota wharf. The depths shown on the two resulting charts are from six feet to seventy-eight fathoms. At the limits of the work, east and west lines were run quite across the channel to Santa Cruz, and also towards San Miguel Island.

Lieutenant Courtis remarks as follows on the performance of the new steamer during the run between Mare Island and Santa Barbara:

"We left San Francisco on the 3d of February, and arrived off Santa Barbara early on the morning of the 5th, after a pleasant trip down. The ship behaved well all the way, and rolled easily, notwithstanding the heavy swell met on the bar off San Francisco entrance and for some time after crossing it."

The ship worked well during the season. No drawback occurred except the loss of the starboard anchor on the 6th of March while the vessel was on duty to the eastward of Point Concepcion. The stormy weather then prevailing was evidenced with loss a few days after at San Buenaventura, where the heavy swell carried away three hundred feet from the middle of the wharf, leaving several hundred feet of the sea-end of the structure standing. Inspection showed, however, that the piles that first yielded to the action of the sea had been honey-combed by the toredo.

The statistics of the work done by the party in the steamer McArthur previous to the end of June of the present year are:

Signals erected	44
Points determined	28
Miles run with soundings	424
Angles measured	2, 129
Number of soundings	8, 514

The officers attached to the McArthur and assisting in the hydrography were Lieuts. E. H. C. Leutze and E. K. Moore, U. S. N., Master J. H. Bull, and Ensign W. Allderdice, U. S. N.

While the party was at work on the 23d of April, the ensign of the steamer Idaho, of the Colorado Steam Navigation Company, was discovered to be Union down. Lieutenant Courtis immediately ran down with the McArthur, and found that the engine of the Idaho had given way. At the request of her commander, Captain Douglass, the Idaho was towed about seven miles to the nearest safe anchorage.

The hydrographic party will be at work during the summer in the vicinity of the Santa Barbara Islands.

Topography south of Point Arguello, Cal.—The detailed topographical survey of the coast of California, between Point Arguello and Point Concepcion, was taken up in the middle of April, by Assistant A. W. Chase, who had been previously at work near Santa Monica. Points needful for the survey, and previously determined by triangulation, were readily identified. The prevailing northwest winds in the vicinity of Point Arguello proved to be a constant detriment to field-work, but the survey was pushed as far as practicable until the end of June, and will be completed early in the present fiscal year. Of the two plane-table sheets, one has been filled; the other is yet in progress. This last will include a minute survey of the light-house reservation at Point Arguello. In the course of his field-operations, Assistant Chase set up and determined fifty-nine signals for the use of the hydrographic party. The statistics of topography preceding the end of June, 1877, are:

Shore-line surveyed (miles)	19
Area of topography (square miles)	10

Reconnaissance.—In order to perfect the scheme of triangulation which had been in part developed by Assistant W. E. Greenwell in the preceding season, he again took the field on the 25th of May of the present year. Proceeding from Los Angeles with a view of selecting points that would connect properly with stations which have been already occupied at San Buenaventura and Gaviota, it was found that the San Lucia Mountains shut out the view of the coast, but without affording along the crest of that range lines of suitable length for primary triangulation. The reconnaissance was intended to bring into the scheme, if practicable, a quadrilateral adjacent to Point Concepcion, three of its stations being quite near to the coast, and the fourth at Tepusquet, which is about thirty miles northeast of Cape Arguello. The month of June was passed in the endeavor to perfect the scheme, but in addition to local difficulties, the constant haze made it impossible to identify distant summits. At the end of June, Assistant Greenwell was yet in the field, but was authorized to defer the reconnaissance for the selection of stations until the prevailing fogs and haze had in a measure disappeared.

Tidal observations.—The series of tidal observations at Fort Point with a self-registering gauge of the old form, and the meteorological series there have been continued by Mr. E. Gray. For some years previous to 1877 this and other tidal stations on the western coast were in charge of Col. G. H. Mendell, United States Engineers, to whose care and attention the survey is indebted for scrupulous exactness manifested by the observers in following the instructions sent from the office. At the beginning of the present year Assistant George Davidson undertook the supervision of operations at the tidal stations in Sections X and XI, in addition to his duties in the field. As the wharf on which the tide-gauge rests at Fort Point is much decayed it has been deemed advisable to abandon that station. Another self-registering gauge has already been set up by Mr. Davidson at Saucelito inside of San Francisco Bay on the north side of the entrance. The apparatus was started in February last, and has worked satisfactorily.

Geodetic connection.—At the opening of the fiscal year to which this report corresponds, Assistant George Davidson was engaged at Mount Diablo in the measurement of horizontal angles for connecting that station with points which had been selected in the Sierra Nevada Mountains. Exclusive of the azimuth-mark, eight signals were observed on, the most distant being one hundred and thirty-eight miles from the theodolite; another was one hundred and twenty miles from the observer; and the remaining six lines of sight averaged sixty miles in length.

The season is reported as having been excessively smoky, and the observations were, in consequence, delayed. Meanwhile, however, preparations were made for the latitude, time, and azimuth observations.

The latitude observations and the measurement of vertical angles from Mount Diablo were entrusted to Assistant William Eimbeck, of Assistant Davidson's party. By means of an improved heliotrope, which shone through haze when the top of the mountain on which the instrument was placed could not be seen, Mr. Davidson succeeded in observing on the most distant stations. Horizontal angles were measured with the 20-inch theodolite, No. 5. The instrument was used in many positions for the purpose of testing the graduation.

Of the work at Mount Diablo, which was closed on the 8th of September, the following are statistics:

Theodolite pointings on nine stations	1,596
Azimuth observations	491
Observations (vertical angles)	519
Time observations (on forty-one stars)	149
Latitude observations	914

Assistant Eimbeck made observations on five nights, for latitude, upon twenty-two pairs of stars. The customary observations were also made for value of the micrometer, exclusive of many thousands for testing the parts and graduation of the theodolite.

While observations were in progress at Mount Diablo, the opportunity was taken, as in other instances, to note the direction from that station of the principal peaks that could be identified in the Sierra Nevada range of mountains, and thus adding to the list of geographical positions. For the elevations of the subsidiary points, vertical angles were recorded.

After closing the observations, the transit instrument, zenith telescope, vertical circle, and other instruments, were cleaned and the chronometers were adjusted for rate. In preference to trusting the instruments to other hands, Mr. Davidson himself performed this important adjunct service.

In September the instruments and such of the equipage as could not be dispensed with, were transferred to Mount Helena, and after great labor were placed in position on the summit. To protect the observing tent from the violent winds by which the others were occasionally torn down, a wall five feet high was found requisite on the north side, and another somewhat less in height towards the south. By such expedients and close watching the instruments were preserved, although the stoutest of the men employed in the party were frequently blown over by the force of the winds.

In October, during a heavy southeast storm, seven and a half inches of rain fell at the observing station, and in the Sierra Nevada the summits were covered by a heavy fall of snow. The heliotropers at Round Top, although much exposed and snowed in to a distance of thirty miles from immediate relief, kept at their duty. Arrangements had been previously made by contract with mountaineers accustomed to snow-shoes, to bring off the heliotropers, if such action seemed absolutely necessary for their safety.

The great storm was followed by clear weather. Assistant Davidson, by working during every favorable moment, was enabled to close his observations on the line to Round Top (one hundred and forty-six miles in length) by the 6th of November. The Lola Mountain heliotropers, fearing in advance the consequences of the great storm in October, having left the station, the two who manfully remained and showed signals from Round Top during the snow blockade, readily agreed to do service at Lola, and by great industry they reached that station on the 13th of November. On

Snow Mountain the heliotroper, though alone and snowed in, bravely kept his post and showed signals when practicable. By this steadiness Mr. Davidson was enabled to close observations on the lines to Round Top and Lola on the 27th of November.

At the station on Mount Helena, in additon to the ordinary elongation mark about seven and one-third miles distant, Assistant Davidson set up near the large theodolite a collimator for the determination of azimuth. Great care was taken in the construction of the pier of this second telescope, and in regard to its adjustment; and numerous observations were recorded for independent determinations of azimuth by the method commonly employed at field-stations, and also by means of the collimator. At permanent observatories collimating telescopes are in common use. The only difficulty, and one which hitherto has inclined field-observers to prefer the distant azimuth-mark, is in obtaining a stable stand for the collimator, so that no change may take place in the interval between the night observations for azimuth and the reduction of the azimuth to adjacent lines of the triangulation, which last work must be done in the day-time. Assistant Davidson expresses confidence in the stability of the pier which supported the collimator at Helena, and the hope of obtaining results that may warrant the substitution of that method for the record of measurements on the ordinary azimuth-mark. The two sets of observations recorded by his party will in due time be discussed under the expectation that as the use of the distant azimuth-mark is not convenient in the region of the Sierra Nevada, the method of observing for azimuth by means of a collimator may be applied with full confidence in the results.

The work at Mount Helena Station included observations upon the seven primary stations of the triangulation, and also upon Snow Mountain signal. The elongation mark observed on was thirty-two hundred feet below the summit of Helena. For latitude four hundred and thirty-five observations were recorded during five nights upon twenty-two pairs of stars; and time was ascertained from two hundred and sixty-five observations of the transits of thirty-eight stars. The ordinary statistics of the geodetic work are thus stated in the field-report:

Telescope-readings for horizontal angles	1,778
Ocular microscope pointings	7,693
Observations for vertical angles	1,770
Azimuth observations	1,119

Including the stations of the scheme of triangulation, the direction and height, by vertical angles, of twenty-two objects were recorded at Mount Helena. Before leaving the station a topographical sketch was made of the summit.

Assistant Davidson, exclusive of the records of regular processes in the geodetic work, made numerous observations for testing the various parts of the instruments which he had in use. His journals contain an aggregate of thirty-seven thousand observations in thirty-five volumes. All the field-notes have been duplicated as usual. An important result of observations made by Assistant Davidson in the course of the season was the connection of Snow Mountain with the scheme of geodetic operations, the intervisibility between that station and Round Top Mountain not having been previously ascertained. That determination insures both diagonals, one of which is one hundred and sixty miles long, in the great western geodetic link, which will be designated the "Davidson Quadrilateral."

At the beginning of the present year Mr. Davidson accepted the charge of the tidal stations on the Pacific coast, a service for which the survey had been previously indebted to the care and attention of Col. G. H. Mendell, United States Engineers.

Assistant Davidson's proposed transfer of the tidal station from Fort Point to Saucelito was effected by keeping a self-registering gauge in operation during three months at each of the two positions. The datum-plane was transferred across the Golden Gate instrumentally. At the Fort Point side the three bench-marks were connected by levellings with each other and with the tide-staff, and then a mark was set up near the fort for transferring to a mark at Lime Point the two marks, as referred to the surface of the Golden Gate, being on the same level. From Lime Point levellings were carried to the Saucelito tide-gauge, where bench-marks were made and properly secured. As an additional precaution in the transfer, simultaneous and reciprocal vertical angles were measured between the marks on opposite sides of the Golden Gate, accompanied by readings of the barometer, thermometer, and hygrometer.

Under the direction of Assistant Davidson the observations needful in the transfer of the tidal station were made by Subassistant B. A. Colonna and Mr. J. F. Pratt. Upwards of a thousand observations were recorded while this work was in hand.

In order to connect the new Boneta light-house with the coast triangulation, and to locate the new buoys on the bar, the same observers were directed to recover the marks for identifying the adjacent stations, to establish an additional station on the summit of Point Lobos, and also to determine the position of the flag-staff of the Ocean Beach House. From these it will be easy at any time to locate any object off or in the Golden Gate. For this work Messrs. Colonna and Pratt erected six signals and occupied two stations. Angles connecting the signals were measured by upwards of three hundred observations with the theodolite.

Details connected with the suboffice at San Francisco have been continued under the direction of Assistant Davidson, who meets the frequent inquiries for information, and the calls of other assistants for data pertaining to their work. As a member of the Advisory Board of Commissioners for improving the outline of the water-front of the city of San Francisco, Professor Davidson has co-operated with Rear-Admiral John Rodgers, U. S. N., and Col. G. H. Mendell, United States Engineers. For the material of their joint report much personal attention was given, and study based on observations at home and abroad, of which ample notes had been previously taken by Professor Davidson. In March of the present year Assistant Eimbeck was transferred to duty on the eastern coast; Messrs. T. J. Lowry and W. H. Stearns were for short periods in service with the party of Assistant Davidson, as was also Mr. D. B. Wainwright.

As no appropriation was made at the last session of Congress for continuing the work of the geodetic connection, Assistant Davidson, after computing the results of his work and turning in the records, will employ his party in clearing and preparing for measurement the sites which have been selected for base-lines to check the several branches of triangulation west of the Rocky Mountains.

Reconnaissance east of the Sierra Nevada Mountains, Cal.—For the selection of points suitable for geodetic connection with those which have been occupied, as mentioned under the preceding head, Assistant A. F. Rodgers took the field in September, 1876, and examined the mountain region eastward of the great quadrilateral which has been successfully laid out across the State of California from Mount Helena and Mount Diablo. As all the lines of that great figure cross the Sacramento Valley, for which nothing similar is presented east of the Sierra Nevada range, it was not to be expected that a quadrilateral of such proportions could be repeated in going eastward between the thirty-eighth and thirty-ninth parallels.

Although the two stations with which the additional work will join are upwards of nine thousand feet high, Mr. Rodgers found, in desirable directions to the eastward, that the view was impeded, and that no figure could be laid down comparable in conditions with the first quadrilateral. Points were tested for intervisibility at Carson Cone, Pah Rah (a peak of the Virginia Mountains), at Cory's Peak, and at Augusta Peak.

Assistant Rodgers kept the field, ascending the mountains through formidable fields and slopes of snow and ice; but the severity of the weather upon these great heights constrained him, however, to desist at the close of November. He resumed reconnaissance in the following spring, with the view to locate, if practicable, a scheme of large triangles somewhat further south than the series indicated in his previous reconnaissance.

Descriptive notes of the several summits visited by Assistant Rodgers, the character of the region, means for travel, the approximate height of the mountain, and its bearing from others in the scheme thus far laid out, have been recorded and filed for reference in the office.

Late in May of the present year Mr. Rodgers started from Salt Lake City, and passing southward examined the region of the Wasatch Mountains as low down as Richfield. From a position upwards of eight thousand feet high on the flank of Mount Nebo, snow and ice fields not permitting a higher ascent, pointings were made with a theodolite in all directions. Salt Lake, eighty miles distant, was seen in the northwest, and in the northeast the cathedral-like domes of the Uintah Mountains were visible. Westwardly, over numberless inferior ranges, the Snake Range Mountains and others were in view, one hundred and twenty miles distant, in Nevada. North of Beaver City summits could be readily seen; and, after careful examination, no doubt remained in regard to the practicability of crossing the Wasatch Mountains with triangulation.

On his return westward, Mr. Rodgers crossed the Tushar Mountains below Richfield, and made a detour to northward as far as Fillmore. The country in that region was carefully examined, and observations were noted as at other localities. The field-report states that in the valley west of the village a site for a base-line of indefinite length could be readily had. This is important, the station being intermediate, in a chain of quadrilaterals proposed for the geodetic connection between the Atlantic and Pacific.

Assistant Rodgers states that daily, after leaving Salt Lake City, and until the 9th of June, squalls of snow were noticed on the mountains bordering his line of travel.

After leaving Fillmore, the party went southward and westward, by Cove Creek Fort and Beaver City, to Minersville, and from thence westwardly to Hot Springs, in the Escalante Desert. Of the springs, the following remark is made in the report: "They boil out of a mound ten feet high and a quarter of a mile long, in the midst of a vast plain of alkali and sage-brush. The hot water is led into cooling-boxes, or tanks, and is sold by the bucket to teamsters and travelers."

While crossing the boundary line to pass into Nevada, Mr. Rodgers experienced the only uninterruptedly clear day that occurred during the period of his journey from Salt Lake. By the way of Hamilton, he traveled to Eureka, in the return westward having traversed a region of about seven hundred miles, for the most part on horseback. Taking the railroad at Eureka, the party was again at San Francisco on the 19th of June.

Topography from Timber Gulch to Stewart's Point, Coast of California.—At the close of the fiscal year 1875–'76, Assistant L. A. Sengteller was engaged in the vicinity of Fort Ross in reconnaissance for triangulation to the northward along the coast, as a basis for extending the topographical survey in the same direction. The dense forest that skirts the coast of Sonoma County made the determination of points extremely difficult, as lines of sight could be had only by cutting away the intervening timber. One of the stations adopted as the most available, on account of many local impediments, was the top of the trunk of a tree, cut off eighty-two feet above the ground. This was occupied with the theodolite, and the expedient proved, as in other like cases in the experience of Assistant Sengteller, a matter of great advantage in a region that otherwise could not have been mapped with even ordinary accuracy. In a previous instance his theodolite was used on a tree after it had been cut off one hundred and thirty-three feet above the ground. In regard to the region he remarks:

"From Russian River to Point Arena, and commencing again about four miles north of Point Arena and running to Noyo River, there is no mountain visible from the coast. The want of elevations has been much felt in developing the tertiary triangulation, and in its junction with the larger triangulation even more difficulty may be found."

The plane-table survey was resumed on the 21st of July, 1876, near Timber Gulch, where the topographical work had closed in the preceding season. From thence, northward and westward, the coast details were mapped to Stewart's Point Landing, or fifteen miles from the point at which the plane-table work was resumed. Among the features shown on the two sheets resulting from the field-work are all roads within a mile of the coast, all rocks in view at low water, and connected with the rocky shore-line all the landings between Fort Ross and Stewart's Point.

"The character of the topography prosecuted during the season presents a continuous broken shore-line with precipitous and rugged bluffs, and numerous outlying rocks, all backed by country that rises rapidly from the water-line to heights of fourteen hundred to sixteen hundred feet in the distance of one or two miles."

Mr. G. H. Wilson aided in the field-work. The statistics are:

Signals erected	17
Stations occupied	16
Angles measured	126
Number of observations	2, 375
Shore-line traced (miles)	23¼
Roads and trails (miles)	53
Streams (miles)	14
Area of topography (square miles)	16

Having closed in accordance with directions, Assistant Sengteller reported in person at the office, and o the 1st of April of the present year was placed in charge of the Engraving Division.

Reconnaissance for primary triangulation north of San Francisco.—The primary triangulation of the coast above San Francisco Bay rests for the present at the line joining Ross Mountain and Sulphur Peak. These stations were selected and occupied by Assistant Davidson some years ago, and were supposed to be favorably situated for extending a chain of quadrilaterals further to the northward and westward along the coast of California. In order to decide upon the most effective scheme with the least number of points, Assistant Cleveland Rockwell was detailed in August, 1876, to make the reconnaissance above Russian River, and with a small camp outfit, carried on pack-saddles, his party had traversed part of the region before the close of the following month. Mr. Rockwell was taken ill at Cloverdale, but in the middle of November rejoined the party, which, under his direction, had passed on in charge of the aid, Mr. E. F. Dickins, and visited in succession six stations to the northward of the line of completed work.

Mr. Rockwell left Round Valley on the 17th of November, and a few days after visited the summit of a mountain near Spruce Grove. Subsequently he occupied Mount Pierce, which lies about ten miles to the eastward of Cape Mendocino. A station was visited near Shelter Cove, and partial observations were made at subsidiary points as data for the adjustment of the most desirable scheme for the triangulation. With reference to prospective wants, this reconnaissance will be made to include points for connecting the coast series of primary triangles with the stations of any main triangulation that may be prosecuted hereafter in the mountain region of Northern California.

Field-operations were closed by Assistant Rockwell on the 7th of December. He then engaged in the work of plotting the observations and embodying notes and sketches to perfect the results of the reconnaissance, so that the stations ultimately selected may be identified hereafter. The summits visited range in height from three thousand feet to six thousand feet. All are carefully described in the field-notes, and four of the principal points were mapped topographically to represent the contour of the summits adjacent to the proposed points of triangulation.

Early in April of the present year Assistant Rockwell again took the field for the purpose of selecting points to meet the conditions of being intervisible, and to be so related as to form desirable quadrilaterals. These conditions do not readily conjoin in a region which is covered even to the mountain summits by a dense growth of redwood. As reported, the timber growth presents the main obstacle. Lines of sight could not be opened without unusual labor in cutting. Other points were visited in succession in going northward towards Klamath River, and at the end of the fiscal year Mr. Rockwell had adjusted a series of quadrilaterals as far as Eel River, and expected little difficulty in extending the scheme as far north as the Klamath.

SECTION XI.

COAST OF OREGON AND WASHINGTON TERRITORY, INCLUDING THE INTERIOR BAYS, PORTS, AND RIVERS.—(SKETCHES NOS. 19 AND 20.)

Coast hydrography of Oregon.—Lieut. Commander George W. Coffin, U. S. N., Assistant in the Coast Survey, with his party in the steamer Hassler, left San Francisco on the 17th of June last, and reached Astoria after a boisterous passage of four days. Stress of weather made it expedient to put into Drake's Bay, and afterwards to seek shelter at Crescent City, Chetko, and Port Orford. After the arrival at Astoria a party was dispatched without delay to set up signals along the Clatsop beach. As soon as practicable soundings were commenced by running lines normal to the coast off the Columbia River entrance, and to the southward as low down as Tillamook Head. The lines extend to an average of fifteen miles from the shore-line. For the adjustment of soundings on his chart, Lieutenant-Commander Coffin from the outset had tidal observations recorded at Astoria and also at a station in Baker's Bay. By erecting signals forty feet high it was found practicable to keep them in view as far out to seaward as the sounding-lines were carried. This advantage for accuracy in the hydrographic work is, however, offset in part by the strong current and tide rips which make it a matter of difficulty to hold the vessel on any course normal to this part of the Pacific coast.

Most of the work here noticed was done after the opening of the present fiscal year, and will, therefore, be the subject of mention in my next annual report, together with a synopsis of the statistics. The work is yet in progress.

Lieuts. Richardson Clover, F. J. Drake, Charles W. Jarboe, and William H. Driggs, U. S. N., and Master Richard Mitchell are attached to the party in the steamer Hassler. At the date of the last report from Lieutenant-Commander Coffin, the prospect was good for a speedy advance in the work.

Hydrography of the Columbia River, Oregon.—By the operations of preceding seasons the hydrography of the Columbia had been advanced from the entrance upward as far as Cathlamet. Assistant J. J. Gilbert resumed work at the opening of the fiscal year, and prosecuted soundings in the river until September, and so advanced the survey to the upper end of Crim's Island, or somewhat beyond the limit which had been reached in the topographical survey. In November and December Mr. Gilbert took the field with a plane-table and mapped the details of both banks as far up the river as Mount Rainier. The schooner Kincheloe was then laid up in charge of a ship-keeper, and so remained during the winter. Meanwhile the soundings were plotted, and two hydrographic sheets with the records, and a topographical sheet, were forwarded to the office. Field-work on the Columbia was resumed on the 9th of April, and was restricted to the survey of the shores until the opening of June, when the limit reached was nearly coincident with that of the triangulation, which for the present rests at Kalama.

A third hydrographic sheet was commenced in June and was completed by the end of that month. For each of them a separate tide gauge was established, one at Cathlamet, one at Eagle Cliff, and the third at Rinearson's, on the Oregon side of the river. The survey was in progress at the close of the fiscal year. A synopsis of the statistics is appended:

Shore-line surveyed (miles)	63½
Roads (miles)	51
Sloughs (miles)	61
Area of topography (square miles)	43
Miles run in sounding	531
Angles measured	6,061
Number of soundings	36,505

Mr. Thomas P. Woodward is attached to the party as temporary aid.

Tidal observations.—Under the supervision of Col. G. H. Mendell, United States Engineers, the excellent series of tidal and meteorological observations at Astoria, Oreg., was continued by Mr. Louis Wilson until the end of October, 1876. The station was then discontinued and the observer transferred to Port Townshend.

The Astoria series was begun in July, 1853, with a self-registering tide-gauge of the form devised by the late Joseph Saxton. Mr. Wilson was detailed as observer in 1858, and remained at the station until the series of observations was closed.

At Port Townshend Mr. L. Nessel remained as observer until November, 1876, when he was succeeded by Mr. Wilson. A clock with balance-wheel and lever-escapement has been provided for the gauge at this station.

Reconnaissance.—For the primary triangulation of Washington Sound and the Strait of Fuca, a careful study has been made so as to include the least number of well-conditioned quadrilaterals. The examination in reference to the practicability of the lines as marked on the scheme was begun by Assistant J. S. Lawson in September, 1876, and was prosecuted until winter. Resuming early in April, the work was continued until the close of the fiscal year. As the proposed stations were visited in succession, lines of sight were cleared and signals were set up.

The sanction of the Dominion Government and consent of the authorities of British Columbia having been obtained, several of the primary stations for lines across the Strait of Fuca will be located on the shore of Vancouver Island. The aim will be to connect prominent points on the islands of Washington Sound by the least number of lines. Good progress had been made in the reconnaissance when the last report was received from Assistant Lawson. The schooner Fauntleroy has been in service in connection with this work.

Hydrography of Possession Sound, W. T.—For this work Assistant Gershom Bradford was detailed in August, 1876, and sailed from San Francisco with a party in the schooner Yukon. Early in September the schooner was joined at Seattle by the steam-launch Lively. Both vessels were refitted without delay, and hydrographic operations were begun in Possession Sound, and were prosecuted until the 1st of December. The statistics of the work done by the party of Assistant Bradford are:

Miles run, with soundings	253
Angles measured	3, 390
Number of soundings	12, 960

Thirty-three signals were erected for the adjustment of soundings. The hydrographic sheet turned in at the office contains the boat-soundings from Point Edmund to Point Elliott, and along the shores of Whidbey Island from Possession Point to Hawk Station. Cultus Bay, an indentation at the south end of Whidbey Island, was sounded; also Deer Lagoon, which, as having shore-line but no depth at low-water, cannot be safely omitted from the chart of that vicinity.

At Port Madison, Assistant Bradford determined the positions of several sunken rocks off the eastern point of the entrance. One of the rocks has a depth on it of only three feet and a half, and near it there is a rock with less than four feet. Another in the vicinity has on it seven feet at mean low-water.

On the 10th of May, Mr. Bradford closed the operations of his party in this section, and returned to San Francisco. After completing the charts and other office-work connected with his hydrographic operations, he joined the party of Assistant Davidson, to assist in compiling notes for the Coast Pilot of the Pacific seaboard of the United States. Lieut. Richard M. Cutts, U. S. N., at the same time took charge of the party in the schooner Yukon, as will be mentioned in referring to the operations of that officer under another head.

Topography of Admiralty Inlet, W. T.—The detailed survey of the shores of Admiralty Inlet was taken up at Battery Point by Subassistant Eugene Ellicott early in September, 1876. With the limited means available, good progress has been made in the work. On the eastern side of the inlet the topography has been mapped as far south as Dash Point, at the entrance of Commencement Bay. On the opposite side of the inlet the work includes the whole of Vashon Island and Maury Island, and also the western shore of Colvos Passage from Point Orchard southward to Gig Harbor.

Field-work was discontinued on the 10th of December, but was resumed early in May, and at the close of the fiscal year the survey was in progress in Commencement Bay. The following are statistics of the work of this party during the season:

Shore-line surveyed (miles)	125
Area of topography (square miles)	80

As the work advanced the party moved from point to point in a small steam-launch which had been provided at the outset of the season.

Inspection of topography.—Assistant H. L. Whiting reached San Francisco early in October, 1876, and made immediate arrangements for a general review of the topographical features of the Pacific coast of the United States. This service was directed with reference to means for deciding on the modes of operation and the scales best suited for the plane-table work yet to be done in the survey.

In order to take advantage of the remaining part of the favorable season, before the setting in of the rains peculiar to Oregon and Washington Territory, Mr. Whiting proceeded directly to the northern sections. His inspection of that quarter included a thorough examination of the topography which borders the Strait of Juan de Fuca, Admiralty Inlet, and Puget Sound. A comprehensive report presented after his return describes the characteristic formations and contours of the ground, and points out the methods and scales adapted for the most effective delineation.

The shores of the Columbia River were subsequently examined from the mouth upward to the head of navigation at the Cascades, and also those of the Willamette branch from its junction with the Columbia to the head of navigation at Oregon City. Of these rivers the peculiar topographical features are noticed by Mr. Whiting as being the finest subjects for delineation within the range of the survey on the Pacific coast, and as requiring the highest order of artistic skill and experience.

Hydrography of Commencement Bay, W. T.—The party in the schooner Yukon was transferred to the charge of Lieut. Richard M. Cutts, U. S. N., Assistant in the Coast Survey, on the 10th of May of the present year. Before taking up the work for which a projection had been sent, supplementary soundings were made in Admiralty Inlet, southward of Battery Point, which work had been in hand previous to the transfer of Assistant Gershom Bradford to duty at San Francisco. Near the close of that month the steam-tender was used at Apple Tree Cove in searching for a reported rock, but the soundings did not develop the existence of any danger to navigation.

In June the party was employed in the vicinity of Commencement Bay in putting up signals. Subassistant Ellicott was at the same time tracing the shore-line. Soundings had been commenced near the close of the month and the hydrography was under good progress when the last report was received from this section. The details of the work will be stated in my next annual report. Lieutenant Cutts is assisted in the hydrography by Lieuts. A. B. Wyckoff and Uriah R. Harris, U. S. N.

Alaska Coast Pilot.—During the past season Assistant W. H. Dall has been engaged in examining all hydrographic material accessible in the shape of charts, voyages, and marine memoirs relating to the coast of Alaska and the adjacent regions, with reference to the compilation, from such sources, of a Coast Pilot or Directory for the use of navigators. The work is now more than half completed and has necessitated the examination of numerous publications in the Russian, as well as in the German, French, and Spanish languages.

Besides the immediate value of the Coast Pilot of Alaska, which will form one of the series in preparation by the Coast Survey, and designed to cover ultimately the whole coast of the United States, the work now under the charge of Mr. Dall is a necessary preliminary to any systematic examination of the coast to which it relates. Only by such a sifting of the information on record can future reconnaissance work be started where it is most needed, without loss of money or time.

The researches of Mr. Dall have, in addition, gathered some facts of importance relating to the meteorology of Alaska, and other branches of investigation, bearing on hydrography and navigation.

Tidal observations.—As yet no records have been received from the Sandwich Islands. One of the improved self-registering tide-gauges was forwarded to Honolulu at the request of W. D. Alexander, esq., superintendent of the government surveys, whose interest in the geographical development of the island has been unremitting. For a long period it has been desirable to obtain data from Honolulu for comparison with the tidal records of the Pacific coast of the United States. It is understood that several gauges, at different tidal stations, were started by Mr. Alexander with a view of obtaining results, which will be checked by records not dependent upon exactly similar conditions.

COAST SURVEY OFFICE.

Under the charge and direction of Assistant J. E. Hilgard, the multifarious duties of the office, involving a great variety of details, have been ably prosecuted, as heretofore. Many of the operations require general scientific knowledge, some a cultivated taste in various branches of art, and others a thorough command of the principles of geodesy. Brief abstracts will be given under separate heads, referring to the work done in each of the office divisions.

In addition to the wide range of duties pertaining to the work of the survey, Assistant Hilgard, as inspector, has conducted all details in the office of Standard Weights and Measures. A separate report will be presented, at an early date, on the methods pursued in the construction of the metric standards for the several States, in pursuance of a joint resolution of Congress of July 27, 1866. In this place it is only necessary to say that the metric standards, duly adjusted and verified, have been delivered to all the States ready to receive them; some being held subject to call, where no proper place of safe-keeping has been provided; and that a reserve of ten sets of the standards is yet in progress of adjustment and verification. A brief statement of the legislative enactments and executive action in relation to metric standards will be found in Appendix No. 12.

By an international commission, of which Mr. Hilgard was a member on the part of the United States, arrangements were concerted for securing exactness and uniformity in comparisons of various national standards of length and weight. The deliberations of this commission, at meetings held in 1872 and 1874, resulted in the establishment of an International Bureau of Weights and Measures, at Paris. The invitation tendered to Assistant Hilgard to accept the directorship of the bureau marks the sense held in that eminently scientific body of his special fitness for organizing and conducting an institution so exacting in its scientific demands, and so novel in political inception. While declining the proffered honor, he will none the less continue his co-operation as a member of the International Committee of Weights and Measures.

In the summer of 1876, but without remitting in executive duties pertaining to the Coast Survey Office, Mr. Hilgard acted as one of the judges on scientific and mechanical apparatus at the Centennial Exposition in Philadelphia. His intimate knowledge respecting instruments of precision associated him as a leading member of the board of judges, which included some of the ablest scientists of America and Europe. Subsequently, on invitation, he delivered a course of twenty lectures for the Johns Hopkins University, in Baltimore, on the subject of extended territorial surveying, thus contributing the benefit of his long experience to the training of young men for a work which is one of the great needs of our country—the accurate mapping of its entire surface. By all other civilized states in which such work has not been accomplished it is actively prosecuted.

Before reciting in some detail the operations of the several divisions of the office, I will call attention to some special results that have accrued during the year, a part of which form the subjects of papers appended to this report.

In Appendix No. 6 will be found a discussion of the results of two meridional arcs, aggregating eight degrees of latitude, that have been measured incidentally during the progress of the coast survey. Their bearing upon the general figure of the earth is considered, but the conclusions reached must necessarily be modified by the introduction of the great oblique arc from the Saint Croix River to Central Georgia, which has been completed since the date of this report.

Attention is called to the great number of maps and charts published during the year by the method of photolithography. Their titles will be found in Appendix No. 4, and the perfection that has been reached in the process may be judged from the chart of San Luis Obispo Bay and approaches, No. 21, of this volume. The new engraved chart of the Atlantic coast from Cape Sable (sailing-chart A) also deserves special notice. It comprises charts of the principal harbors upon the same sheet with the general chart, the former being copies of the separate charts transferred upon the plate by the electrotype process.

The list of latitude-stars, printed in a former report with approximate places only, for purposes of selection, was reprinted with as exact places as could be readily obtained without reobservation, as Appendix No. 7, Report of 1876.

In the matter of instruments, important progress has been made. Three 20-inch theodolites, constructed by Mr. William Wurdemann for the Coast Survey, were carefully tested as to graduation at the office, and subsequently by actual use in the field, and have been found to give results of superior accordance than heretofore obtained with instruments of a similar class. Appendix No. 11 gives the details establishing these facts.

A leveling instrument of great precision, for use in geodesic leveling, has been designed and constructed at the office. A full account of it will be given after thorough trial in the field.

In Appendix No. 10 will be found a description and illustration of an "optical densimeter," intended to determine the density of sea-water by its refractive power, offering the advantage over a hydrometer or "stemfloat" that its indications are not affected by the motion of the ship. In this connection the water specimen-cup, of the "drop-cylinder" pattern, described in the report of Lieutenant Collins on his examination of the salinity of the waters of Chesapeake Bay (Appendix No. 14), should also be mentioned.

The compensating apparatus for measuring primary base-lines having previously received the addition of a differential or "Borda" temperature-scale, was compared with the standard bar at the lowest temperatures during the winter, and subsequently in summer at the highest temperatures which the comparing-vault attained, in order to obtain the relation between the temperature-scales and the compensation.

The apparatus has received many improvements in mechanical detail, suggested by experience, and is now again ready for field-work.

Of great importance and interest, as bearing upon the question of the permanence of standards of length, are the comparisons made by Assistant Hilgard of different standard yards, an account of which is given in Appendix No. 12.

In executive duties, Assistant Hilgard was aided by Assistant Edward Goodfellow, who efficiently conducted the business of the office during Assistant Hilgard's absence.

Messrs. H. W. Blair and J. B. Baylor, during several months when not attached to field-parties, have been engaged under the immediate direction of the assistant-in-charge, in preparing the new edition of the list of latitude-stars, in comparing the primary base-apparatus and other measuring-bars, in testing the two new 20-inch theodolites, and in other special work of a like nature.

Hydrographic Division.—Commander E. P. Lull, U. S. N., hydrographic inspector, has remained in charge of the work in this division. He had the aid of Lieut. H. E. Nichols, U. S. N., till April 16, 1877, when that officer received orders for foreign service. Acting Master Robert Platt was on duty from January 2 till his detachment April 14, to take command of a hydrographic party. Great pains have been taken by the hydrographic inspector to perfect the indication of all aids to navigation on the charts of the Coast Survey, and to keep them up to date.

Under the direction of Commander Lull, Mr. E. Willenbucher, hydrographic draughtsman, has protracted, plotted, or drawn eight original hydrographic sheets and six reduced drawings, made six projections for the use of field-parties, and examined a number of charts for corrections of aids to navigation.

Mr. Julius Sprandel, hydrographic draughtsman, has protracted, plotted, or drawn nine and verified six original hydrographic sheets, and made four projections for the use of field-parties, besides executing such miscellaneous work as was intrusted to him.

Mr. W. C. Willenbucher, hydrographic draughtsman, on duty during eight and a half months of the year, has protracted, plotted, or drawn twelve original hydrographic sheets, attended to the additions required on the progress-sketches for the annual report, executed other work of a miscellaneous character, and made seven projections for the use of hydrographic parties.

Computing Division.—The work in this division has been directed as heretofore by Assistant Charles A. Schott. The division has lost the services of Mr. Theodore W. Werner, who from continued ill-health was obliged to retire from duty after a connection with the work extending over forty years. Mr. J. Main, another experienced computer, has been compelled to retire from ill-health. The force in the division being thus weakened, and still further reduced in consequence of diminished appropriations, it has demanded the most unremitting effort on the part of the remaining computers, aided by the occasional services of field-officers assigned to office duty, to make the progress of the work commensurate with that of the observations made in the field.

In addition to the direction and supervision of the computations, Assistant Schott has made a number of special investigations during the year, among which may be mentioned the following:

Report on the telegraphic longitude of Key West, Fla., determined in 1873-'74, including computation of transits observed at the United States Naval Observatory; establishment of twenty-seven conditional equations for the adjustment of heights of stations between Kent Island, Md., and Harper's Ferry, Va.; computation, combination, and discussion of three American arcs of the meridian, the Nantucket arc (Massachusetts, New Hampshire, and Maine); the Pamplico-Chesapeake arc (North Carolina, Virginia, and Maryland), and the Peruvian arc in South America; preparation of a new edition of the paper on observations of terrestrial magnetism; notes on the method of observing horizontal angles and directions in geodetic surveys; collection of data, extension and additions to discussion of secular change of magnetic declination. He has also made the usual annual measures of the declination, dip, and intensity of the magnetic force at a station on Capitol Hill.

The work in detail, done by each computer during the year, may be summarized as follows:

Mr. James Main computed and revised the following astronomical azimuth-stations: Cheever, N. Y., 1874; Mount Merino, N. Y., 1874; Beaconhill, N. J., 1875; Gaviota, Cal., 1875; Arguello, Cal., 1876; Paris, S. C., 1875; Prospect Mountain, N. H., 1873; Mooselauk, N. H., 1873; Observatory Hill, N. H., 1874; Croydon, N. H., 1875; Bluff, Fla., 1876; Long Mountain, Va., 1875; Hog

Island, N. C., 1876; Long Shoal Point, N. C., 1876; Moore Mountain, N. C., 1876. Computed and revised the following astronomical latitude-stations: Hog Island, N. C., 1876; Long Shoal Point, N. C., 1876; Santa Cruz West, Cal., 1874; Arguello, Cal., 1876; Gaviota, Cal., 1875; Rouse's Point, N. Y., 1874; Mount Merino, N. Y., 1874; Beaconhill, N. J., 1875; Long Mountain, Va., 1875; Paris, S. C., 1875. Reduced the transits at Key West, Fla., 1873–'74; furnished star-places to field-parties; and attended to miscellaneous astronomical computations.

Dr. Gottlieb Rumpf computed the following secondary and tertiary triangulations: Dry Tortugas, Fla., 1875; vicinity of Baltimore, Md., 1876; Great South Bay, Long Island, N. Y., 1874; Southwest and South Pass, La., 1876; vicinity of Mount Rafinesque, N. Y., 1874–'75; part of survey of N. H., 1874–'75; part of Santa Barbara Channel, Cal., 1875–'76; Saint John's River, Fla., 1876; Cubitt's Crevasse, La., 1875–'76; South West Pass, La., 1875–'76; Cape Cañaveral, Fla., 1874–'75–'76; Placentia Bay, Me., 1875; Tampa Bay, Old Tampa Bay, Hillsboro' Bay, and Boca Ceiga Bay, Fla., 1873–'74–'75; part of San Miguel and Santa Rosa Island, Cal., 1871–'72; Santa Catalina Island, Cal., 1876–'77; coast of California, Timber Ridge to Ten Mile River, 1873; coast of California, Pudding Creek to Russian Gulch, 1873; Las Bolsas Creek to Newport Bay, Cal., 1874–'75; vicinity of Ross Mountain, Cal., 1875–'76. Prepared abstract of angles of the triangulation of Wisconsin, 1875, and of stations Arguello, Cal., 1876, and Gaviota, Cal., 1875. Attended to the preparation of geodetic information needed for the triangulation parties or called for by the office.

Mr. Edward H. Courtenay computed and adjusted in parts the triangulations of Pungo River, N. C., 1871–'72; Core Sound, N. C., 1873; Bay River, N. C., 1868; Cedar Island Bay, N. C., 1872, and Neuse River, N. C., 1863–'66–'67–'68. Assisted in the figure-adjustment of the principal triangulation of New Hampshire, 1873–'74–'75; checked abstract of directions to subordinate objects, same survey; revised abstracts of directions of a number of stations in the Blue Ridge of Virginia and North Carolina; also, revised vertical angles, stations, Indian and Brandon, Ala., 1875; computed operation of spirit-levels between Annapolis, Md., and Washington, D. C., 1875; inserted geographical positions in the register, and prepared geodetic results for future publication, arranging results at all adjusted stations by States. He also attended to miscellaneous geodetic computations, and directed most of the work of temporary computers.

Mr. Myrick H. Doolittle computed the principal and subordinate directions of the survey of New Hampshire, 1874–'75; prepared least square abstract of directions at stations: Paris, S. C., 1875; Mauldin, S. C., 1875; Pinnacle, S. C., 1875; Flat Top, Va., 1876; Moore Mountain, N. C., 1876; Wofford, S. C., 1876; Buffalo, Va., 1876; Hogback, S. C., 1876; Gulf, Ga., 1875–'76; Brandon, Ala., 1875; also, Gaviota, Cal., Arguello, Cal., and Santa Cruz East, Cal., 1875–'76. Prepared abstracts of vertical angles of stations in the Blue Ridge, Va., 1875–'76; adjusted by least squares the primary triangulation between Rabun-Currahee, Ga., and Hogback-Wofford, S. C., 1874–'75–'76; computed the length of the Mosquito Lagoon Base, Fla., 1875; computed height of station, Mount Rafinesque, N. Y., from spirit-levels; solved, with the assistance of Mr. Courtenay, twenty-seven normal equations in the adjustment of heights in the Blue Ridge survey, Va.; computed probable errors of these heights, and performed miscellaneous geodetic computations.

The following-named persons were temporarily attached to the office as computers:

Mr. Josef Lyons was engaged in check-computations of abstracts of vertical measures in the triangulation of the Blue Ridge, Va., and in solving a series of normal equations. In consequence of a general reduction of force, his services were dispensed with one month after the beginning of the fiscal year.

Mr. Herman H. Gerdes attended to the clerical duties of the Computing Division for half a month, after which time his services were discontinued for the reason just stated.

Subassistant B. A. Colonna was engaged in preparing abstract of angles, triangulation of New Hampshire, 1874–'75, in miscellaneous computation, clerical work, and preparing data for field-parties; assisted Mr. Courtenay in the computation of tertiary points of the triangulation of Pamplico Sound, computed apparent places of stars for latitude of Hog Island and Long Shoal Point, N. C., 1876. February 18, 1877, he was reassigned to field-duty.

Subassistant F. D. Granger reported for duty in the Computing Division March 9, 1877. Was engaged in preparing abstracts of directions at primary stations as resulting from least square adjustment, viz: Stations Hogback, S. C., 1876; Wofford, S. C., 1876; John's Mountain, Ga., 1875; Indian Mountain, Ala., 1875; prepared abstracts of vertical angles: Stations Carnes, Ga., 1873; Lavender, Ga., 1874-'75; John's Mountain, Ga., 1875. He also assisted Mr. Doolittle in the solution of normal equations. Mr. Granger was reassigned to field-duty on June 20, 1877.

Mr. C. H. Sinclair was attached to the Computing Division between March 1 and June 5, 1877, after which date he resumed field-duty. He computed the small tertiary triangulation of Taunton River, Mass., 1876, and copied descriptions of stations required for field-parties.

Mr. M. W. Wines, during the month of June, 1877, was engaged in copying reports.

Mr. C. H. Van Orden was attached to the Computing Division during the last five days of June, 1877, engaged in copying descriptions of stations.

Tidal Division.—Under the direction of Mr. R. S. Avery, in charge of this division, all of the observations received from the several tidal stations, both permanent and temporary, are carefully discussed, and the results afford a basis for the formation of tide-tables predicting the heights and times of high-water for the principal ports of the United States. The tables for 1878 for the Atlantic and Pacific coasts were published before the close of July of the present year.

Efforts to improve the mechanical design and mode of working of the self-registering gauges, so as to obtain continuous records, have not been relaxed. The three-roller gauges are now made automatic, so that counterpoises are not needed. This form of gauge has recently been adopted by the United States Engineer Bureau. At stations where the gauge is apt to be jarred suddenly by heavy waves, balance and lever clocks have been substituted for pendulum ones, with good effect.

The following table gives a condensed statement of the several tidal stations occupied during the year. Of these, the stations at Boston, Astoria, and Port Townshend have been discontinued.

A new station was established at Fernandina in March, the intention being to make the stations at North Haven, Sandy Hook, and Fernandina the fundamental points of reference for all places on the eastern coast.

Section.	Name of station.	Name of observer.	Kind of gauge.	Permanent or temporary.	Time of occupation.		Total days.
					From—	To—	
I	North Haven, Me	J. G. Spaulding	S. R.	Permanent	Apr. 26, 1876	Apr. 26, 1877	365
I	Boston Navy-yard, Mass	H. Howland	S. R.	... do	June 1, 1876	Feb. 19, 1877	264
I	Providence, R. I		S. R.	Temporary	Dec. 31, 1875		None.
II	Governor's Island, N. Y	R. T. Bassett	S. R.	Permanent	May 31, 1876	May 31, 1877	365
II	Brooklyn, N. Y	...do	Box	...do	May 31, 1876	May 31, 1877	365
II	Sandy Hook, N. J	J. W. Banford	S. R.	...do	June 1, 1876	June 1, 1877	365
III	Fort Monroe, Va	W. J. Bodell	S. R.	...do	June 1, 1876	June 1, 1877	365
VI	Fernandina, Fla	H. W. Bache	S. R.	...do	Mar. 19, 1877	June 1, 1877	74
VIII	New Orleans, La	G. Faust	Staff	Temporary	June 30, 1876	June 30, 1877	365
X	Fort Point, Cal	E. Gray	S. R.	Permanent	June 1, 1876	Feb. 1, 1877	246
X	...do	W. Diercks	S. R.	...do	Feb. 2, 1877	June 1, 1877	119
X	Saucelito, Cal	E. Gray	S. R.	...do	Feb. 19, 1877	June 1, 1877	102
XI	Astoria, Oreg	L. Wilson	S. R.	...do	May 1, 1876	Oct. 31, 1876	184
XI	Port Townshend, W. T	L. Nessel	S. R.	...do	May 1, 1876	Oct. 31, 1876	184
XI	...do	L. Wilson	S. R.	...do	Nov. 1, 1876	Mar. 1, 1877	121

The office-work of the Tidal Division, in addition to the preparation of tide-tables for 1878, has consisted chiefly in the primary reduction of the tidal observations received from the permanent stations, in the reduction of series of observations made by the hydrographic parties as far as available for charts, and in such tabulations of high and low waters, hourly ordinates, and reductions to staff, as are not done by the observers in the field.

Mr. R. S. Avery, in charge, has inspected the tidal records, attended to the correspondence with observers, furnished data called for by the office, and supervised the work on tides and tide-gauges, besides making such computations as his time would admit of.

Mr. John Downes tabulated and reduced the observations and computed the predictions for the tides for the Atlantic coast.

Mr. L. P. Shidy reduced observations at a large number of hydrographic stations on both the Atlantic and Pacific coasts, computed predictions of tides at stations having large diurnal inequality, and aided in miscellaneous investigations and discussions.

Mr. F. H. Parsons was employed temporarily in the division until ordered to field-duty.

Miss M. Thomas aided in the summation of hourly readings, and in such miscellaneous work as was from time to time needed.

Drawing Division.—Although the force in this division, under the general direction of Mr. W. T. Bright, has been materially reduced, the progress made compares favorably with that of previous years. The application of photolithography to the publication of charts at an early date after the receipt of the original maps and field-notes has been availed of whenever desirable, and has enabled the office to meet the demand for important charts.

The results of the final discussion of the trans-Atlantic determinations of longitude having been applied to all charts of recent issues, it was deemed advisable to indicate the change of longitude upon the older charts; this has been done upon the copper-plate projections and upon the plates intended for the charts of the Coast Pilot.

Changes in the location of buoys, the establishment of new range-marks for channels, the location of new lights and other data coming under the general head of "aids to navigation" are added to the chart-room editions by hand. For the use of the engravers, topographical details are worked up upon hard paper impressions of the pantograph outlines of harbor charts; the names for general lettering upon the original plates are also furnished.

In Appendix No. 3 will be found a statement of the information furnished from this division in reply to special calls during the year, and in Appendix No. 4 an abstract giving the titles of the charts completed or in progress.

The report of the miscellaneous work executed by the division includes the following details:

Projects for new charts prepared	17
Projections made on copper for new charts	10
Diagrams prepared	48
Projections for topographic and hydrographic field-parties	55
Photolithographic charts and sketches completed	16
Copies of field-sketches made for files of the office	74
Information furnished in form of tracings, &c., in reply to special calls	62

The character of work performed by the several draughtsmen has been as follows:

Mr. A. Lindenkohl has drawn the principal finished coast and harbor charts; constructed projections on copper, and for field use, and has brought up the progress-sketches to the years 1874 and 1875. He has made various diagrams, verified new drawings and engravings, and has been engaged in numerous other incidental duties.

Mr. H. Lindenkohl, whose skill is made applicable to any duty required of the division, has furnished the drawings or tracings for all the photolithographic charts issued during the past year. He has also made finished drawings upon various scales for engraving, constructed diagrams, made copper-plate projections, and attended to much miscellaneous duty. He engraved the topographical details upon the plate of entrance to Tampa Bay, Fla., scale $\frac{1}{40000}$.

Mr. L. Karcher has constructed the greater number of projections called for by the various field-parties; made the more finished tracings required to meet calls for information from the several departments; drawn the hydrography for a number of charts intended for engraving, assisted in the preparation of the material for the charts issued by the photolithographic process, and made projects for coast and harbor charts.

Mr. P. Erichsen has reduced the topography for a number of finished coast charts, scale $\frac{1}{80000}$; supplied the details for pantographed harbor charts, colored diagrams, and made all the mechanical drawings of instruments of precision required for illustration in the annual reports.

Mr. C. Junken has principally been employed in reducing the hydrography for the $\frac{1}{80000}$ scale charts; applied the new telegraphic longitude to the plates of the charts previously issued, and made field projections.

Mr. C. A. Meuth has attended to the lettering of plane-table sheets, made tracings and projects and performed miscellaneous duties in correcting charts and sketches.

Mr. H. Eicholtz has attended to coloring buoys and light-houses, as well as adding aids to navigation upon the chart-room editions of catalogued charts.

Mr. G. A. Morrison performed the clerical duties of the division, and corrected charts when not otherwise engaged.

Mr. Hull Adams remained attached to the division engaged in miscellaneous work until August, when he was detached from office-duty.

Mr. A. Haake was given temporary employment in making projects from January 1, 1877, to February 3.

Mr. E. Molkow was transferred from the Engraving Division in May and has corrected charts and made diagrams.

Mr. Bion Bradbury, aid, after returning from field-duty was assigned to the division in June for practice.

Engraving Division.—From the beginning of the fiscal year until April 1 this division was in charge of Assistant J. S. Bradford, who was relieved at that date to resume direction of the work of the Coast Pilot. Assistant L. A. Sengteller succeeded Mr. Bradford.

Special attention has been given by Mr. Sengteller to the corrections needed to bring up to date the plates of the principal charts, his experience in the field, more especially upon the Pacific coast, having led him to observe the great value of these charts to mariners, and the entire dependence placed upon them.

With this work much of the time of the engravers has been occupied; the sketches showing the progress of the various operations of the survey have received additions for the report of the Superintendent; and since June the engraving of the plates for the second volume of the Coast Pilot has been pushed forward as rapidly as possible.

The table given in Appendix No. 5 presents a statement of the plates completed, continued, or begun during the year.

Messrs. J. Enthoffer, A. Sengteller, W. A. Thompson, and R. F. Bartle have continued work as topographical engravers.

Messrs. E. A. Maedel, F. Courtenay, A. Petersen, and H. M. Knight have been employed as letter-engravers; and Messrs. J. G. Thompson, J. J. Young, E. H. Sipe, and W. H. Davis as miscellaneous engravers.

Mr. E. Molkow, during part of the year, continued the use of the pantograph, and from August 1 to October 15 acted temporarily as copyist of the division, when he was transferred to the Drawing Division.

Mr. L. Kerr performed the duties of copyist in a most satisfactory manner until July 31, when he left the office; his extended knowledge of the duties, combined with ready adaptability and interest, have caused his loss to be sensibly felt.

As previously mentioned, Mr. E. Molkow was assigned in place of Mr. Kerr, and subsequently Mr. G. A. Morrison was ordered (October 18) to the same duty, which he is now discharging in a creditable manner.

Electrotype Division.—The work of this division involves the production of altos, and bassos or printing-plates, from the original engraved plates; the preparation of photographic reductions for the use of draughtsmen and engravers, the making of the silver solutions, collodion, and other chemical preparations used in the laboratory, and the care of the batteries for the automatic electric clocks and bells used in the office.

Dr. Anton Zumbrock, in charge, reports the making of seventy-one electrotype plates, forty-two of which were altos, and twenty-nine bassos. The total weight of these plates was twelve hundred and seventy-three pounds; the entire surface, fifty-three thousand one hundred and seventy-five square inches.

With the aid of the improved camera, introduced last year, thirty-five negatives, six positives, and seventy-seven prints have been obtained. Dr. Zumbrock was aided by Mr. Frank Over.

Division of Charts and Instruments.—Under the direction of Mr. John T. Hoover, in charge, distribution is made of the charts to sale agents in the principal sea-ports of the United States, and of the annual reports of the Superintendent to libraries and public institutions both at home and abroad; the papers embodying the methods and results of the survey are kept on hand to supply constant demands from colleges, scientific associations, and persons interested in State and other surveys; records are kept of all instruments sent to or from the field; supplies of stationery are furnished upon requisitions from the divisions of the office, or from field-parties, and the accounts of office expenditures and disbursements are kept.

In the archives Mr. G. A. Stewart has continued to perform the duty of receiving and registering the original and duplicate field-records, and of filing for reference the original topographic and hydrographic maps and charts.

The lists of these original sheets have been brought up to date and published as appendices to the report of the Superintendent for 1875.

During the year, nineteen thousand four hundred and seventy copies of charts and sketches have been printed.

The presses have been worked by Mr. Frank Moore, aided by Mr. D. N. Hoover.

Sixteen thousand seven hundred and seventy-five copies of maps and charts have been issued from the chart-room, under the immediate charge of Mr. Thomas McDonnell. This aggregate number is an increase over that of last year by upwards of four thousand copies, and indicates the growing demand for maps and charts based upon accurate surveys.

Of the annual reports of the Superintendent, two thousand eight hundred and thirty copies of various years have been issued, an increase over the distribution last year of seventeen hundred and ninety copies.

In the folding-room the work of backing with muslin the sheets required for office use and for the field-parties has been done by Mr. H. Nissen.

Mr. G. N. Saegmuller has had the supervision of work in the instrument-shop, including the construction and repair of instruments, and the testing of their adjustments for field-parties.

Among the improvements introduced by Mr. Saegmuller may be mentioned the process of cloth-dusting, by means of which the surfaces of brass, which would otherwise reflect light in a way trying to the eyes of an observer, are covered with a fine coating of green cloth.

Mr. John Clark, since his return from duty connected with the care of the Coast Survey exhibit at the Centennial Exposition, has been engaged mostly upon the preparation of the primary-base apparatus for field-service on the Pacific coast; these preparations involving improvements in its construction, which have been executed by Mr. Clark under the immediate direction of the assistant in charge. He has also aided in the comparisons of standard meters, in comparisons of the measuring-bars of the subsidiary-base apparatus, and has constructed an instrument for leveling of precision after designs furnished by the office.

Messrs. W. Jacobi, E. Eshlemann, and W. Suess were employed as mechanicians.

Mr. A. Yeatmann, aided by Mr. F. E. Lackey, has done all carpenter-work required by the office, including the wood-work of instruments and their packing for transportation.

The duties of writer in my office were performed by Mr. W. B. French until he was ordered to field-duty, early in May; since then by Mr. W. A. Herbert, with the occasional aid of Mr. F. H. Parsons.

Mr. R. L. Hawkins has continued as principal accountant in the office of the disbursing agent, with the aid of Mr. W. A. Herbert, until May 5; and of Mr. W. B. Flenner until he left the office, at the end of March.

On account of failing health, Mr. Samuel Hein, at the age of sixty-eight, after having performed the duties of disbursing agent of the Coast Survey for many years, tendered his resignation. This was reluctantly accepted, to take effect on the 1st of March, when, at greatly reduced compensation, he entered upon duties more suited to his age and physical strength, but effective by reason of his experience and knowledge of details in the service.

With the strictest integrity and sensitive appreciation of the responsibilities of his position, Mr. Hein always combined a never-ceasing devotion to the interests of the public service, and genial courtesy towards every one. Those who know him will cherish the hope that he may remain in our midst for many years as an example of honest purposes and earnestness in work.

Upon the resignation of Mr. Hein, he was succeeded, with the sanction of the Secretary of the Treasury, by Mr. John W. Porter, who had been some years employed in the Treasury Department in various responsible positions, including that of chief clerk of the department. His duties as disbursing agent have been satisfactorily discharged.

I take pleasure in recording, as heretofore, the services of Assistant W. W. Cooper, who acceptably conducts official details under my immediate direction.

Respectfully submitted.

C. P. PATTERSON,
Superintendent United States Coast Survey.

Hon. JOHN SHERMAN,
Secretary of the Treasury.

APPENDICES.

APPENDIX No. 1

Distribution of surveying-parties upon the Atlantic, Gulf, and Pacific coasts of the United States during the fiscal year 1876–'77.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION I.				
Atlantic coast of Maine, New Hampshire, Massachusetts, and Rhode Island, including sea-ports, bays, and rivers.	No. 1	Hydrography	Lieut. J. F. Moser, U. S. N., assistant; Masters J. B. Murdock and F. E. Greene, U. S. N.	Hydrography of the sea-approaches to Mount Desert Island, Me. (See also Sections II and IV.)
	2	Hydrography	Lieut. J. M. Hawley, U. S. N., assistant; Masters Richard Mitchell, G. C. Hanus, and A. H. Cobb, U. S. N.	Soundings continued in Eggemoggin Reach, coast of Maine.
	3	Tides	J. G. Spaulding	Series continued with self-registering tide-gauge, and meteorological observations at North Haven, Penobscot entrance, Me.
	4	Topography	A. W. Longfellow, assistant; C. H. Van Orden.	Topographical survey of the shores of Penobscot River, from Hampden upwards to Bangor, Me.
	5	Hydrography	F. F. Nes, assistant	Supplementary soundings north and south of the entrance to Saco River, Me.
	6	Triangulation	Prof. E. T. Quimby	Triangulation of New Hampshire in the vicinity of Mount Washington.
	7	Tides	H. Howland	Tidal and meteorological series of observations, closing in March, 1877, at the Boston Navy-yard, Mass.
	8	Special hydrography.	Acting Master Robert Platt, U. S. N., assistant; Albert Mertz and J. P. Underwood, ensigns, U. S. N.	Tidal currents observed in the Gulf of Maine. (See also Section II.)
	9	Triangulation	A. M. Harrison, assistant; C. H. Sinclair and W. C. Hodgkins, aids.	Triangulation of Taunton River, Mass., from Dighton upwards to the head of navigation.
	10	Tides		Series of observations continued with self-registering tide-gauge at Providence, R. I.
SECTION II.				
Atlantic coast and sea-ports of Connecticut, New York, New Jersey, Pennsylvania, and Delaware, including bays and rivers.	1	Topography	R. M. Bache, assistant	Detailed topographical survey, extended in the vicinity of New Haven, Conn.
	2	Scientific observations.	C. S. Peirce, assistant; Edwin Smith, subassistant.	Pendulum-observations at New York City, for measuring the earth's gravitation.
	3	Triangulation	Richard D. Cutts, assistant; J. F. Pratt, aid.	Primary triangulation extended across the Hudson River near Albany, N. Y.
	4	Tides	R. T. Bassett	Observations continued with self-registering tide-gauge at Governor's Island, New York Harbor, and with box-gauge at Brooklyn, Long Island.
	5	Hydrography	Acting Master Robert Platt, U. S. N., assistant; Acting Ensign George Glass, and Mates J. F. Lee and J. A. Smith, U. S. N.	Supplementary soundings in Gedney's Channel, New York entrance. (See also Section I.)
	6	Tides	J. W. Banford	Series continued with self-registering tide-gauge at Sandy Hook, N. J.
	7	Triangulation	Prof. E. A. Bowser	Stations at Goat Hill and Mount Rose occupied for determining points in Northern New Jersey.
	8	Hydrography	Lieut. J. F. Moser, U. S. N., assistant; Masters J. B. Murdock and O. W. Lowry, U. S. N.	Hydrography completed in Barnegat Bay, N. J. including Tom's River. (See also Sections I and IV.)

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION II—Continued.	No. 9	Coast Pilot	J. S. Bradford, assistant; Lieut. Fred. Collins, U. S. N., assistant; J. R. Barker.	Sailing-notes for the coast and harbors of New Jersey, and the shores of Delaware Bay, compiled for the Atlantic Coast Pilot. (See also Sections III, IV, and V.)
	10	Triangulation	Prof. L. M. Haupt	Triangulation continued in the eastern part of Pennsylvania.
SECTION III.				
Atlantic coast and bays of Maryland, Virginia, including sea-ports and rivers.	1	Coast Pilot	J. S. Bradford, assistant; Lieut. Fred. Collins, U. S. N., assistant; J. R. Barker.	Sailing-notes for the coast of Maryland and Virginia, and the estuaries of Chesapeake Bay, compiled for the Atlantic Coast Pilot. (See also Sections II, IV, and V.)
	2	Special observations.	F. H. Gerdes, assistant; H. Caperton.	Life-saving stations on the coast of Delaware, Maryland, and Virginia determined in position and marked on original sheets of the survey.
	3	Triangulation, topography, and hydrography.	J. W. Donn, assistant	Minute survey of the shore and wharf lines, including the hydrography of the harbor of Baltimore City, for United States commissioners.
	4	Magnetic observations.	Charles A. Schott, assistant	Magnetic declination, dip, and intensity determined at a station on Capitol Hill, Washington, D. C.
	5	Topography	Charles Junken	Topographical survey and compilation of maps of the vicinity of Smith's Island, in Chesapeake Bay, for the boundary commissioners of Maryland and Virginia.
	6	Topography	J. W. Donn, assistant	Detailed survey of the shores of James River, Va., from City Point upward to Kingsland Creek.
	7	Topography	C. M. Bache, assistant	Plane-table survey northward and eastward of Norfolk, Va.
	8	Tides	W. J. Bodell	Tidal observations continued with self-registering gauge at Fortress Monroe, Va.
	9	Reconnaissance	S. C. McCorkle, assistant	Reconnaissance for the selection of points of triangulation in West Virginia.
SECTION IV.				
Atlantic coast and sounds of North Carolina, including sea-ports and rivers.	1	Triangulation	A. T. Mosman, assistant; J. B. Baylor, aid; W. B. Fairfield.	Primary stations occupied near the Blue Ridge for triangulation in Virginia and North Carolina.
	2	Coast Pilot	Lieut. Fred. Collins, U. S. N., assistant; Masters F. Winslow and A. H. Cobb, U. S. N.	Special hydrographic examination of the coast of North Carolina between Hatteras and Oregon Inlet, including the vicinity of Frying Pan Shoals, and compilation of notes for the Atlantic Coast Pilot. (See also Sections II, III, and V.)
	3	Hydrography	Lieut. Richard Wainwright, U. S. N., assistant; Masters W. P. Ray and F. H. Lefavor, U. S. N.	Hydrography of Ocracoke Inlet, and supplementary work in Pamplico Sound, Currituck Sound, and East Lake, N. C.; and in North Landing River, Va.
	4	Astronomical observations.	Edwin Smith, subassistant; Chas. Tappan.	Latitude and azimuth determined at Long Shoal Point, and at Hog Island in Pamplico Sound, N. C.
	5	Hydrography	Lieut. J. F. Moser, U. S. N.; Masters J. B. Murdock and O. W. Lowry, U. S. N.	Hydrography completed in Core Sound, and Bogue Sound, N. C. (See also Sections I and II.)
	6	Topography	C. T. Iardella, assistant; Master G. C. Hanus, U. S. N.	Topography of the vicinity of Cape Fear River at Wilmington, N. C.
SECTION V.				
Atlantic coast and sea-water channels of South Carolina and Georgia, including sounds, harbors, and rivers.	1	Primary triangulation.	C. O. Boutelle, assistant; H. W. Blair, aid; J. B. Boutelle and W. B. French.	Primary triangulation from the Atlanta base-line extended northward and eastward across the boundary between South Carolina and North Carolina.
	2	Coast Pilot	Lieut. Fred. Collins, U. S. N., assistant; Masters F. Winslow and A. H. Cobb, U. S. N.	Examination of harbors and sounds between Cape Fear and Saint Mary's River, and compilation of sailing-notes for the Atlantic Coast Pilot. (See also Sections II, III, and IV.)

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION VI.				
Atlantic and part of the Gulf coast of the Florida peninsula, including reefs and keys, and the seaports and rivers.	No. 1	Tides	H. W. Bache	Series of tidal observations commenced at Fernandina, Fla., with self-registering tide-gauge.
	2	Triangulation, topography, and hydrography.	H. G. Ogden, assistant; Master A. C. Dillingham, U. S. N.; W. I. Vinal, subassistant.	Detailed survey of Saint John's River, Fla., extended from Jacksonville southward to Hogarth's Bay.
	3	Hydrography.	Lieut. Commander J. C. Kennett, U. S. N., assistant; Lieuts. Washburn Maynard and W. I. Moore, U. S. N.; Masters W. F. Low and S. H. May, U. S. N.	Inshore hydrography of the eastern coast of Florida, from Matanzas Inlet southward to Mosquito Inlet.
	4	Triangulation, topography, and hydrography.	Charles Hosmer, assistant; Joseph Hergesheimer, subassistant.	Survey of the coast and sea-water passages near Cape Cañaveral, Fla., including parts of Banana River, and Indian River.
SECTION VII.				
Gulf coast and the sounds of West Florida, including ports and rivers.	1	Triangulation, topography, and hydrography.	F. W. Perkins, assistant	Detailed survey and hydrography of the western coast of Florida, from Horse Shoe Point southward to Cedar Keys.
	2	Hydrography	Lieut. R. D. Hitchcock, U. S. N., assistant; Lieut. J. N. Hemphill, U. S. N.; Masters John Hubbard, T. G. C. Salter, and J. L. Hunsicker, U. S. N.	Hydrography of the Gulf coast from Pine Point westward to Choctawhatchee, including Saint Andrew's Bay and its approaches.
	3	Triangulation	Prof. W. B. Page	Determination of points by triangulation in Kentucky, between Cumberland Gap and Lancaster Court-House.
	4	Triangulation	Prof. A. H. Buchanan	Measurement of base-line near Lebanon, Tenn., and selection of points for triangulation between Knoxville and Nashville.
	5	Reconnaissance	F. P. Webber, assistant; F. D. Granger, subassistant.	Selection of station-points for triangulation in the northwestern part of Alabama.
SECTION VIII.				
Gulf coast and bays of Alabama, and the sounds of Mississippi and Louisiana to Vermillion Bay, including the ports and rivers.	1	Hydrography	Lieut. Commander C. D. Sigsbee, U. S. N., assistant; Lieut. J. E. Pillsbury, U. S. N. (part of season); Lieuts. S. M. Ackley and W. O. Sharrer, U. S. N.; Masters M. F. Wright, W. E. Sewell, and Henry McCrea, U. S. N.	Deep-sea soundings and temperature observations on numerous lines in the waters of the Gulf of Mexico.
	2	Triangulation and topography.	W. H. Dennis, assistant; Master Kossuth Niles, U. S. N.; Andrew Braid, subassistant.	Topographical survey of the shores of Barataria Bay, La.
	3	Special hydrography.	H. Mitchell, assistant; H. L. Marindin, assistant; J. B. Weir, aid.	Special hydrographic survey of Cubitt's Gap; also above the Head of the Passes, Mississippi River, and in Southwest Pass.
	4	Tides	G. Faust	Height of water at New Orleans recorded regularly by means of a tide-gauge.
	5	Triangulation, topography, and hydrography.	C. H. Boyd, assistant; Master Alexander McCrackin, U. S. N.; C. H. Van Orden and Bion Bradbury.	Detailed survey of the shores and waters of Mississippi River extended upward from Bonnet Carre to Point Houmas, La.
	6	Reconnaissance	G. A. Fairfield, assistant	Selection of stations for triangulation in Illinois.
	7	Reconnaissance	J. A. Sullivan, assistant	Reconnaissance for stations near the Gasconade River, in Missouri, and of the region westward towards the Wasatch Mountains.
	8	Triangulation	Prof. J. E Davies	Triangulation for the determination of points in the vicinity of Madison, Wis.
SECTION IX.				
Gulf coast of Western Louisiana and of Texas, including bays and rivers.	1	Triangulation	R. E. Halter, assistant	Triangulation of Laguna Madre from Corpus Christi Bay southward to Baffin's Bay, Texas.

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION X.				
Coast of California, including the bays, harbors, and rivers.	No. 1	Reconnaissance	W. E. Greenwell, assistant	Reconnaissance for points of triangulation near the coast between San Diego and Santa Barbara, Cal.
	2	Topography	Stehman Forney, assistant	Topographical survey of the western part of Santa Catalina Island, off the coast of California.
	3	Inspection	H. L. Whiting, assistant	Reconnaissance of the coast of California and examination of topographical features. (See also Section XI.)
	4	Triangulation	O. H. Tittman, assistant; D. B. Wainwright, aid.	Triangulation completed between Laguna Station and points on Anacapa, and Santa Barbara Island, Cal.
	5	Hydrography	Lieut. Commander H. C. Taylor, U. S. N., assistant; Lieuts. Richard M. Cutts, Richardson Clover, A. B. Wyckoff, and F. J. Drake, U. S. N.	Hydrography of the approaches to San Miguel and Santa Rosa Island, and supplementary soundings in the vicinity of Santa Monica, coast of California.
	6	Hydrography	Lieut. Frank Courtis, U. S. N., assistant; Lieuts. E. H. C. Leutze and E. K. Moore, U. S. N.; Master J. H. Bull, U. S. N., and Ensign W. Allderdice, U. S. N.	Inshore hydrography eastward of Point Concepcion and lines of soundings across the Santa Barbara Channel.
	7	Topography	A. W. Chase, assistant	Detailed survey of the coast from Point Concepcion northward towards Point Arguello, Cal.
	8	Reconnaissance	W. E. Greenwell, assistant	Examination for stations of primary triangulation between Los Angeles and Point Arguello, Cal.
	9	Tides	E. Gray	Observations with self-registering tide-gauge at Fort Point, San Francisco entrance, and series commenced at Sancelito.
	10	Geodetic connection.	George Davidson, assistant; William Eimbeck, assistant; B. A. Colonna, subassistant; J. F. Pratt, aid.	Geodetic measurements and determinations of latitude and azimuth at Mount Diablo and Mount Helena, for triangulation across the Sierra Nevada.
	11	Reconnaissance	A. F. Rodgers, assistant	Examination for station-points of triangulation in the region between the Sierra Nevada and Salt Lake City.
	12	Triangulation and topography.	L. A. Sengteller, assistant; G. H. Wilson.	Detailed survey of the coast of California from Timber Gulch northward to Stewart's Point.
	13	Reconnaissance	Cleveland Rockwell, assistant; E. F. Dickins, aid.	Reconnaissance for stations in the coast-range of mountains north of Ross Mountain and Sulphur Peak.
SECTION XI.				
Coast of Oregon and of Washington Territory, including the interior bays and the ports and rivers.	1	Hydrography	Lieut. Commander G. W. Coffin, U. S. N., assistant; Lieuts. Richardson Clover, F. J. Drake, C. W. Jarboe, and W. H. Driggs, U. S. N.; Master Richard Mitchell, U. S. N.	Hydrography of the coast of Oregon from Tillamook Head northward to Columbia River entrance.
	2	Topography and hydrography.	J. J. Gilbert, assistant; T. P. Woodward.	Topography of the shores and soundings in the Columbia River between Cathlamet and Cottonwood Island.
	3	Tides	L. Nessel, E. Gray	Series of observations closed at Astoria, Oreg., and continued with self-registering tide-gauge at Port Townshend, W. T., until May.
	4	Reconnaissance	J. S. Lawson, assistant	Selection of stations for primary triangulation across the waters of Washington Sound and the Strait of Fuca.
	5	Hydrography	Gershom Bradford, assistant	Supplementary soundings along the shores of Whidbey Island and Admiralty Inlet, W. T.

APPENDIX No. 1—Continued.

Coast-sections.	Parties.	Operations.	Persons conducting operations.	Localities of work.
SECTION XI—Continued.	No. 6	Topography	Eugene Ellicott, subassistant	Topography of the shores of Admiralty Inlet and Colvos Passage from Point Orchard south to the entrance of Commencement Bay, W. T.
	7	Inspection	H. L. Whiting, assistant	Coast reconnaissance and examination of topographical features adjacent to the waters of Puget Sound, and also along the Columbia River. (See also Section X.)
	8	Hydrography	Lieut. Richard M. Cutts, U. S. N., assistant; Lieuts. A. B. Wyckoff and Uriah R. Harris, U. S. N.	Hydrography of Commencement Bay, W. T., in progress.

APPENDIX No. 2.

Statistics of field and office work of the United States Coast Survey to the close of the year 1876.

Description.	Total to December 31, 1875.	1876.	Total to December 31, 1876.
RECONNAISSANCE.			
Area in square statute miles	167, 390	34, 776	202, 166
Parties, number of, in year		9	
BASE LINES.			
Primary, number of	13	0	13
Subsidiary, number of	102	3	105
Primary, length of, in statute miles	79	0	79
Subsidiary and line-measures, length of, in statute miles	231¾	6½	238¼
TRIANGULATION.			
Area in square statute miles	85, 180	12, 953	98, 133
Stations occupied for horizontal angles, number of	8, 314	245	8, 559
Geographical positions determined, number of	15, 367	430	15, 797
Stations occupied for vertical angles, number of	463	22	485
Elevations determined, number of	1, 036	147	1, 183
Lines of spirit-levelling, length of	630	3½	633½
Parties (triangulation and levelling), number of, in year		23	
ASTRONOMICAL WORK.			
Azimuth-stations, number of	126	9	135
Latitude-stations, number of	217	9	226
Longitude-stations (telegraphic), number of	83	0	83
Longitude-stations (chronometric and lunar), number of	110	0	110
Astronomical parties, number of, in year		6	
MAGNETIC WORK.			
Stations occupied, number of	384	1	385
Permanent magnetic stations, number of, in year		2	
Magnetic parties, number of, in year		3	
TOPOGRAPHY.			
Area surveyed in square miles	25, 208	893	26, 101
Length of general coast in miles	5, 748	221	5, 969
Length of shore-line in miles (including rivers, creeks, and ponds)	70, 375	2, 187	72, 562
Length of roads in miles	36, 765	1, 408	38, 173
Topographical parties, number of, in year		21	
HYDROGRAPHY.			
Parties, number of, in year		19	
Number of miles run while sounding	292, 067	8, 306	300, 373
Area sounded, in square miles	70, 647	2, 109	72, 756
Miles run additional of outside or deep-sea soundings	49, 444	2, 519	51, 963
Number of soundings	13, 533, 066	462, 244	13, 995, 310
Soundings in Gulf Stream for temperature	4, 072	0	4, 072
Tidal stations, permanent	203	10	213
Tidal stations occupied temporarily	1, 566	47	1, 613
Tidal parties, number of, in year		33	
Current-stations occupied	246	170	416
Current-parties, number of, in year		2	
Number of deep-sea soundings in year		438	
Specimens of bottom, number of	10, 423	77	10, 500

APPENDIX No. 2—Continued.

Description.	Total to December 31, 1875.	1876.	Total to December 31, 1876.
RECORDS.			
Triangulation, originals, number of volumes	2,015	171	2,186
Astronomical observations, originals, number of volumes	1,190	31	1,221
Magnetic observations, originals, number of volumes	353	10	363
Duplicates of the above, number of volumes	2,209	115	2,324
Computations, number of volumes	2,319	170	2,489
Hydrographical soundings and angles, originals, number of volumes	6,872	356	7,228
Hydrographical soundings and angles, duplicates, number of volumes	714	125	839
Tidal and current observations, originals, number of volumes	2,834	177	3,011
Tidal and current observations, duplicates, number of volumes	1,890	75	1,965
Sheets from self-registering tide-gauges, number of	2,352	108	2,460
Tidal reductions, number of volumes	1,604	39	1,643
Total number of volumes of records	22,000	1,269	23,269
MAPS AND CHARTS.			
Topographical maps, originals	1,470	60	1,530
Hydrographic charts, originals	1,363	64	1,427
Reductions from original sheets	779	12	791
Total number of manuscript maps and charts, to and including 1876	2,540	....	2,552
Number of sketches made in field and office	2,903	45	2,948
ENGRAVING AND PRINTING.			
Engraved plates of finished charts, number of	204	9	213
Engraved plates of preliminary charts, sketches, and diagrams for the Coast Survey Reports, number of	562	6	568
Electrotype-plates made	1,146	70	1,216
Finished charts published	191	7	198
Preliminary charts and hydrographical sketches published	484	10	494
Printed sheets of maps and charts distributed	345,650	19,048	364,698
Printed sheets of maps and charts deposited with sale-agents	126,902	5,704	132,606
LIBRARY.			
Number of volumes	5,991	228	6,219
INSTRUMENTS.			
Cost of	$109,347 82	$8,149 34	$117,497 16

APPENDIX No. 3.

Information furnished from the Coast Survey Office, by tracings from original sheets, &c., in reply to special calls during the year ending June 30, 1877.

Date.	Name.	Data furnished.
1876.		
July 15	War Department	Hydrographic survey of South Pass Bar, made in May and June, 1875, with ends of jetties added in 1876.
15	J. B. Eads, civil engineer	Do.
Aug. 3	War Department	Comparative chart of the South Pass surveys, made in 1875 and April and May, 1876, at end of jetties, with calculations of increase and decrease of depth on bar.
5	State Geological Department of Georgia	Geographical positions and heights of stations in Northern Georgia.
Sept. 16	H. P. Walker, esq	Hydrography of head of Key Biscayne Bay, Fla.
Nov. 1	Maj. W. P. Craighill, United States Corps of Engineers	Hydrography of White Shoal, James River, Va., survey of 1871–'72.
1	......do	Hydrography of channel off Hog Island, James River, Va., survey of 1873.
1	......do	Hydrography of Goose Hill or Jamestown flats, James River, survey of 1873.
1	......do	Hydrography of bar off Swan's Point, James River, survey of 1874.
1	......do	Hydrography of bar in James River, off mouth Chickahominy River, survey of 1874.
1	......do	Hydrography of Harrison's Bar, James River, survey of 1875.
8	George E. Waring, jr., esq	Topographical survey of part of the island of Rhode Island, from Quaker Hill to the Glen, from shore to shore.
18	Messrs. Borden & Lovell, New York	Distance, in statute miles, by shortest sailing-line, from foot of Murray street, New York, to wharf of Old Colony Steamboat Company, through the sound.
21	J. B. Eads, civil engineer	Sketch of Cubitt's Gap and vicinity showing location of cross-section from survey of 1876; scale, 1-4,800.
24	United States Revenue Marine Bureau	Hydrographic survey of the Mississippi River, vicinity of Poverty Point, and unfinished proof of Coast Chart No. 95; scale, 1-80,000.
29	C. S. Solomon, esq	Magnetic variation in Georgia.
Dec. 14	Capt. S. O. Hemenway, of Florida	Reconnaissance of the Saint John's River from Welaka to Volusia; scale, 1-80,000.
18	William Rotch, esq., engineer Fall River Water Works	Description of bench-marks vicinity of Fall River, Mass.
26	George Lamb, esq., Boston, Mass	Compiled map of South Bay and Fort Hill Channel, Boston Inner Harbor, survey of 1847.
26	Col. R. S. Williamson, light-house engineer	Topographical survey Light-House Reservation, Point Stockhoff, Cal.
26	August Faul, esq., superintend't city parks, Baltimore, Md.	Triangulation sketch Baltimore and vicinity, Md.
27	Firm of Lathrop, Bishop & Lincoln, Boston, Mass	Survey of part of South Bay, Boston Inner Harbor.
1877.		
Jan. 5	Austin Corbin, esq., Brooklyn, N. Y	Shore-line of Long Island coast from Rockaway Beach to Coney Island, from survey of 1835.
8	G. W. Call, Sonoma County, Cal	Topographical survey of Fort Ross and vicinity, Cal.
14	Capt. W. J. Twining, Corps of Engineers	Six charts of Catalogue No. 133, with addition of Pocomoke River to Shelltown, for boundary commissioners between Maryland and Virginia.
24	Prof. G. H. Cook, New Jersey	Projection, in two parts, on a scale of three inches to the mile, from Sandy Hook northward to Yonkers and westward to Bound Brook, N. J.
30	Maj. Gen. John Newton, Corps of Engineers	Hydrographic survey of Kill Van Kull and southern part of Newark Bay, N. Y. and N. J.
31	G. W. Colton, esq., New York	Geographical position of Cape Cañaveral and Cape Florida light-houses and approximate position of Fort Capron.
Feb. 17	B. M. Harrod, assistant city engineer, New Orleans	Hydrographic survey of Bonnet Carre Crevasse, Mississippi River.
17	Gen. Daniel Butterfield, New York	Hydrographic survey of Shrewsbury River, N. J.
27	Campbell, Wylie & Co., Charleston, S. C	Hydrographic survey of Bull River and North Nimbee Creek, S. C.

APPENDIX No. 3—Continued.

Date.	Name.	Data furnished.
1877.		
Mar. 12	Baltimore Sun	Information as to limits of salt and fresh water in the Chesapeake and Delaware Bays.
16	John S. Albert, engineer, Philadelphia, Pa	Coast Chart No. 37, Cape Henry to Currituck Beach light, with certain additions by hand.
16	C. H. Mallory & Co., New York	Hydrographic survey Mississippi River, vicinity Point a la Hache.
22	J. J. Van Allen, New York	Area, in acres, of Montauk Point, eastern end of Long Island.
22	Capt. W. A. Jones, U. S. A., light-house engineer sixth district.	Hydrographic survey of upper part of Key Biscayne Bay, Fla.
22	J. B. Eads, civil engineer in charge jetty works South Pass, Mississippi River.	Distance, measured on original hydrographic sheets, on line of deepest water, from Carrollton's Derrick to wharf at Quarantine.
Apr. 5	S. I. Kimball, chief of Revenue Marine Bureau	Positions of life-saving stations on the Atlantic coast from Penobscot Bay, Me., to Cape Charles, Va.
5	James H. Gardiner, esq., Newburgh, N. Y	Information as to number of acres contained in Polypus Island, near Cornwall Landing, Hudson River.
9	Governor of Washington Territory	Hydrographic survey of Blunt's Reef, off Cape Mendocino, Cal.
9	Commodore Robert H. Wyman, U. S. N., superintendent Hydrographic Office.	Topographical survey of Los Coronados, Mexico, determined by United States Coast Survey in 1851.
27	Brevet Brig. Gen. W. F. Raynolds, Corps of Engineers, engineer of fourth light-house district.	Topographical survey Barnegat Inlet and vicinity, survey of 1874.
May 16	Senator John T. Morgan, of Alabama	Chart of Mobile Bay, showing improvements of Dog River Bar Channel.
June 18	Manton Marble, esq	Topographical surveys showing sites of old Forts Frederick and Saint George, on Saint George's River and Pemaquid Harbor, Me.
19	W. W. Allen, esq	Topographical survey coast of California from Bolsas Creek to Santa Ana River, survey of 1874.
22	Greenleaf Cilley, esq	Topographical survey of entrance to Duck Trap River, Me.

APPENDIX No. 4.

DRAWING DIVISION.

Charts completed or in progress during the year ending June 30, 1877.

1. Hydrography. 2. Topography. 3. Drawing for photographic reduction. 4. Details upon photographed and pantographed outlines. 5. Inking and lettering sheets. 6. Verification.

Title of charts.	Scale.	Draughtsmen.	Remarks.
Sailing chart No. 1, Cape Sable to Sandy Hook	1-1, 200, 000	1. A. Lindenkohl. 1. H. Lindenkohl	Additions.
General coast chart No. I, Quoddy Head to Cape Cod, Mass.	1-400, 000	1, 2, and 6. A. Lindenkohl 1. H. Lindenkohl.	Continued.
Coast chart No. 3, Petit Manan light to Naskeag Point	1-80, 000	4. P. Erichsen	Do.
Coast chart No. 4, Naskeag Point to White Head light, including Penobscot Bay.	1-80, 000	1. A. Lindenkohl	Additions.
Coast chart No. 7, Kennebec entrance to Cape Porpoise	1-80, 000	1. C. Junken	Do.
Coast chart No. 11, Monomoy and Nantucket Shoals to Muskeget Channel, Mass.	1-80, 000	1. A. Lindenkohl. 1. C. A. Meuth. 1. L. Karcher.	Do.
Coast chart No. 13, entrance to Buzzard's Bay to Block Island.	1-80, 000	1 and 2. L. Karcher. 2. H. Lindenkohl	Do.
Coast chart No. 14, Point Judith and Block Island to Plum Island.	1-80, 000	1. A. Lindenkohl	Do.
Isle au Haut Bay and Eggemoggin Reach, Me	1-40, 000	1. L. Karcher. 6. P. Erichsen	Commenced.
Belfast Bay and Penobscot River, Me	1-40, 000	2. P. Erichsen	Continued.
Portsmouth Harbor, N. H	1-20, 000	1. C. Junken	Additions.
Boston Harbor (South Bay) Mass	1-5, 000	1. C. Junken	Do.
Monomoy entrance to Nantucket Sound	1-40, 000	1. H. Lindenkohl. 1. C. Junken	Photolithograph; completed.
Narragansett Bay, R. I	1-40, 000	2. A. Lindenkohl. 1. L. Karcher	Additions.
Port of Providence, R. I	1-10, 000	1 and 2. L. Karcher	Do.
Coast chart No. 15, Plum Island to Welch's Point	1-80, 000	1. C. Junken	Do.
Coast chart No. 19, Great South Bay, Fire Island, and Long Beaches.	1-80, 000	1. C. Junken	Do.
Coast chart No. 20, New York Bay and Harbor	1-80, 000	1 and 2. A. Lindenkohl. 1. C. Junken	Do.
Coast chart No. 21, Sandy Hook to Barnegat light, N. J	1-80, 000	1. A. Lindenkohl. 1. H. Lindenkohl	Continued.
Coast chart No. 25, part of Delaware Bay and River, middle sheet.	1-80, 000	1. A. Lindenkohl	Additions.
Coast chart No. 26, Delaware River, Wilmington to Trenton	1-80, 000	1. A. Lindenkohl	Do.
Hell Gate, N. Y	1-5, 000	1. C. Junken	Do.
Coast chart No. 31, entrance to Chesapeake Bay, Hampton Roads, &c.	1-80, 000	1. C. Junken	Do.
Coast chart No. 36, Magothy River to head of bay	1-80, 000	1. A. Lindenkohl. 1. C. Junken	Do.
Coast chart No. 37, Cape Henry to Currituck Beach light and approaches to Chesapeake Bay.	1-80, 000	1. A. Lindenkohl 2. H. Lindenkohl	Commenced.
Hampton Roads, Va	1-40, 000	1. C. Junken	Additions.
Hampton Roads and Norfolk Harbor, Va	1-30, 000	1. C. Junken	Commenced.
James River No. 1, Newport News Point to Deep Water light.	1-40, 000	1 and 2. A. Lindenkohl. 2 and 5. H. Lindenkohl.	Completed.
Do	1-50, 000	1 and 2. H. Lindenkohl. 1. C. Junken, 1. L. Karcher.	Photolithograph; completed.
James River No. 2, Point of Shoals to Sloop Point	1-40, 000	1 and 2. A. Lindenkohl. 2. H. Lindenkohl.	Completed.
Do	1-50, 000	1 and 2. A. Lindenkohl. 1 and 2. H. Lindenkohl.	Photolithograph; completed.
Nansemond River, Va	1-40, 000	1 and 2. A. Lindenkohl. 1 and 2. H. Lindenkohl.	Completed.
Albemarle Sound	1-200, 000	2. H. Lindenkohl	Additions.
Coast chart No. 42, Pamplico Sound to Hatteras Inlet	1-80, 000	2. L. Karcher	Continued.
Core Sound, N. C	1-40, 000	1 and 2. A. Lindenkohl. 1. L. Karcher. 1. C. Junken. 2. P. Erichsen.	Additions.

APPENDIX No. 4—Continued.

Title of charts.	Scale.	Draughtsmen.	Remarks.
Beaufort Harbor, N. C	1-40, 000	1. A. Lindenkohl	Additions.
Coast chart No. 52, Winyah Bay, Cape Roman, &c	1-80, 000	2. P. Erichsen	Commenced.
Coast chart No. 53, Georgetown to Long Island, S. C	1-80, 000	1 and 2. H. Lindenkohl. 2. P. Erichsen	Do.
Winyah Bay and Georgetown Harbor, S. C	1-40, 000	1. A. Lindenkohl. 1 and 2. H. Lindenkohl.	Photolithograph; completed.
Savannah River, Ga	1-40, 000	1. C. Junken	Additions.
Sailing chart No. V, Gulf of Mexico	1-1, 200, 000	1. H. Lindenkohl	Do.
Coast chart No. 58, Cumberland Sound to Saint John's River, &c.	1-80, 000	1. A. Lindenkohl	Completed.
Coast chart No. 66, from Key Biscayne to Carysfort Reef	1-80, 000	2. H. Lindenkohl. 1. C. Junken	Additions.
Coast chart No. 70, Key West, Marquesas Keys, &c	1-80, 000	1. C. Junken	Do.
Inside passage, east coast of Florida (in eight sheets), viz:			
No. 1, Head of Halifax River	1-20, 000	1. L. Karcher. 1 and 2. H. Lindenkohl.	Photolithograph; completed.
No. 2, Halifax River, vicinity of Daytona	1-20, 000	1. L. Karcher. 1 and 2. H. Lindenkohl.	Do.
No. 3, Mosquito Inlet and vicinity of New Smyrna	1-20, 000	1 and 2. H. Lindenkohl. 1. L. Karcher.	Do.
No. 4, Hillsborough River	1-20, 000	1. L. Karcher. 1 and 2. H. Lindenkohl.	Do.
No. 5, Mosquito Lagoon, northern part	1-20, 000	1 and 2. H. Lindenkohl. 1. L. Karcher.	Do.
No. 6, Mosquito Lagoon, southern part	1-20, 000	1. L. Karcher. 1 and 2. H. Lindenkohl.	Do.
No. 7, Head of Indian River to Titusville	1-25, 000	1. L. Karcher. 1 and 2. H. Lindenkohl.	Do.
No. 8, Indian River from Titusville southward	1-25, 000	1 and 2. H. Lindenkohl. 1. L. Karcher.	Do.
Tampa Bay entrance, Fla	1-40, 000	1. A. Lindenkohl. 1. C. Junken. 2. H. Lindenkohl.	Completed.
Pensacola Bay and entrance, Fla	1-30, 000	1 and 2. C. Junken	Additions.
Comparative chart, South Pass, Mississippi River survey, 1875-'76.	1-4, 800	1. A. Lindenkohl. 1. H. Lindenkohl	Completed.
Coast chart No. 89, Bon Secours Bay to Round Island	1-80, 000	1. C. Junken	Additions.
Coast chart No. 94, passes of the Mississippi River	1-80, 000	2. P. Erichsen; C. Junken	Do.
Coast chart No. 95, Mississippi River from Grand Prairie to New Orleans.	1-80, 000	5. L. Karcher. 1. C. Junken	Completed.
General coast chart No. XVI, from Galveston to the Rio Grande.	1-400, 000	1. H. Lindenkohl	Additions.
Coast chart No. 109, Aransas and Copano Bays	1-80, 000	1. A. Lindenkohl	Do.
Lower chart of reconnaissance Pacific Coast, San Diego to San Francisco.	1-200, 000	1. A. Lindenkohl. 5. H. Lindenkohl	Do.
Santa Barbara Channel, Point Vincent to Point Conception	1-200, 000	2. A. Lindenkohl. 2. H. Lindenkohl	Continued.
Santa Cruz Island, Cal	1-20, 000	2. P. Erichsen (compiling plane-table sheets.)	Completed.
Cape Mendocino and Blunt's Reef, Cal	1-40, 000	1 and 2. H. Lindenkohl. 1. C. Junken	Photolithograph; completed.
Mare Island Straits, Cal	1-10, 000	1 and 2. H. Lindenkohl. 1. C. Junken	Do.
Budd's Inlet, Wash. Ter	1-20, 000	1 and 2. H. Lindenkohl	Do.
Progress sketch, Saint Louis and vicinity	1-400, 000	A. Lindenkohl	Commenced.
Progress sketches, additions to		A. Lindenkohl; H. Lindenkohl	Continued.
Sketch showing magnetic stations		H. Lindenkohl	Completed.

MAPS AND CHARTS PUBLISHED BY THE PHOTOLITHOGRAPHIC PROCESS DURING THE FISCAL YEAR ENDING WITH JUNE, 1877.

1876.

July 10. Lake Champlain, No. 3.
10. Lake Champlain, No. 4.
10. Map of the water front of the city of New Haven, in 13 sheets.
Aug. 26. Monomoy passage to Nantucket Sound.
Sept. 25. Budd's Inlet, Puget Sound.

1877.

— — Inside passage, east coast of Florida.
Jan. 2. Sheet No. 1, Head of Halifax River.
2. Sheet No. 2, Halifax River, vicinity of Daytona.
9. Sheet No. 3, Mosquito Inlet and vicinity of New Smyrna.
12. Mare Island Strait.

1877.

Jan. 19. Inside passage, &c., sheet No. 4, Hillsborough River.
27. Inside passage, &c., sheet No. 5, Mosquito Lagoon, northern part.
31. Inside passage, &c., sheet No. 6, Mosquito Lagoon, southern part.
Feb. 10. Inside passage, &c., sheet No. 7, head of Indian River to Titusville.
10. Inside passage, &c., sheet No. 8, Indian River, from Titusville southward.
10. Castine harbor.
Mar. 20. Nansemond River.

APPENDIX No. 5.

ENGRAVING DIVISION.

Plates completed, continued, or commenced July 1, 1876, to June 30, 1877, inclusive.

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

Title of plates.	Scale.	Engravers.
COMPLETED.		
Sailing-chart.		
No. V, Key West, Fla., to the Rio Grande (edition of 1877)	1-1, 200, 000	3. H. M. Knight. 4. F. Courtenay, A. Petersen, and E. H. Sipe.
Coast-charts.		
No. 13, Cuttyhunk to Block Island, including Narragansett Bay.	1-80, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel, A. Petersen, H. M. Knight, and J. G. Thompson.
No. 14, Long Island Sound, from Point Judith and Block Island to Plum Island (edition of 1876).	1-80, 000	2. W. A. Thompson. 4. J. G. Thompson, E. H. Sipe, and W. H. Davis.
No. 24, entrance to Delaware Bay (edition of 1877)	1-80, 000	4. H. M. Knight and J. G. Thompson.
No. 25, part of Delaware Bay and River (edition of 1877)	1-80, 000	4. H. M. Knight, J. G. Thompson, and W. H. Davis.
No. 26, Delaware River, from Wilmington to Trenton (edition of 1877).	1-80, 000	2. W. A. Thompson. 3. H. M. Knight. 4. A. E. Maedel, A. Petersen, H. M. Knight, E. H. Sipe, and W. H. Davis.
Harbor-charts.		
Penobscot Bay, Me	1-40, 000	4. H. M. Knight, J. G. Thompson, and E. H. Sipe.
Richmond's Island Harbor, Me. (edition of 1876)	1-20, 000	4. H. M. Knight and E. H. Sipe.
Portsmouth Harbor, N. H. (edition of 1876)	1-20, 000	2. H. C. Evans. 3. H. M. Knight. 4. E. A. Maedel, A. Petersen, H. M. Knight, J. G. Thompson, and W. H. Davis.
New Bedford Harbor, Mass. (edition of 1876)	1-40, 000	4. W. H. Davis.
Fisher's Island Sound (edition of 1877)	1-40, 000	4. A. Petersen.
Delaware and Chesapeake Bays (edition of 1877)	1-200, 000	4. H. M. Knight, J. G. Thompson, and E. H. Sipe.
Beaufort Harbor, N. C	1-40, 000	2. R. F. Bartle. 3. H. M. Knight. 4. A. Petersen and J. G. Thompson.
Core Sound and Straits, N. C	1-40, 000	2. R. F. Bartle. 4. A. Petersen and H. M. Knight.
Entrance to Pensacola Bay, Fla. (edition of 1877)	1-30, 000	1, 2, 3, and 4. H. M. Knight.
San Diego Bay, Cal. (edition of 1877)	1-40, 000	4. E. A. Maedel, H. M. Knight, and E. H. Sipe.
CONTINUED.		
Sailing-chart.		
No. I, Atlantic coast (Sailing-chart A), from Cape Sable, Me., to Cape Hatteras, N. C. (upper sheet).	1-80, 000 1-1, 200, 000	4. A. Petersen and J. G. Thompson.
General coast-chart.		
No. I, west part, from Isle au Haut, Me., to Cape Cod, Mass.	1-400, 000	1 and 2. J. Enthoffer.
Coast-charts.		
No. 3, Frenchman's and Blue Hill Bays, Me	1-80, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel.
No. 4, Penobscot Bay, Me	1-80, 000	1 and 2. J. Enthoffer. 4. E. A. Maedel and A. Petersen.
No. 6, Kennebec entrance to Saco River, Me	1-80, 000	3. H. M. Knight. 4. A. Petersen and H. M. Knight.
No. 7, Seguin Island to Kennebunkport, Me	1-80, 000	3. H. M. Knight. 4. A. Petersen and H. M. Knight.
No. 20, New York Bay and Harbor	1-80, 000	1. J. G. Thompson. 3. W. A. Thompson. 4. A. Petersen, H. M. Knight, J. G. Thompson, and E. H. Sipe.
No. 21, Sandy Hook to Barnegat Bay, N. J	1-80, 000	1. J. G. Thompson. 4. F. Courtenay.
No. 22, Barnegat Bay to Absecon light-house, N. J	1-80, 000	4. F. Courtenay.
No. 37, Cape Henry, Va., to Currituck Beach light-house, N. C.	1-80, 000	1 and 2. A. Sengteller. 4. A. Petersen and H. M. Knight.
No. 42, Pamplico Sound (eastern sheet), Roanoke Island to Hatteras Inlet, N. C.	1-80, 000	1 and 2. J. J. Young.
No. 54, Long Island to Hunting Island, S. C	1-80, 000	1 and 2. A. Sengteller.
No. 95, Mississippi River, No. 2, from Forts to New Orleans, La.	1-80, 000	1 and 2. A. Sengteller.
No. 107, Matagorda Bay, Tex	1-80, 000	3. H. M. Knight. 4. A. Petersen and W. H. Davis.

APPENDIX No. 5—Continued.

Title of plates.	Scale.	Engravers.
Coast-charts—Continued.		
No. 108, Pass Cavallo and San Antonio Bay, Tex	1–80,000	4. W. H. Davis.
No. 109, Aransas and Copano Bays, Tex	1–80,000	4. J. G. Thompson.
Harbor-charts.		
Blue Hill and Union River Bays, Me	1–40,000	1. E. Molkow.
Isle au Haut Bay and Eggemoggin Reach, Me	1–40,000	1. E. Molkow. 1 and 2. W. A. Thompson.
Penobscot River and Belfast Bay, Me	1–40,000	1. E. Molkow. 1 and 2. R. F. Bartle. 4. E. A. Maedel and J. G. Thompson.
Lake Champlain, No. 1, Rouse's Point to Cumberland Head.	1–40,000	4. E. A. Maedel, F. Courtenay, and A. Petersen.
Lake Champlain, No. 2, Cumberland Head to Ligonier Point	1–40,000	4. E. A. Maedel and F. Courtenay.
Lake Champlain, No. 3, Burlington to Coles Bay	1–40,000	1 and 2. H. C. Evans.
Lake Champlain, No. 4, Coles Bay to Whitehall	1–40,000	1 and 2. W. A. Thompson. 4. E. A. Maedel.
Albemarle Sound, N. C	1–200,000	2. A. Sengteller and W. A. Thompson. 4. E. A. Maedel.
Entrance to Tampa Bay, Fla	1–40,000	2. W. A. Thompson and H. Lindenkohl. 3. H. M. Knight. 4. E. A. Maedel and E. H. Sipe.
Entrance to San Francisco Bay, Cal	1–40,000	1. E. Molkow.
COMMENCED.		
Sailing-chart.		
No. I, Atlantic coast (Sailing-chart A), from Cape Sable, Me., to Cape Hatteras, N. C.	1–80,000 1–400,000 1–1,200,000	1. J. G. Thompson. 2. W. A. Thompson. 3. W. A. Thompson. 4. J. G. Thompson.
General coast-chart.		
No. I, eastern part, from Quoddy Head to Isle au Haut, Me	1–400,000	1 and 2. J. Enthoffer. 4. E. A. Maedel.
Coast-charts.		
No. 70, Marquesas Keys, Key West, &c., Fla	1–80,000	4. F. Courtenay.
No. 83, Apalachicola Bay, Fla	1–80,000	1. J. Enthoffer and E. H. Sipe. 2. A. Sengteller. 4. W. H. Davis.
Harbor-charts.		
Approaches to Isle au Haut Bay and Eggemoggin Reach, Me.	1–40,000	1. E. Molkow.
James River, No. I, Newport News to Deep Water Shoals, Va.	1–40,000	1 and 2. J. Enthoffer.

APPENDIX No. 6.

THE PAMPLICO-CHESAPEAKE ARC OF THE MERIDIAN AND ITS COMBINATION WITH THE NANTUCKET AND THE PERUVIAN ARCS, FOR A DETERMINATION OF THE FIGURE OF THE EARTH FROM AMERICAN MEASURES. REPORT BY CHARLES A. SCHOTT, ASSISTANT.

COMPUTING DIVISION, *February* 17, 1877.

The Pamplico-Chesapeake arc of the meridian is the second arc measured by, and incidental to the ordinary geodetic work of the Coast Survey. Its southern extremity is at Ocracoke Inlet, North Carolina, in latitude 35° 04′.0; its northern extremity is at present at the head of Chesapeake Bay, in Maryland, in latitude 39° 35′.5 It is situated nearly in longitude 76° 08′ or 5h 04m.5 west of Greenwich.

The primary triangulation of the arc is shown on plates 6 and 7 accompanying this report.

Leaving the Atlantic coast just south of Ocracoke Inlet the arc crosses Pamplico Sound and Albemarle Sound, passing over the marshes and low lands of North Carolina and Virginia; it then enters Chesapeake Bay and extends near and over its eastern shore, which is low and almost level ground. The total development of the arc is nearly 4° 31′.5, about equal to 502 kilometres or 312 statute miles. Compared with our first arc, for which see Coast Survey Report of 1868, Appendix No. 9, p. 147 and following, it exceeds the length of the Nantucket arc by very nearly one-third. The geodetic and astronomical work was executed between the years 1844 and 1876, under Superintendents A. D. Bache, B. Peirce, and the present head of the survey, and principally by the following Assistants: J. Ferguson in upper Chesapeake Bay, 1844–'45; E. Blunt, in middle and lower Chesapeake Bay, 1846–'53; R. D. Cutts, vicinity of entrance of bay, 1867–'69; R. E. Halter, in Currituck Sound, 1873; W. M. Boyce, in Albemarle Sound, 1847–'49; A. A. Humphreys, U. S. E., vicinity of Roanoke and Croatan Sounds, 1850; and G. A. Fairfield, in Pamplico Sound, 1870–'75. The above statements refer to the principal triangulation which is supported by several base-lines, the statistics of which may be given as follows:

Locality of line.	Date of measure.	Observer.	Apparatus and reference.	Length in metres. (Committee.)
Kent Island, Md	May and June, 1844	J. Ferguson	Four double-metre iron bars; see Coast Survey Report of 1866, p. 140.	8 687.5446 ±.0381
Bodies Island, N. C	November, 1848	A. D. Bache	Six-metre compensation-bars Nos. 1 and 2	10 841.7254 ±.0255
Beach below Cape Henry, Va	August, September, and October, 1867.	R. D. Cutts	Six-metre iron rods, contact slides Nos. 1 and 2, subsidiary apparatus.	14 270.931
Beach below Cape Henry, Va*	May, 1869	do	do	5 952.582
Craney Island, Va	September, 1869	R. E. Halter	do	5 136.572 ±.037
Portsmouth Island, N. C†	May, 1870	G. A. Fairfield	do	9 038.3875 ±.0491

* Known as Currituck base. † Also known as Ocracoke base.

The statistics of the astronomical observations are contained in the following table:

Resulting latitudes, determined astronomically, by means of the zenith telescope, or the meridian telescope, excepting No. 3, which was determined by means of the zenith sector. The probable errors assigned are those arising from errors in the tabular places (declination) of the stars and from errors of observation. In all cases the astronomical latitude refers or has been referred to the geodetic station △

No.	Locality.	Time of observation.	Observer.	Resulting latitude.	Probable error.
				° ′ ″	″
1	Principio	July, August, and September, 1866	R. D. Cutts	39 35 32.75	±0.05
2	Pool's Island	June and July, 1847	T. J. Lee	39 17 09.65	0.12
3	Webb	October and November, 1850	G. W. Dean and A. D. Bache	39 05 25.46	0.04
4	Marriott	June, 1846; May and June, 1849	T. J. Lee, A. D. Bache, and J. Hewston	38 52 24.82	0.06
5	Calvert	July and August, 1871	A. T. Mosman	38 21 31.87	0.11
6	Tangier Island	June and July, 1871	......do	37 47 56.54	0.08
7	Wolf Trap	April, May, and June, 1871	A. T. Mosman and E. Smith	37 24 01.99	0.07
8	Cape Henry light	August, 1866	G. Davidson	36 55 30.32	0.08
9	Knott Island	March and April, 1873	A. T. Mosman	36 33 55.37	0.09
10	Stevenson's Point	January and February, 1847	C. O. Boutelle	36 06 15.97	0.12
11	Sand Island	January, 1876	E. Smith	35 50 25.29	0.09
12	Long Shoal Point	September, 1876	......do	35 34 36.25	0.11
13	Hog Island	August, 1876	......do	35 21 51.88	0.12
14	Portsmouth Island*	March and April, 1871; February and March, 1873; March, 1873.	A. T. Mosman	35 04 02.67	0.05

* The latitude of the last station is the mean of three determinations at different places with different instruments, all referred geodetically to Portsmouth Island, northeast base △, viz:

	Observed.	Reduction to △	Seconds reduced to △
	° ′ ″ ″	″	″
Portsmouth Island, northeast base	35 04 03.15 ± 0.10	− 0.24	02.91
Portsmouth Island, Station I	04 10.36 ± 0.08	− 7.74	02.62
Portsmouth Island, Station II	03 47.17 ± 0.10	+15.32	02.49
Mean			02.67

The middle of the arc is in latitude 37° 20′ nearly, and the mean of the 14 astronomical latitudes is 37° 16′ nearly, the station Wolf Trap being nearest to this latitude it has been used for the determination of the geodetic latitude of the arc. There are two other stations within the limits of the arc, viz: Taylor, determined in May, 1847, by T. J. Lee, and Shellbank, determined in March and April, 1847, by C. O. Boutelle. They are omitted to avoid unequal subdivisions of the arc, Taylor falling between Webb and Marriott, and Shellbank between Stevenson's Point and Sand Island.

To render the arc independent of the geodetic latitude and azimuth of the larger triangulation of which it forms a branch, and to base it upon geodetic data of its own, the preceding astronomical results for latitude are all referred to the station Wolf Trap by means of the geodetic differences $\Delta\varphi$; the last column of the following table exhibits the apparent station-errors or apparent local deflections in latitude obtained by subtracting the mean or geodetic latitude from each individual value.

Station.	Astronomical latitude ϕ	Difference of latitudes $\Delta\phi$	Astronomical latitudes referred to Wolf Trap.	Apparent local deflection.
	° ′ ″	° ′ ″	° ′ ″	″
Principio	39 35 32.75	−2 11 32.64	37 24 00.11	−3.58
Pool's Island	39 17 09.65	−1 53 03.67	05.98	+2.29
Webb	39 05 25.46	−1 41 22.34	03.12	−0.57
Marriott	38 52 24.82	−1 28 23.28	01.54	−2.15
Calvert	38 21 31.87	− 57 29.84	02.03	−1.66
Tangier Island	37 47 56.54	− 23 53.08	03.46	−0.23
Wolf Trap	37 24 01.99	0.00	01.99	−1.70
Cape Henry light	36 55 30.32	+ 28 32.07	02.39	−1.30
Knott Island	36 33 55.37	+ 50 07.38	02.75	−0.94
Stevenson's Point	36 06 15.97	+1 17 46.11	02.08	−1.61
Sand Island	35 50 25.29	+1 33 40.16	05.45	+1.76
Long Shoal Point	35 34 36.25	+1 49 30.75	07.00	+3.31
Hog Island	35 21 51.88	+2 02 15.76	07.64	+3.95
Portsmouth Island	35 04 02.67	+2 20 03.51	06.18	+2.49
Mean			37 24 03.69	

If we were to include the two extra stations mentioned the final mean would be 0″.13 less than the above, viz:

Station.	Astronomical latitude ϕ	Difference of latitudes $\Delta\ \phi$	Astronomical latitudes referred to Wolf Trap.	Apparent local deflection.
	° ′ ″	° ′ ″	° ′ ″	″
Taylor	38 59 45.97 ± 0.11	−1 35 44.14	37 24 01.83	−1.86
Shellbank	36 03 20.03 ± 0.09	+1 20 43.43	03.46	−0.23
Mean of 16 stations			37 24 03.56	

Owing to the apparently systematic character of the local deflections, the first mean value is preferable to the second. It may also be noted here that the geodetic latitude of Wolf Trap, based upon a large number of astronomical observations of the primary triangulation between Maine and Virginia, is 37° 24′ 01″.40, showing that our arc may possess, as a whole, an apparent local deflection (common to all points) of +2″.3; but more likely the difference is due to a defective spheroid of development; in fact, this is almost certain. A + sign of the apparent station-error indicates a deflection of the plumb-line towards the sea or the disturbed zenith lies north of the geodetic zenith.

RESULTING AZIMUTHS DETERMINED ASTRONOMICALLY.

The theodolites employed were a three-decimetre Gambey at stations Nos. 4, 5, 6, 7, 8, 10, and 13; a three-decimetre Brunner at stations Nos. 11 and 12; a two-foot Troughton at stations Nos. 1, 3, 9, and 10½; and a thirty-inch Troughton and Simms at station No. 2. Polaris was observed at all stations except No. 7, when 51 Cephei and λ Ursæ Minoris were used. At No. 3 some other stars besides Polaris were observed. The probable errors given are those arising from the errors of observation combined with those in the measure of the angle between the azimuth-mark and a direction in the triangulation.

No.	Locality.	Time of observation.	Observer.	Azimuth referred to side of triangulation.	Resulting astronomical azimuth.	Probable error.
					° ′ ″	″
1	Principio	August and September, 1866	R. D. Cutts	Principio to Turkey Point	1 34 43.50	±0.43
2	Webb	October and November, 1850	A. D. Bache and G. W. Dean	Webb to Marriott	346 43 50.47	±0.30
3	Marriott	June, 1849	A. D. Bache and J. Hewston	Marriott to Webb	166 46 20.23	±0.48
4	Calvert	August and September, 1871	A. T. Mosman	Calvert to Meekin	252 05 68.92	±0.17
5	Tangier Island	June and July, 1871	do	Tangier Island to Smith Point light.	114 13 30.85	±0.48
6	Wolf Trap	May and June, 1871	do	Wolf Trap to New Point Comfort.	14 28 25.46	±0.33
7	Cape Henry light	November, 1866	R. D. Cutts	Cape Henry light to Cape Charles light.	205 38 21.06	±0.48
8	Knott Island	August, 1869	A. T. Mosman	Knott Island to Ragged Island.	172 34 08.67	±0.69
9	Stevenson's Point	April, 1848	C. O. Boutelle	Stevenson's Point to Palmetto.	342 30 67.30	±0.43
10	Sand Island	January and February, 1876	E. Smith	Sand Island to South Base	287 31 08.53	±1.50
11	Long Shoal Point	September, 1876	do	Long Shoal Point to Gull Island, 1873.	295 10 04.66	±0.50
12	Hog Island	August, 1876	do	Hog Island to Ocracoke light.	346 24 53.26	±0.32
13	Portsmouth Island	March, 1871	A. T. Mosman	Portsmouth Island to Ocracoke light.	232 32 14.30	±0.30

There is also an azimuth observed at Bodies Island, which has been omitted in the above table on account of its proximity to Sand Point. It was measured in February, 1846, by C. O. Boutelle, referred to line Roanoke Marshes, this astronomical azimuth is 98° 28′ 13″.65±0″.43. Referring the above azimuths to the line Wolf Trap to New Point Comfort, by means of the geodetic differences of azimuths (Δa), we obtain the following results and apparent local deflections in azimuth:

Station.	Referring object.	Astronomical azimuth a			Δa			Astronomical azimuth referred to Wolf Trap–New Point Comfort.			Apparent local deflections.
		°	′	″	°	′	″	°	′	″	″
Principio	Turkey Point	1	34	43.50	+12	53	51.18	14	28	34.68	+3.75
Webb	Marriott	346	43	50.47	−332	15	15.58			34.89	+3.96
Marriott	Webb	166	46	20.23	−152	17	43.44			36.79	+5.86
Calvert	Meekin	252	05	68.92	−237	37	32.40			36.52	+5.59
Tangier	Smith Point light	114	13	30.85	−99	44	57.86			32.99	+2.06
Wolf Trap	New Point Comfort	14	28	25.46			0.00			25.46	−5.47
Cape Henry light	Cape Charles light	205	38	21.06	−191	09	52.06			29.00	−1.93
Knott Island	Ragged Island	172	34	08.67	−158	05	36.23			32.44	+1.51
Stevenson's Point	Palmetto	342	30	67.30	−328	02	30.66			36.64	+5.71
Sand Island	South base Bodies Island	287	31	08.53	−273	02	45.89			22.64	−8.29
Long Shoal Point	Gull Island, 1873	295	10	04.66	−280	41	41.09			23.57	−7.36
Hog Island	Ocracoke light	346	24	53.26	−331	56	24.95			28.31	−2.62
Portsmouth Island	......do	232	32	14.30	−218	03	46.19			28.11	−2.82
Mean								14	28	30.93	
Also Bodies Island	Roanoke Marshes	98	28	13.65	−83	59	49.46			24.19	−6.74

The systematic character of the apparent deflection in azimuth is more pronounced than in the case of the latitudes; a + sign of the apparent station-errors indicates a deflection of the plumb-line towards the land or the disturbed zenith east of the geodetic zenith.

The geodetic azimuth derived from many stations in the principal Atlantic coast triangulation is 14° 28′ 27″.25, indicating an apparent deflection of the whole arc of about +3″.7.

Respecting the larger wave of disturbance in the resultant direction of gravity, we thus see that along the arc the plumb-line appears relatively attracted *northward* in localities between the head of Chesapeake Bay and Bodies Island, and *southward* (or seaward) between Bodies Island and the southern terminus, near Ocracoke Inlet; also the plumb-line appears attracted *westward* between the head of Chesapeake Bay and Tangier Island, and *eastward* (or seaward) between Bodies Island and Ocracoke Inlet. Superposed on this more general wave of deflection there are other local ones of small extent, though comparable in magnitude with the larger one. In general, for all that part of the arc traversing Maryland, the plumb-line appears deflected *northwesterly* toward the Blue Ridge; whereas for the opposite end of the arc, traversing North Carolina, the plumb-line appears deflected *southeasterly*, or toward the sea. These two opposed directions appear more or less neutralized over that part of the arc which is situated in Virginia. This points to the further conclusion that the crust of the earth forming the adjacent sea-bottom is comparatively dense.

The apparent station-errors as given partake more of the character of *relative* deflections than *absolute* ones; yet, after deducting the supposed part of the deflection to which the arc, as a whole, may be subject, probably enough remains to bear out the above general statement. At present we have no means of knowing the absolute deflections.

According to Hitchcock and Blake's geological map accompanying the third volume of the Statistics of the Ninth Census of the United States, 1870,* the arc traverses, in the south, for three-fourths of its course, a formation of alluvium. In the northern quarter it reaches tertiary and cretaceous formations, and it nearly extends, at the head of the bay, to the eozoic rocks.

In order to find the linear distances between the parallels of the astronomical stations, the same process as used in the Nantucket arc has been followed, viz: to redevelop the elliptic arc contained between any two parallels, making use of the geodetic latitudes already existing. Thus the triangulation originally placed on Bessel's spheroid is to be redeveloped from the same surface; but before doing this a correction to the geodetic latitudes is needed to change them into the values

* Washington, 1872.

they would have had in case the mean values $\varphi_m = 37° 24' 03''.69$ and $\alpha_m = 14° 28' 30''.93$ for Wolf Trap had at first been used. Instead of recomputing the φ and α of all the points and starting from these values, φ_m and α_m, it is found more convenient to correct the existing geodetic positions by means of a differential expression.

Our formulæ for computing positions as given in Coast Survey Report of 1860, Appendix No. 36, may be stated as follows:

$$\Delta\varphi = \varphi_, - \varphi \qquad = - s\,\mathrm{B}\cos\alpha - s^2\,\mathrm{C}\sin^2\alpha - \text{etc.}$$
$$\Delta\lambda = \lambda_, - \lambda \qquad = s\,\mathrm{A}_,\sec\varphi_,\sin\alpha + \ \ . \ \ . \ \ .$$
$$\Delta\alpha = \alpha_, - \alpha + 180° = 180° - \Delta\lambda\sin\tfrac{1}{2}(\varphi_, + \varphi)\sec\tfrac{1}{2}\Delta\varphi - \ \ . \ \ . \ \ .$$

Where φ and λ = latitude and longitude, respectively, of starting point,

$\varphi_,$ and $\lambda_,$ = latitude and longitude, respectively, of any other point, whose distance s and azimuth α from the starting point are known, $\alpha_,$ will be the reverse azimuth, and A, B, C, &c., are tabular quantities depending on the arguments φ and $\varphi_,$.

The differences in latitude $\Delta\varphi$, in longitude $\Delta\lambda$, and in azimuth $\Delta\alpha$ are expressed in seconds; the linear distance s must be given in metres in connection with the tabular quantities.

We have with sufficient approximation $d\,.\,\Delta\varphi = \frac{\mathrm{B}}{\mathrm{A}_,}\,\Delta\lambda\cos\varphi_,\,d\alpha$.

According to the preceding investigation $d\alpha = +\,3''.68$, and multiplying the above by sin 1'' we obtain the corresponding change in $\Delta\varphi$. The change in the initial latitude is 2''.29, by which amount the whole arc is displaced to the north. The effect of this shift can safely be neglected.

Station.	Geodetic latitude from main triangulation.			Geodetic longitude from main triangulation.			Correction to ϕ or $d\,.\,\Delta\phi$ + 2''.29.	Corrected geodetic latitude.		
	°	'	''	°	'	''	''	°	'	''
Principio	39	35	34.037	76	00	18.080	+2.278	39	35	36.315
Pool's Island	39	17	05.067	76	15	51.172	+2.291	39	17	07.358
Webb	39	05	23.736	76	40	32.161	+2.311	39	05	26.047
Marriott	38	52	24.673	76	36	37.110	+2.308	38	52	26.981
Calvert	38	21	31.240	76	23	36.773	+2.297	38	21	33.537
Tangier Island	37	47	54.478	75	59	16.651	+2.277	37	47	56.755
Wolf Trap	37	24	01.397	76	14	44.749	+2.290	37	24	03.687
Cape Henry light	36	55	29.325	76	00	31.889	+2.278	36	55	31.603
Knott Island	36	33	54.015	75	55	20.189	+2.274	36	33	56.289
Stevenson's Point	36	06	15.285	76	11	26.671	+2.287	36	06	17.572
Sand Island	35	50	21.236	75	40	08.948	+2.260	35	50	23.496
Long Shoal Point	35	34	30.644	75	46	56.134	+2.266	35	34	32.910
Hog Island	35	21	45.633	76	03	42.115	+2.281	35	21	47.914
Portsmouth Island, or northeast base	35	03	57.888	76	03	10.886	+2.280	35	04	00.168

To redevelop the arc we make use of Bessel's expression for the length of an elliptic arc between the latitudes φ' and φ (see Astronomische Nachrichten No. 333, pp. 338, 339, June, 1837*), viz:

$$\mathrm{S} = g\,\frac{(\varphi' - \varphi)}{3600} - \frac{180}{\pi}\,g\,(2\,\alpha\sin(\varphi' - \varphi)\cos(\varphi' + \varphi) - \alpha'\sin 2(\varphi' - \varphi)\cos 2(\varphi' + \varphi)$$
$$+ \frac{2}{3}\alpha''\sin 3(\varphi' - \varphi)\cos 3(\varphi' + \varphi) - \text{etc.}).$$

Where φ' and φ = latitude of higher and lower parallel, respectively,

a = equatorial radius = 6377397$^{\mathrm{m}}$.16 [6.804643464]

b = polar semi-axis = 6356078 .96 [6.803189284]

$n = \dfrac{a - b}{a + b}$ [7.2238037] − 10

$\mathrm{N} = 1 + \left(\frac{3}{2}\right)^2 n^2 + \left(\frac{3}{2}\cdot\frac{5}{4}\right)^2 n^4 + \ \ . \ \ . \ \ .$ [0.00000274]

* See, also, "Ordnance Trigonometrical Survey of Great Britain and Ireland," by Lieutenant-Colonel James, London, 1858. On page 267 Captain Clarke reproduces Bessel's formula.

$$\text{N}\,a \;= \frac{3}{2}\,n + \frac{3\,.\,5}{2\,.\,4}\cdot\frac{3}{2}\,n^3 + \frac{3\,.\,5\,.\,7}{2\,.\,4\,.\,6}\cdot\frac{3\,.\,5}{2\,.\,4}\,n^5 + \;.\;.\;. \qquad \log\,a \;= 7.3998945 - 10$$

$$\text{N}\,a' = \frac{3\,.\,5}{2\,.\,4}\,n^2 + \frac{3\,.\,5\,.\,7}{2\,.\,4\,.\,6}\cdot\frac{3}{2}\,n^4 + \;.\;.\;. \qquad \log\,a' = 4.72060 \quad - 10$$

$$\text{N}\,a'' = \frac{3\,.\,5\,.\,7}{2\,.\,4\,.\,6}\,n^3 + \frac{3\,.\,5\,.\,7\,.\,9}{2\,.\,4\,.\,6\,.\,8}\cdot\frac{3}{2}\,n^5 + \;.\;.\;. \qquad \log\,a'' = 2.01136 \quad - 10$$

$$\text{N}\,a''' = \text{etc.}$$

g = average length of a degree in the meridian, found by $a\,(1-n)^2\,(1+n)\,\text{N} = \frac{180}{\pi}\,g$. Hence, $\log g = 5.04579465$

S = distance of parallels (on Bessel's ellipsoid), expressed in metres. The difference $\varphi' - \varphi$ in first term must be taken in seconds. Reduced to numbers, the logarithms of which are given, the expression for distance of parallels becomes—

$$\begin{aligned} \text{S} = [1.48949215]\,(\varphi' - \varphi) &- [4.5048417]\;\sin\;(\varphi' - \varphi)\cos\;(\varphi' + \varphi) \\ &+ [1.5245147]\;\sin 2\,(\varphi' - \varphi)\cos 2\,(\varphi' + \varphi) \\ &- [\bar{8}.63916\quad]\;\sin 3\,(\varphi' - \varphi)\cos 3\,(\varphi' + \varphi) \\ &+ \;.\;.\;. \end{aligned}$$

Applying this to the corrected latitude results, we obtain the following meridional distances, in metres (committee), between the parallels passing through the stations:

Station.	Metres (committee).	
Principio		0.000
	34 196.501	
Pool's Island		34 196.501
	21 625.136	
Webb		55 821.637
	24 021.889	
Marriott		79 843.526
	57 145.930	
Calvert		136 989.456
	62 176.305	
Tangier Island		199 165.761
	44 177.127	
Wolf Trap		243 342.888
	52 774.444	
Cape Henry light		296 117.332
	39 924.837	
Knott Island		336 042.169
	51 122.303	
Stevenson's Point		387 164.472
	29 403.215	
Sand Island		416 567.687
	29 294.371	
Long Shoal Point		445 862.058
	23 574.080	
Hog Island		469 436.138
	32 902.231	
Portsmouth Island		502 338.369

The unit of length in which the linear measures are expressed is the "committee metre," the property of the American Philosophical Society of Philadelphia. It is one of the original metres remitted by the French Committee of the year VII to Mr. Trallès, who gave it to Mr. Hassler, and by whom it was brought to America in 1805 and presented to the Philosophical Society. It was again taken to Paris and compared (August 24, 1867) with the standard platinum metre of the Conservatoire des Arts et Métiers, and was found, at the temperature of melting ice, $=1^{\text{m}}.00000336$ of the platinum metre of the Archives.* To express, therefore, our linear results in terms of the prototype metre, they require an increase of their $\frac{1}{297619}$ part, or their logarithms require an addition of 0.00000146. The distances given in the following table have been increased by this quantity.

* See account of the comparison by F. A. P. Barnard, (then) Assistant in the Coast Survey, and H. Tresca, of the Conservatoire, in Coast Survey Report of 1867, Appendix No. 7, pp. 134–137.

Result of measure of the Pamplico-Chesapeake arc of the meridian:

Designation.	No.	Station.	Astronomical latitude.	Amplitude.	Geodetic distance of parallels.
			° ′ ″	° ′ ″	m.
ϕ	1	Portsmouth Island	35 04 02.67 ±0.05	0.00	0.00
ϕ^{i}	2	Hog Island	35 21 51.88 ±0.12	0 17 49.21	32 902.34
ϕ^{ii}	3	Long Shoal Point	35 34 36.25 ±0.11	0 30 33.58	56 476.50
ϕ^{iii}	4	Sand Island	35 50 25.29 ±0.09	0 46 22.62	85 770.97
ϕ^{iv}	5	Stevenson's Point	36 06 15.97 ±0.12	1 02 13.30	115 174.28
ϕ^{v}	6	Knott Island	36 33 55.37 ±0.09	1 29 52.70	166 296.76
ϕ^{vi}	7	Cape Henry light	36 55 30.32 ±0.08	1 51 27.65	206 221.73
ϕ^{vii}	8	Wolf Trap	37 24 01.99 ±0.07	2 19 59.32	258 996.35
ϕ^{viii}	9	Tangier Island	37 47 56.54 ±0.08	2 43 53.87	303 173.63
ϕ^{ix}	10	Calvert	38 21 31.87 ±0.11	3 17 29.20	365 350.14
ϕ^{x}	11	Marriott	38 52 24.82 ±0.06	3 48 22.15	422 496.26
ϕ^{xi}	12	Webb	39 05 25.46 ±0.04	4 01 22.79	446 518.23
ϕ^{xii}	13	Pool's Island	39 17 09.65 ±0.12	4 13 06.98	468 143.44
ϕ^{xiii}	14	Principio	39 35 32.75 ±0.05	4 31 30.08	502 340.06

A discussion of the probable error of the length of the arc, based upon the probable errors of the base-lines and the errors developed in the triangulation, gave $\pm\frac{1}{155000}$ of its length, equal to $\pm 3\frac{1}{4}$ metres (about 0.4 inch in a statute mile).

ESTABLISHMENT OF THE CONDITIONAL EQUATIONS BETWEEN THE ANGULAR AND LINEAR MEASURES OF AN ARC OF THE MERIDIAN AND THE CORRECTIONS TO ASSUMED SPHEROID.*

In order to bring the observed latitudes $\varphi\ \varphi'\ \varphi''$ . . . . in accord with the measured meridional distances, they require the small corrections $x\ x'\ x''$ . . . . the sum of the squares of which is to be made a minimum, the variables being two quantities determining the figure of the earth, considered as an ellipsoid of revolution. Starting from the expression for the distance S between two parallels φ' and φ of which the corrected values are $\varphi' + x'$ and $\varphi + x$ and putting

$$g_{,} = \text{an approximate value of } g$$
$$\alpha_{,} = \text{an approximate value of } \alpha$$

as determined by $g = \frac{g_{,}}{1+i}$ and $\alpha = \alpha_{,}\,(1+k)$;

$$\text{also } \rho = 1 - 2\,\alpha\cos(\varphi' - \varphi)\cos(\varphi' + \varphi) + 2\,\alpha'\cos 2\,(\varphi' - \varphi)\cos 2\,(\varphi' + \varphi)\ \ldots$$

Here we may put $\alpha' = \frac{5}{6}\alpha^2$

and $\mu = \frac{180 \times 3600}{\pi} = \frac{1}{\sin 1''}$, and its logarithm 5.3144251; then the difference,

* See Bessel, in Astronomische Nachrichten, No. 333, p. 338, and following (June, 1837); also Captain Clarke, in British Ordnance Survey (London, 1858), pp. 267–268.

$x' - x$ expressed in seconds, is given in terms of the small corrections i and k by the conditional equation—

$$x' - x = \frac{1}{\rho}\left[\frac{3600\ S}{g_{,}} - (\varphi' - \varphi) + \mu\left(2\,\alpha_{,}\sin(\varphi' - \varphi)\cos(\varphi' + \varphi) - \frac{5}{6}\alpha_{,}^{2}\sin 2(\varphi' - \varphi) \times \cos 2(\varphi' + \varphi) + \ldots\ldots\right)\right] + \frac{3600\ S}{g_{,}\cdot\rho}\,i$$

$$+ \frac{\mu}{\rho}\left(2\,\alpha_{,}\sin(\varphi' - \varphi)\cos(\varphi' + \varphi) - \frac{5}{3}\alpha_{,}^{2}\sin 2(\varphi' - \varphi)\cos 2(\varphi' + \varphi) + \ldots\ldots\right)k$$

Putting the first term which does not involve i and k, equal to m, the coefficient of the second term equal to a, and that of the third equal to b, we have—

$$x' - x = m + a\,i + b\,k.$$

And a similar equation will obtain for the combination of the most southerly latitude with each of the other latitudes in any one arc. For convenience of computation, we put $10000\,i = p$ and $10\,k = q$ and assume $g_{,} = 111121^{m}$ and $\alpha_{,} = \frac{1}{299.2033}$. We have also—

$$n = \tfrac{2}{3}\,\alpha + \tfrac{1}{6}\,\alpha^{3} + \tfrac{1}{21}\,\alpha^{5} + \ldots\ldots \qquad \text{and } \log g_{,} = 5.04579614$$

$$\log \alpha_{,} = 7.3998945 - 10$$

The assumed value of $g_{,}$ is very near the value belonging to Bessel's ellipsoid, and the value $\alpha_{,}$ is exactly corresponding to his value of the compression.

COMBINATION OF ARCS OF THE MERIDIAN.

Although two arcs theoretically suffice to deduce a result for the figure of the earth, considered as an ellipsoid of revolution, yet the two arcs measured by the Coast Survey have their mean latitudes too close together to be suitable for such a purpose; but by combining them with the Peruvian arc, measured between 1735 and 1744, we may obtain a fair result for the earth's meridional ellipse passing through North America in the average longitude of 75° 09′ west of Greenwich.

The data of the Nantucket arc of the meridian (in longitude 70° 23′ west of Greenwich), measured by the Coast Survey between 1846 and 1867, I take from my report of November 30, 1867, published in Coast Survey Report of 1868, Appendix No. 9, pp. 147–153:

Designation.	No.	Station.	Astronomical latitude.	Amplitude.	Geodetic distance of parallels.	
			° ′ ″	° ′ ″	m.	
ϕ	1	Nantucket Cliff............	41 17 32.86 ±0.06	0.00	0.00	
ϕ^{i}	2	Manomet	41 55 35.33 ±0.05	0 38 02.47	70 429.77	
ϕ^{ii}	3	Thompson	42 36 38.28 ±0.10	1 19 05.42	146 432.14	
ϕ^{iii}	4	Agamenticus	43 13 24.98 ±0.07	1 55 52.12	214 404.07	
ϕ^{iv}	5	Mount Independence	43 45 34.43 ±0.06	2 28 01.57	273 939.65	
ϕ^{v}	6	Sebattis	44 08 37.60 ±0.09	2 51 04.74	316 657.97	
ϕ^{vi}	7	Farmington.................	44 40 12.06 ±0.05	3 22 39.20	375 225.38	$\pm 1^{m}.30$

The data for the Peruvian arc I take from Bessel's paper in the Astronomische Nachrichten, No. 333 (the same as used by Captain Clarke in "Comparisons of standards of length," London, 1866, pp. 283). To convert toises into metres, we have the accepted value $1^{t} = 1^{m}.9490363$ and its log: 0.289819930.

The average longitude of the Peruvian arc is 78° 56′ west of Greenwich:

Designation.	No.	Station.	Astronomical latitude.	Amplitudes.	Geodetic distance of parallels.
			° ′ ″	° ′ ″	m.
ϕ	1	Tarqui	−3 04 32.068	0.000	0.00
ϕ^{i}	2	Cotchesqui	+0 02 31.387	3 07 03.455	344 736.77

RESULTING CONDITIONAL EQUATIONS OF EACH ARC OF THE MERIDIAN.

A.—The Nantucket arc.

$$\begin{aligned}
x^{i} - x &= +\ 0.629'' + 0.2283\,p + 0.1401\,q \\
x^{ii} - x &= +\ 1.141 + 0.4747\,p + 0.2630\,q \\
x^{iii} - x &= -\ 2.640 + 0.6949\,p + 0.3482\,q \\
x^{iv} - x &= -\ 2.776 + 0.8879\,p + 0.4032\,q \\
x^{v} - x &= -\ 1.729 + 1.0263\,p + 0.4315\,q \\
x^{vi} - x &= +\ 1.444 + 1.2161\,p + 0.4552\,q
\end{aligned}$$

B.—The Pamplico-Chesapeake arc.

$$\begin{aligned}
x_{,}^{i} - x_{,} &= -\ 1.463'' + 0.1068\,p + 0.1819\,q \\
x_{,}^{ii} - x_{,} &= -\ 0.840 + 0.1833\,p + 0.3087\,q \\
x_{,}^{iii} - x_{,} &= +\ 0.708 + 0.2783\,p + 0.4625\,q \\
x_{,}^{iv} - x_{,} &= +\ 4.103 + 0.3737\,p + 0.6123\,q \\
x_{,}^{v} - x_{,} &= +\ 3.420 + 0.5396\,p + 0.8638\,q \\
x_{,}^{vi} - x_{,} &= +\ 3.785 + 0.6691\,p + 1.0512\,q \\
x_{,}^{vii} - x_{,} &= +\ 4.200 + 0.8404\,p + 1.2869\,q \\
x_{,}^{viii} - x_{,} &= +\ 2.716 + 0.9837\,p + 1.4738\,q \\
x_{,}^{ix} - x_{,} &= +\ 4.170 + 1.1853\,p + 1.7200\,q \\
x_{,}^{x} - x_{,} &= +\ 4.660 + 1.3707\,p + 1.9293\,q \\
x_{,}^{xi} - x_{,} &= +\ 3.087 + 1.4486\,p + 2.0128\,q \\
x_{,}^{xii} - x_{,} &= +\ 0.210 + 1.5187\,p + 2.0853\,q \\
x_{,}^{xiii} - x_{,} &= +\ 6.072 + 1.6296\,p + 2.1944\,q
\end{aligned}$$

C.—The Peruvian arc.

$$x^{i}_{,,} - x_{,,} = +\ 1.175'' + 1.1225\,p + 5.6312\,q$$

COMBINATION OF ARCS OF THE MERIDIAN FOR DETERMINING THE FIGURE OF THE EARTH CONSIDERED AS A SPHEROID.

Referring to the conditional equations of the form

$$x' - x = m + a\,i + b\,k$$

we have for each arc to make the sum of the squares $x^2 + x'^2 + x''^2 + \ . \ . \ . = $ a minimum with respect to the variables i and k. First considering x this will give the equation

$$o = n x + [m] + [a] i + [b] k \qquad . \ . \ . \ (1)$$

where n = number of latitude stations in the arc. Rectangular brackets indicate, as usual, sums of similar quantities. For the determination of i and k, to be found from all the arcs, each arc furnishes equations of the form:

$$o = [a x] + [a m] + [a a] i + [a b] k \qquad \ldots (2)$$
$$o = [b x] + [b m] + [a b] i + [b b] k \qquad \ldots (3)$$

By substitution of equation (1) these change into

$$o = [a m] - \frac{[a][m]}{n} + \left([a a] - \frac{[a][a]}{n}\right) i + \left([a b] - \frac{[a][b]}{n}\right) k \quad \ldots (4)$$
$$o = [b m] - \frac{[b][m]}{n} + \left([a b] - \frac{[a][b]}{n}\right) i + \left([b b] - \frac{[b][b]}{n}\right) k \quad \ldots (5)$$

for which we may write

$$\begin{cases} o = \mathrm{N} + \mathrm{A} i + \mathrm{B} k \\ o = \mathrm{N}_{,} + \mathrm{B} i + \mathrm{C} k \end{cases}$$

and since each arc furnishes a pair of equations of this form, the values of i and k are found from the final normal equations—

$$\begin{cases} o = [\mathrm{N}] + [\mathrm{A}] i + [\mathrm{B}] k \\ o = [\mathrm{N}_{,}] + [\mathrm{B}] i + [\mathrm{C}] k \end{cases}$$

In the numerical work we exchange i for p and k for q. The following results are obtained—

Nantucket arc.................
$$\begin{cases} o = -\ 1.0896 + 1.1516\, p + 0.4327\, q \\ o = -\ 0.5928 + 0.4327\, p + 0.1708\, q \end{cases}$$

Pamplico-Chesapeake arc......
$$\begin{cases} o = +\ 10.3323 + 4.1744\, p + 5.6130\, q \\ o = +\ 14.5352 + 5.6130\, p + 7.5872\, q \end{cases}$$

Peruvian arc..................
$$\begin{cases} o = +\ 0.6594 + 0.6300\, p + 3.1606\, q \\ o = +\ 3.3083 + 3.1606\, p + 15.8554\, q \end{cases}$$

And by combination...........
$$\begin{cases} o = +\ 9.9021 + 5.9560\, p + 9.2063\, q \\ o = +\ 17.2507 + 9.2063\, p + 23.6134\, q \end{cases}$$

whence $p = -\ 1.3422$ with the weight 2.37
$q = -\ 0.20726$ with the weight 9.38

or

$i = -\ 0.00013422 \pm 0.00008840$
$k = -\ 0.020726 \pm 0.0444$;

also $g = 111135^{\mathrm{m}}.9 \pm 9.8$ and $\frac{a-b}{a} = \frac{1}{305.5 \pm 13.5}$

The corrections to the astronomical latitudes are as follows:

Nantucket arc.		Pamplico-Chesapeake arc.		Peruvian arc.	
	″		″		″
Nantucket	+ 1.49	Portsmouth Island	− 1.18	Tarqui	+ 0.75
		Hog Island	− 2.83		
Manomet	+ 1.78	Long Shoal Point	− 2.33	Cotchesqui	− 0.75
		Sand Island	− 0.94		
Thompson	+ 1.94	Stevenson's Point	+ 2.29		
		Knott Island	+ 1.34		
Agamenticus	− 2.15	Cape Henry light	+ 1.49		
		Wolf Trap	+ 1.63		
Mount Independence	− 2.96	Tangier Island	− 0.09		
		Calvert	+ 1.04		
Sebattis	− 1.70	Marriott	+ 1.24		
		Webb	− 0.46		
Farmington	+ 1.21	Pool's Island	− 3.44		
		Principio	+ 2.25		

With a mean error of a latitude determination $\pm\ 2''.02$, and the probable error $\pm 1''.36$, the following table gives a comparison of our results with similar results for the figure of the earth; the first column of results are those upon which, up to this time, all geographical latitudes and longitudes of the Coast Survey depend. The second set of results are considered the most reliable so far deduced, and depending on a combination of five selected arcs under the hypothesis of the average figure of the earth approximating to being represented by a spheroid:

Data for figure of earth.	Bessel, 1841.	Clarke, 1866.	Coast Survey, 1877.
Equatorial radius, a	$6\ 377\ 397^{m}.2$	$6\ 378\ 206^{m}.4$	$6\ 378\ 054^{m}.3$
Polar semi-axis, b	$6\ 356\ 079^{m}.0$	$6\ 356\ 583^{m}.8$	$6\ 357\ 175^{m}.0$
Compression $\frac{a-b}{a}$	$\frac{1}{299.15}$	$\frac{1}{294.98}$	$\frac{1}{305.48}$
Average length of a degree of the meridian, g	$111\ 120^{m}.6$	$111\ 132^{m}.1$	$111\ 135^{m}.9$
Length of a quadrant	$10\ 000\ 856^{m}$	$10\ 001\ 888^{m}$	$10\ 002\ 232^{m}$
Number of arcs combined	10	5	3
Their aggregate length	50° 35'.4	76° 35'.0	11° 01'.2

Bessel's arcs are situated in Europe and Asia, with one arc in America (the Peruvian). Clarke's arcs are situated in Europe, Asia, Africa, and America (the Peruvian). The Coast Survey arcs are in the Western Hemisphere, near to the average longitude 75° 09' west of Greenwich. The arcs are all in its northern quadrant excepting a *part* of the Peruvian arc which lies across the equator. Owing to an absence of measures in a high latitude our special combination must necessarily be weak for the determination of the compression; this is sufficiently shown by the large probable error assigned to the above value. This probable error, however, includes within its range the best value for the compression, as far as known. As a special combination of arcs for North America the results indicate that the curvature of the meridians is probably not materially differing in the two hemispheres (the Eastern and Western), but that our two arcs demand a spheroid of somewhat larger size than that given by Bessel's numbers for the earth as a whole. This will appear clearer if we adopt for the compression $\frac{1}{295}$, and determine by means of our equations the corresponding values of the semi-axes; they become $a = 6378769$ and $b = 6357146$ very nearly. The surface of this spheroid lies about563 metres outside Clarke's spheroid and is concentric therewith, whereas for our first spheroid its surface at the equator lies 152 metres inside, and at the pole 591 metres outside Clarke's spheroid, which latter it therefore intersects. If the form of the meridian was not restricted to an ellipse it is probable that in our middle latitudes the average surface would project beyond the elliptic surface. The result from the combination of the three American arcs, which is of most interest to us, is the preference it gives to Clarke's spheroid over that of Bessel's; an early abandonment of the latter as the fundamental surface upon which to develop the triangulations of the Coast Survey is thus indicated. Our triangulation thus being supposed developed on too small a surface (Bessel's spheroid), our geodetic latitudes in the north will apparently be too great, and the so-called station-errors, astronomic minus geodetic latitudes, will have a $-$ sign predominating; those in the south will appear too small, and the apparent station-errors will have a $+$ sign predominating.* If we suppose the geodetic latitude to refer to the middle latitude 40°, geodetic results for positions differing from it in latitude 5°, north and south of it, would be affected by nearly $2\frac{1}{2}$ seconds (of arc), that is about their $\frac{1}{7000}$ part; the actual *increase* needed will probably be less, and may be estimated as one part in 9000, for quantities depending on the dimensions of Bessel's spheroid.

No change in our geodetic data is at present contemplated, nor would it be timely to enter into any further discussion of these arcs, since we may confidently expect that both Coast Survey arcs will ere long be extended northward. Besides, we shall have the additional testimony of the nearly completed oblique arc of the primary triangulation, supported by numerous astronomical stations between Maine and Georgia, which arc has already reached an extent of nearly $17\frac{1}{2}$°.

Under the supposition of an elliptic equator Captain Clarke finds (Comparisons of standards of length, appendix, p. 285) the minimum quadrant to lie or intersect the equator in longitude $74\frac{1}{2}$°

* In the coast triangulation between Maine and North Carolina appearances support this view; for the southern part of the Blue Ridge primary triangulation the value $A - G$ is about $+ 3''.5$; the work, however, is as yet incomplete.

west of Greenwich, almost precisely the average longitude of our three arcs. Their result as given above is not particularly favorable to the assumption.

I may be permitted to remark that geodesy would derive much benefit from a remeasure and extension of the Peruvian arc, which it will now probably be conceded falls short of the precision which its favorable position on the earth's surface demands; being at the equator, it has great effect in the combination with arcs in high latitudes for the deduction of the earth's figure; hence its apparent fair accord with other arcs is no sure proof of the accuracy of its determination. Its chief defect lies in the paucity of astronomical latitudes (there being but the necessary two), and this in a country where large local deflections of the plumb-line must be expected.

The arc of nearly one degree and a half, measured in the last century in connection with the establishment of the boundary between the States of Maryland and Delaware, by Mason and Dixon, which lies not far east of the northern part of the Pamplico-Chesapeake arc, has not been taken into account in the foregoing discussion. Its accuracy, although fully equal to the best work of its day, falls far short of geodesic measures made within the last fifty years, and the small amplitude of the arc makes its value ineffective in any estimation of the magnitude and figure of the earth from geodesic operations accomplished up to this time. An account of the Mason and Dixon arc is given in the Philosophical Transactions of the Royal Society, 1768, and in reference to it, the the Astronomer Royal of Great Britain, Sir George B. Airy, in his treatise "On the Figure of the Earth" (Encyclopædia Metropolitana, 1830, p. 209), uses the following language: "The results of this measure must, we think, be received as equal in authority to those of any other measure." It is, therefore, only owing to the increased perfection of instrumental means and methods that we now dismiss from further consideration the first measured North American arc, which, moreover, is now superseded by the present measures.

An account is given in the Comptes Rendus (Paris) 1867 of a meridional arc of nearly 10° then being measured in Chili by Mr. Pissio. Judging from the statement of instrumental means used, the impression made respecting its accuracy is rather an unfavorable one. No report of the results having since been published, it has not been introduced into this discussion.

APPENDIX No. 7.

THE MAGNETIC OBSERVATORY AT MADISON, WIS.—REPORT BY CHARLES A. SCHOTT, ASSISTANT.

COAST SURVEY OFFICE,
Washington, D. C., October 8, 1877.

DEAR SIR: In conformity with your instructions of September 3, 1877, charging me with the duty of examining into and providing for the efficiency of the Magnetic Observatory at Madison, Wis., I applied to the assistant in charge of the office for the photographic traces and records, and on their receipt at once computed the scale-values of the instruments, prepared the necessary reading-scales for the traces, and partly read them off, and scrutinized the results.

The *unifilar magnetometer* appears to be in a satisfactory condition, and six months of traces were available for tabulation on the 1st of September. One division of scale equals 1′.159 (times the torsion factor).

The *bifilar magnetometer* produced traces of almost straight lines, and its failure is due to want of sensitiveness of adjustment. By the method of angles (record recovered by me), one division of scale equals $\frac{1}{453}$; by the method of weights (the more reliable), $\frac{1}{416}$ of the horizontal force. For efficiency this amount should have been about ten times smaller. Respecting the temperature compensation, we have no precise information.

The *vertical-force magnetometer* appears to have done tolerably well in the first month (March), but soon after lost its stability, its construction not bearing so high a degree of sensitiveness as was given to it. Perhaps a small percentage of the traces may be found useful in the discussion. The scale-value was well determined, and one division I found to equal $\frac{1}{7088}$ part of the vertical force. A few traces have been read off and tabulated. The temperature-compensation appears to have been well made.

The purely photographic work is, upon the whole, effective, yet it will bear improvements.

September 13 I arrived at Madison, accompanied by Mr. Suess, and, after inspecting the magnetic observatory, called on Mr. Van Slyke, one of the trustees of the university, to arrange for the proper ventilation of the vault, a point of importance not only for the comfort of the observer, but for the performance and preservation of the instruments and the reliability of the scale-values of the force-magnetometers, they being affected by deposition of moisture.

Through the liberality of Mr. Van Slyke, the work for ventilation was immediately attended to; a six-inch earthenware pipe was laid below the level of the floor, with an opening in the center of it, and with a slight inclination southward. The approaches to the observatory, which in wet weather had been almost inaccessible, were graded and the sides sodded. After this the inner walls of the vault were perfectly dry, and no inconvenience was felt by us for want of fresh air, though engaged for hours in the adjustment of the instruments. The brick stove, though not in use, and the old vertical air-duct, were left untouched, serving still as ventilators. I have no apprehension whatever of any further trouble on account of moisture or foul air. While the work of digging and relaying of floor went on, Mr. Suess was engaged in cleaning the instruments and in instructing Mr. Mason respecting improvements in the photographic process; also in fastening the wooden supports on the top of the piers bearing the scales, telescopes, cylinders, and clock, which had become loose, warping from the effect of moisture. The funnels on the lamps were lowered to give ascending slope to escape-pipes. The lamps were fastened to their stands, and the metallic reading-lamp, which had frequently disturbed the vertical-force magnet, was replaced by a stearine candle, fastened in a block of wood.

In the mean time, with the assistance of Mr. Braid, whom I found engaged in making a new determination of the absolute magnetic measures, I made a small local triangulation connecting three magnetic stations with the triangulation of the State, and described the stations.

Collating Mr. Braid's results for declination with those obtained last year by Mr. Hilgard, jr., I noticed a large discrepancy, requiring explanation. I therefore suggested to him the desirability of observing also with the old magnetometer (No. 6), which had been used the year before, in order to make the results strictly comparable (the new instrument used by Mr. Braid as yet having been but roughly tested at Washington). We observed jointly on several days to make sure of the absolute measures, and on the last day I established a new station two hundred and fifty feet farther south of the dome of the main building than the old station, fearing that local disturbance from that object, and from its iron tank and connecting pipes, was sensible. When the observations of 1876 were made, this tank and the pipes were not in place, but when the magnetic observations were started in March *they were.* These changes, consequently, have no special significancy with respect to our differential instruments. I observed also for astronomical azimuth of mark at the two stations. Computations made since show that the local disturbance extends to the absolute station of 1876, and that the determination of the annual change will have to wait for another year.

The scale-values of the three instruments, as finally determined by me, are as follows: The declinometer, one division of scale = $1'.195$, corresponding on the cylinder to $1^{mm}.975$ for reading off the traces. The horizontal force-magnetometer, one division of scale = $\frac{1}{3481}$ of the force, corresponding on the cylinder to $1^{mm}.807$ for reading off the traces. The vertical-force magnetometer, one division of scale = $\frac{1}{4565}$ of the force, corresponding on the cylinder to $1^{mm}.713$ for reading off the traces. The torsion of the declinometer-suspension was measured. A new roller, of about 3^{mm} diameter, was put in for the bifilar suspension. The cups of sulphuric acid inside the glass cases were replaced by powdered unslaked lime.

Observations for effect of changes of temperature were made both for the horizontal and vertical-force magnetometers, in order to ascertain the probable range of variation in the traces due to changes of temperature in the vault during the year. For the correction of the readings of the intensity instruments on account of changes of temperature, I purpose to employ the ordinary observations themselves as safer than the determination of the temperature co-efficient from special observations. The persistence of temperature in the vault is very great; we could only cool down the magnet a very few degrees, and, after the application of ice for two hours, we had to desist on account of moisture appearing on the magnets, speculum, and mirrors, and subsequently, after about three hours of heating up by means of lamps, funnels, and india-rubber tubes, the magnet rose in temperature but a very few degrees. The horizontal-force magnet is a little too lively, and I intend, at a suitable time, to introduce a copper damper for the *bifilar* magnetometer, having about one-half the mass of the one now with the *vertical*-force magnetometer. This latter I propose to take out, and substitute for it one of half the mass. That it acts too powerfully is illustrated by the fact that when the instrument was first examined the vertical-force magnet tilted over after it was removed and the magnet again balanced after it was replaced.

The magnetic work, in the local charge of Dr. J. E. Davies, assisted by Mr. David Mason as operator, is left in safe hands, and I trust it will now continue without serious interruption, though the delicacy of the instruments requires constant watchfulness.

The keeping up of annual determinations of the absolute measures of declination, dip, and intensity is, of course, an essential feature of the magnetic establishment.

I propose to make a preliminary discussion of some of the observations taken by each of the instruments.

Yours, very respectfully,

CHAS. A. SCHOTT,
Assistant Coast Survey, in charge of Observatory.

CARLILE P. PATTERSON, Esq.,
Superintendent United States Coast Survey.

APPENDIX No. 8.

NOTES CONCERNING ALLEGED CHANGES IN THE RELATIVE ELEVATIONS OF LAND AND SEA.
REPORT BY HENRY MITCHELL, ASSISTANT.

There is a popular impression, shared by some eminent geologists, that the northeastern shore of our continent is rapidly rising from the sea, so rapidly, that the change of depth over rocky bars upon the coast of Maine has been noticeable within a generation of practical boatmen. Professor Shaler has estimated that the emergence is "probably over a foot in a century, and may be as much as three feet in the same time" upon this coast.*

About a quarter of a century ago Professor Bache, then Superintendent of the Coast Survey, made special effort to establish benches at all the tidal stations, with a view not only to the perpetuation of the datum plane of our soundings, but also as initials for the measurement of the variations in the relative level of land and sea. Assisting in this early work I became familiar with the prevailing impression among the boatmen that an emergence of the coast was in progress, or as they expressed it, that the rocks were "growing." It may be presumed that a current notion has at least a nucleus of truth, but in our country, settled so recently by people from distant lands, there are many traditions and doctrines that are not yet corrected for latitude and longitude. I am inclined to think that the "growing" rocks are imported; and from this negative point of view I have made a study of the records of early voyagers for notices of objects near the sea-level which could be identified with those now visible.

There is no difficulty in showing that the larger estimate for emergence is in excess, but as regards the smaller estimate I have passed through much uncertainty, because in a locality where the tides are of great range it is often impossible to determine to what plane of reference the early soundings were reduced. I have found it necessary to reject all data that are not directly or indirectly associated with information concerning the stage of the tide, and I ask your attention to my care in this respect, because in this lies all the merit that I may claim.

It is proposed to show, to the extent that the evidence may warrant—

1st. That the attention of early explorers was attracted by the salt marshes, which broke the monotony of our otherwise then wooded country, and that these were then, as now, at ordinary high-water level.

2d. That rocks upon our coast, long notorious as dangers to navigation, have not risen since they were first discovered.

SALT MARSHES.

When, in his journal of July, 1534, Jacques Cartier describes a scene on the southern and western coasts of the Gulf of Saint Lawrence "*as full of as fine fields and prairies as we have seen, flat as a lake throughout*";† and again, further on, uses the words, "*plenty of prairies,*" and "*many fine prairies,*" we may at least *suspect* that he saw the same meadows that are now mowed for salt grass, or cultivated within dykes. And when we come down to the later descriptions of Champlain and Lescarbot we are no longer left in doubt. The salt meadows of Port Royal (now the Annapolis Basin, Nova Scotia) are indicated upon Champlain's map of 1604 by the letter L several times repeated, and in the legend this letter L stands for "prairies which are inundated by the great tides";‡ and, not content with this, Champlain explicitly states in the text of his book that the L'Equille (now Annapolis River), from its mouth as far up as he navigated it, presented numerous "*prairies,*" but that they were inundated by the great tides.

* Atlantic Coast Pilot (edition of 1875), page 886.

† "*Tout plat comme seroit un lac.*"

‡ *Prairies qui sont innondées des eaux aux grandes marées.*

Lescarbot's map of Port Royal, bearing date of 1609, indicates the marshes by topographical signs that would be unmistakable, even if he did not also explain himself in the text of his book.*

"One might be astonished," he says, "that these prairies could exist in a country all covered with wood. To satisfy the curious, I will explain that the high tides, principally those of March and September, overflow the banks, which hinders the trees from taking root; but everywhere that the sea does not overflow is covered with wood."

And again, still more explicitly, in his farewell song—

Adieu, then, sweet shores, with mountains about,
That shelter Port Royal by double redoubt;
Adieu, verdant valleys, that twice in each moon
Receive far and wide the waves of Neptune.†

This verse, taken in connection with the prose quotation preceding, certainly places the height of the marshes at or above ordinary high-tide and below the two spring-tides of each moon. The difference of elevation between ordinary high-water and high-water of spring-tide is two and a quarter feet (if we take half the difference of range given in the "Official Copy" of the British "Tide-Tables") at Digby Gut. The verse expresses very well the present physical condition of those marshes which have not been reclaimed. Salt hay still grows upon some of those indicated upon the maps of Champlain and Lescarbot, as I have personally observed, while others have been dyked for two centuries. Dier'ville, who visited Port Royal in 1699, described very well the manner of building the dykes and the automatic sluice-gates employed.‡

There are no indications in the history of dyke-construction of any change of elevation of the marshes, which has reduced the necessary height of the barriers against the tide. My friend Thomas B. Akins, esq., formerly Commissioner of the Archives of Nova Scotia, has kindly responded to my inquiries into this matter, and I quote the following from his letter:

"Where old French dykes exist without any additional dyking outside of them (which is very rare), they have been added to by subsequent work, and have evidently been lower than the subsequent dykes made by the English; but allowance, in such cases, must be made for the falling in of the old work and the settling of embankments after so many years. I may mention that in or about the year 1760 a very high tide occurred, that swept away all the dykes in Nova Scotia. They were, at this time, all French dykes, and at least eighteen inches lower than those afterwards erected."

He elsewhere says that a great storm, known as the "Saxby gale," from a naval officer named Saxby, who foretold it, overflowed the dykes again, submerging fifteen to twenty thousand acres of land, about ten years ago.

In his map of *Chouacoit* (Saco, Me.), Champlain represents topographically some of the salt marshes, and calls them, in the legend, "*Marais*." In the text, however, he speaks of the river as bordered by *prairies*. He also speaks of going (westward) six or seven leagues, where he found, on landing, two prairies, each about one league long by a half league wide, evidently referring to the great salt marshes of Wells, which skirt the coast for about five miles, and are divided into very unequal parts at present by the inlet from the sea, which is prone to shift.

This great marsh, only a few years after Champlain's visit, proved attractive to settlers, under the patent of Ferdinando Gorges, and subsequently "six score acres" of it were sold for a good price by deed bearing date of 1643.§

On Champlain's map of *Le Beau Port* (Gloucester, Mass.), which is his best, in many respects, the extensive marshes which lie between this port and the Essex River are represented, as well as

* *Histoire de la Nouvelle France,* Chapter XIII.

† *A Dieu a la Nouvelle France du* 30 *juillet* 1607. See *Les Muses de la Nouvelle France.* The second couplet runs thus:

"*Adieu vallons herbus que le flot de Neptune*
Va baignant largement deux fois à chaque lune."

‡ *Relations du voyage du Port Royal de L'Acadie.* Amsterdam, 1710. This book is mostly in rhyme, but that to which I refer is sober prose.

§ Collections of Maine Historical Society.

the little patch of salt meadow at the south end of Freshwater Cove. He refers to them in the legend as *prairies*.

On his map of *Port Fortuné* (Old Stage Harbor, Chatham, Mass.), the littoral salt marshes of Harwich appear, and are still referred to in the legend as *prairies*. Here the spring-tides that overflow the meadows are only seven inches higher than ordinary high-water.

The Pilgrims and Puritans, unlike their French contemporaries in America, were not observers of natural phenomena from scientific or æsthetic points of view, but they were quick to recognize in the salt marshes the "green pastures" provided for the elect. In "New England's Prospect" I find the best piece of evidence that I have to offer regarding the elevation of these tide-lands. "The lowest ground," says the author (whose account was first published in 1634), "be the marshes, over which every full and change the sea flows: these marshes be rich ground, and bring plenty of hay of which the cattle feed and like."* At full and change the sea still flows over these same marshes, and the grass is still cut, for the cattle still like it.

How long these salt meadows have lain "*all flat as a lake*" at the feet of our New England hills no one knows, but that they belong to the present hour, geologically speaking, may be inferred from the fact that no elevated plains exist to represent similar deposits at other stages of the supposed undulation of the earth's crust. Perhaps, bordering upon the sea, they may be at the fulcrum of the tilting movement between ocean and continent, and therefore at rest.

It may be objected to my whole line of argument thus far, that, in premising a present correspondence between the surface of the marsh and the high-tide level, I have admitted a possible dependence of the former upon the latter. If the alleged change were in the opposite sense, *i. e.*, falling instead of rising, this objection would be valid, because new deposits would be made upon the marsh as fast, perhaps, as submergence took place; but in the *rise* of the marsh the only change of volume that could take place would be that due to shrinkage, and this would be confined to the stratum above the water-table, as in the case of dyked lands. I use the word *shrinkage* not *sinkage*, because it is not caused by the increased weight due to drainage. Our marshes, as I showed in my paper on "Reclamation of tide-lands," will scarcely yield under twelve hundred pounds to the square foot.

ROCKS.

Percé Rock, near the town of that name on the peninsula of *Gaspé*, Gulf of Saint Lawrence, is thus described in Imray's Sailing Directions (1877): "Within Bonaventure Island, and close to the main, nearly dry at low-water, is the Percé Rock, so named from having two large holes in it, one so large as to admit the passage of boats at high-water. It is so precipitous as to be nearly inaccessible, and two hundred and eighty-eight feet high, and at a distance appears like a citadel. The rock is joined to the main by a reef."

This remarkable object is described by Champlain as seen by him on the 15th of July, 1603, as follows: "Thence one comes to the *Isle Percée*, which is a very high rock, steep on the two sides where there is a hole through which '*chaloupes & basteaux*' can pass at high tide; and at low tide one can go from the main land to the said island, which is only some four or five hundred paces."

These two descriptions seem to indicate that no change of elevation has taken place. You will observe that both high and low water planes are stated in each, and, since the range of the tide is only three feet at neaps and five feet at springs, we have here a veritable *bench-mark* established two hundred and seventy-five years ago!

The permanence of this point is a very interesting fact in connection with the alleged changes of elevation all along the valley of the Saint Lawrence during the earthquake of 1663 "which tore up mountains by the roots and tumbled them into the sea—which caused new mountains to spring up from former plains," &c., according to the description given in the "Biography of the Venerable Mother Mary of the Incarnation Superior of the Ursulines of New France," of which a brief review may be found in the *Journal des Sçavans*, May 16, 1678. This earthquake was felt in New England, and forms the subject of a paper in the first volume of the proceedings of the American Academy of Arts and Sciences.

* See Publications of the Prince Society.

Isle Percée is mentioned as a point in the western boundary of Acadia in diplomatic correspondence of 1685, and in 1751 reference is made to it in both the French and English Mémoirs to the Commissaires after the treaty of Aix-la-chapelle. I am thus particular about identifying my object and showing that it was never lost sight of, because, to the eastward of the meridian passing through this point, Captain Bayfield's charts of 1835–'45, compared with Cook and Lane's of 1766, show great changes or discrepancies. The ice has played a part in these high latitudes, perhaps, in grinding down and transporting rocks, but its action will not altogether account for the differences between the new and old charts.

Green Ledge.—This is a rocky shoal at the entrance to Green Bay, on the eastern coast of Nova Scotia, and nearly on the same meridian (64¼°) as Percé Rock above mentioned. It uncovers on the last quarter of the tide, according to the chart of Captain Shortland, R. N. (1862), so that its summit, at ordinary low-tides, is one and a quarter feet above the surface of the sea (the *range* being seven feet). This object is represented upon Champlain's map of *Port de la Haie* (1604) by the same conventional sign which, in his map of Port Royal, he explains as indicating flats left bare at low-tide. He gives soundings in the neighborhood which represent about the same depth in *brasses* as Captain Shortland gives in fathoms.*

Mary Ann Rocks.—These (so called upon our Coast Survey chart of Cape Cod Bay, but commonly known as the Fishing Rocks) are two peaks that appear above the sea at low-tide. They lie in deep water although within a mile of the shore. They are the only objects in the portion of the bay below Plymouth that coasters fear. They are about one thousand feet apart, and it seems to have been one of these that Champlain saw "*à fleur d'eau*" (at water-level) after leaving *Port Saint Louis* (Plymouth) on a southerly course, July 19, 1605. It was low-tide on that date between six and seven o'clock, and from the account of his day's journey it is evident that he left port very early in the morning, so that he must have passed the rocks some time during their visibility.

Mr. Thomas Bassett, branch pilot of Plymouth, in answer to my inquiries writes that these rocks emerge one hour and a quarter before low-tide, and at low-tide are eighteen inches out of water. He further says that the more northern of the two peaks is seen first as the tide falls away.

Bulwark Shoal.—"This dangerous ledge," says our Coast Pilot for 1874, "has fourteen feet at low-water." It is situated in the seaward approaches to Portland, Me. In the "English Pilot, the fourth book," 1742, a chart by Cyprian Southack, 1720, is furnished, upon which this ledge appears, with the words "Ledge of rock ten foot at low-water."

Drunker's Ledge.—"These are two distinct ledges," according to our Coast Pilot for 1874. "One is dry at half tide, the other has four feet at mean low-water, and at low spring-tides it is nearly bare." The same chart by Cyprian Southack, 1720, referred to above, represents these ledges with the words "Two ledges of rocks to be seen at low-water."

Bulwark Shoal and Drunker's Ledge, far from supporting any theory of *emergence*, might be cited in vindication of a theory of *subsidence* if confirmed by other testimony.

Cyprian Southack was a member of the Governor's Council of Nova Scotia, and published charts from "actual surveys," but he was a man of no precision, as I have shown in a former report.

Brazil Rock.—This is, perhaps, the most notorious rock in American waters. Situated eight miles S. E. by E. ½ E., by compass, from Cape Sable light, it lies directly in what would be the track of our largest vessels but for this lion in the path. I undertook to hunt up the record of this rock with great confidence, but was much perplexed by what seems to me a palpable error in my earliest and most eminent authority, *M. de Chabert.* This savant was sent by the Government of France in 1750 to rectify the charts of the coast of Acadia, and his report was commended before the French Academy deservedly, because his geographical positions were well determined. But as regards Brazil Rock he makes the following strange statement:

It is "three and a half leagues southeast a quarter east from the point of the cape by compass, as I have myself redetermined it while I was there; it breaks and uncovers at low-water."

The recent British survey gave two fathoms at mean low-water upon this rock, and the last edition of the Wilson Sailing Directions says: "This a flat rock covering a space of but one cast of

* The value of Champlain's *brass* is uncertain; if it was five feet of the *Système Ancien* it was about five and a third feet of our measure.

twelve feet." Des Barres, in his large map of Cape Sable, as well as in his smaller charts, gives Brazil Rock ten feet of water. His sailing-directions of 1775 also give ten feet; but in his sailing-directions of 1776 he says: "The Brazil is a small flatt rock with twelve feet of water and within a cable distance all round you have six to eight fathoms."

The fact that Champlain did not see this rock, although he cruised about Cape Sable several days, and the improbability of a twelve feet submergence without destroying the resemblance existing between Chabert's chart of Cape Sable Island and the most recent one published, have satisfied my mind that the heavy summer growth of kelp must have been seen by Chabert and mistaken for the bare rock.

The fact that Des Barres finally decided upon twelve feet, after stating a less depth, indicates that he referred to spring-tides in one case and mean tides in the other. Since the tides are at this point only of six feet range, the plane of reference, whether from a long series of observations or not, can differ but little from the truth.

Before introducing any further evidence from Des Barres, I ought to state that his plane of reference has always been regarded as the level of spring-tides in all the comparisons made to determine the rate of deposit in our harbors, within my knowledge; and I find, upon one of his maps of Boston Harbor, a note made by me long ago to the effect that his spring-tide was the lower of the two occurring in each moon. From what source this information first came to us I do not know, but I find no remark by Des Barres himself concerning it.

Jig Rock.—This object lies off McNutt's Island, at the entrance to Shelburne, N. S. It had six feet upon its summit, according to Des Barres, in 1776. It has, upon Captain Shortland's chart (corrected to 1865), one and one-quarter fathoms at mean low-water. If Des Barres datum-plane is low-water spring-tides, these two statements agree perfectly.

Trinity Ledge.—Des Barres, in his sailing-directions, says this ledge "lies S. W. ½ S. distant six miles from the southermost point of Cape St. Mary's," Nova Scotia. "When the tide is out three stones appear above water." The chart of Captain Shortland, R. N., bearing date of 1862, gives this ledge, with the words, "*Dry at low-water of spring-tide*" (abbreviated). We may presume that the three stones were the origin of the name, and must have been seen previous to Des Barres' time; but the fact that one must wait for the low-water of spring-tides to see them *now*, certainly goes to disprove any theory of *emergence* as touching the last century.

Harding's Ledge.—This is a cluster of rocks lying in the approach to Boston Harbor. It has been the scene of more shipwrecks than any other off-shore object in this neighborhood, and may therefore be presumed to have been regarded as important by Des Barres. In his "Nautical Remarks and Directions for Boston Bay, from surveys principally by George Callender, 1769," he says, "Harding's largest rock is four feet out at low-water." Upon the most recent survey, that of the United States Commission for Boston Harbor, executed by Albert Boschke, 1863, the elevation of the largest rock is given at three and a half feet above the plane of low-water spring-tides.

This evidence, as opposed to emergence, requires no comment.

Great Ledge.—For this obstruction, at the eastern entrance to Wood's Hole, Massachusetts, Des Barres' chart contains the words, "Ledge dry at low-water." Our Coast Survey chart of 1857 represents, by the usual conventional signs, four rocks *awash* at mean low-water, and I have myself seen one of these rocks out of water, so that I think Des Barres still correct if his plane was low-water spring-tide. As the whole range of the tide from high to low water is less than two feet at this point, it is pretty close reckoning to distinguish between planes of reference.

Great Ledge (Buzzard's Bay, Massachusetts).—This ledge has one projection indicated as *awash* at mean low-water upon the "Coast Survey Chart of New Bedford corrected to 1870." Des Barres found it "dry at low-water"—probably at spring-tides.

From the foregoing it has been seen that the study thus far extends from Wood's Hole, latitude 41° 31′, longitude 70° 39′, to Percé Rock, latitude 48° 30′, longitude 64° 13′, embracing 7° of latitude (420 nautical miles) and 6° 26′ of longitude (266 nautical miles). It would, of course, be quite unwarrantable to conclude that a parallelogram with these limits has remained unchanged, but a smaller district may be claimed as beyond dispute. If, confining ourselves to Champlain's points, we draw a line from Green Ledge to Annapolis, Nova Scotia, thence to Wells, in Maine, thence to Gloucester, thence to Mary Ann Rocks, thence to Harwich, Massachusetts, thence to point of beginning at Green Ledge, we inclose a district of 20,000 square miles. Within this district lies Trinity Rocks, and near it Harding's and Brazil, which have not changed during the past century; so that it is fair to conclude that no tilt in either direction has taken place in the Gulf of Maine.

The arc of the meridian between Green Ledge and Percé Rock, measuring two hundred and seventy-one nautical miles, passes near the *Grand Pré* and across the meadows of Cumberland Basin. It is to these two salt-marsh districts that Mr. Akins refers particularly in his letter already quoted, when he speaks of the ancient French and modern English dykes with the conclusion that no change of elevation can be alleged. So that we have really four stationary points in this arc.

I must, in closing, reiterate that to the eastward of this meridian, and especially in Newfoundland, great changes present themselves in the comparison of charts, the depths appearing to be at some points less and at other points greater now than formerly.

Respectfully submitted:

HENRY MITCHELL,
United States Coast Survey.

To CARLILE P. PATTERSON, LL. D.,
Superintendent United States Coast Survey.

APPENDIX No. 9.

DESCRIPTION OF AN APPARATUS DEVISED FOR OBSERVING CURRENTS IN CONNECTION WITH THE PHYSICAL SURVEY OF THE MISSISSIPPI RIVER. REPORT BY H. L. MARINDIN, ASSISTANT.

UNITED STATES COAST SURVEY SERVICE,
Boston, Mass., September 11, 1877.

SIR: In accordance with your instructions dated February 26, 1877, directing me to proceed to New Orleans, La., and organize my party on Coast Survey schooner Research, and after receiving from Prof. H. Mitchell, Assistant Coast Survey, directions for the continuance of the physical hydrography of the Mississippi Delta, I proceeded to New Orleans, and on the 22d of March the vessel sailed for Cubitt's Gap, where lay our first work, arriving there on the 25th of the same month.

The first work of the party, however, was to finish the hydrography of that part of the Mississippi River lying between Cubitt's Gap and the head of the Passes. This was done with the aid of the steam launch attached to the Research this season, and which throughout the season was of great assistance to the party.

While engaged in sounding this part of the river the days unfavorable to the prosecution of this work were employed in running the shore-line of the new lands formed in Cubitt's Gap since its opening. The topographical survey of the Gap, with the necessary triangulation, together with the soundings in the river spoken of above, engaged the party from March 26 to June 25.

Up to the 21st of May the weather had been very unfavorable for current observations, with the exception of a very limited number of days, and none were attempted until the 22d, when the party began observations on a section of the main stream above Cubitt's Gap.

As it had been found necessary to obtain closer results than by the method heretofore used, viz, that by observing from a stationary boat with float and lines, a description of the manner of observing and of the floats used will be given below.

At the close of the survey of the Gap, which included the hydrography of the main pass of the Gap from the point where last year's survey left off to the outer face of its bar, a distance of about five miles, the party sailed for Southwest Pass, where the physical hydrography was continued, extending it to a section in Pass à l'Outre.

During the course of the survey we were desirous of making simultaneous observations with the United States engineers in South Pass, but only in one instance did we succeed, owing to the difficulty of agreeing beforehand on the day and the early discontinuance of current observations by the engineers.

The physical hydrography comprised sections of Main River, above and below Cubitt's Gap; a section of Pass à l'Outre, for comparison with Southwest Pass; and six sections in Southwest Pass. These were repeated at different times and under different conditions.

I give below a statistical table of work performed by the party during the season, which began on the 26th day of March and ended on the 20th day of August, having, during the first part of the month, received your instructions to close as soon as the state of the work would permit.

TABLE OF STATISTICS.

Hydrography:	
Number of soundings taken	14,565
Number of angles measured	5,050
Number of nautical miles run	183
Number of signals erected	37
Number of tide-gauges observed	2

Topography:	
Number of miles of shore-line run	127
Number of acres of land surveyed	3,219
Triangulation:	
Number of signals put up	16
Number of stations occupied	6
Number of angles observed	420
Area of square miles	15
Physical hydrography:	
Number of sections observed	9
Number of observations of currents	496
Number of angles measured	1,610
Number of soundings on sections	1,047
Number of base-lines measured	13

The number of finished sheets to be turned in to the office is as follows:

	Scale.
One original hydrographic, part of main river between Cubitt's Gap and Head of Passes.	1–4,800
One original hydrographic, main pass of Cubitt's Gap	1–4,800
One original hydrographic, bar of Main Pass Gap	1–4,800
One original topographical, of Cubitt's Gap	1–10,000
One original physical hydrographic, main river sections	1–2,400
Three original hydrographic, of upper part of Southwest Pass	1–4,800

During the season I have been assisted by Mr. John B. Weir, Aid, and Messrs. Russell and Raeder, acting paymaster's yeoman and carpenter's mate, in a very efficient manner. Mr. Weir's suggestions in regard to the apparatus used in the current-observations have been tried in many instances and have proved very satisfactory.

Having received your instructions, the party was dissolved on the 20th of August. The schooner Research was laid up at the head of South Pass and housed over with lumber; all the boats, including the steam-cutter, were placed on board-platforms built on shore, and housed over. The whole was left in charge of H. T. Hutchinson, carpenter's mate, assisted by S. E. O. Wheeler, quartermaster, as ship-keepers.

The method followed in all our current-observations this season, with reference to the manner of observing, has been that pursued in gauging large streams. Base-lines were accurately measured at the points selected for cross-sections; these were laid out so as to be parallel to the axis of the stream. At the ends of the base, angles were measured on the passage of the floats over the ranges, the lower instrument (theodolite) taking the angle on the float as it passed the upper range, and the upper theodolite taking the angle at the time of the transit of float over the lower range; this gave two points on the path of the float. The time of transit over the ranges was taken with a stop-watch to a quarter of a second, by the time-keeper, who was stationed midway between the two observers at the ends of the base-line, where any signal from the observers could be distinctly seen or heard.

The signal as to the kind of float placed overboard, whether a surface or a subfloat, and its depth, was given by steam-whistle from the launch and recorded by the time-keeper. In this manner a transverse curve of velocity across the Mississippi River, with about twenty points of measurement, could be obtained in less than three-quarters of an hour.

The floats were dropped from the steam-launch sufficiently above the upper range to allow the float to have acquired the velocity of the stream before arriving at the upper range, and another boat was stationed below the lower range to pick up the surface-floats.

In observing a vertical curve of velocities with the subfloats it was inconvenient, if not impossible, to have on hand the number of subfloats required to obtain velocities at numerous points of the curve; consequently, the steam-cutter after dropping the float followed it down stream, keeping at a certain distance, and picked it up after passage over the lower range. This necessitated the steaming up to the dropping-buoy before another float could be placed overboard, a loss of time, it must be admitted, but during which no material change in the velocity of the stream can occur where the current is not tidal.

DESCRIPTION OF FLOATS.

Surface-floats.—Those used were the usual cylindrical tin cans loaded to eleven inches draught. Height of cylindrical part of can = 11 inches; diameter = 8 inches; height of cone top projecting above the surface of the water = 3 inches. Nozzle one inch in diameter at apex of cone for cork stopper. The cone can be surmounted by a small flag thrust into the cork stopper; the flag need not be more than five inches square, as this is large enough for the observer to find in the field of view of his telescope, even across the Mississippi River, a distance of 4,000 feet.

With these floats transverse curves of velocities were observed by dropping them at distances of one hundred and fifty to two hundred feet, giving thus from fifteen to twenty points of actual measurement in each transverse curve.

Surface-floats of the above dimensions have been found very convenient for use. They can be loaded easily from any material at hand, such as old nails, iron filings, earth, or sand, and are large enough so that the wind can have little influence on them.

Subcurrent floats and observations.—All the subcurrent observations have been of the free-float kind (with the exception of a few trials of Revy's current-meter), and as the form of the apparatus used was somewhat changed from that previously in use, a detailed description is given below.

It had seemed desirable to do away, if possible, with corrections for influence of surface-float in subcurrent observations; or since, theoretically, this cannot be done, at least so to reduce it that it would practically amount to nothing. With this end in view, the area of the surface-float and the size of the connecting-wire were much reduced and the area of the subfloat greatly enlarged. The form of the surface-float was also changed so as to give the greatest buoyancy with the least resistance to the current. The connected surface-float is a semi-ellipsoid, the vertical section being a semi-ellipse, with major axis = 0.5 feet and semi-minor axis = 0.2 feet, and the horizontal section a circle. It is made of thin sheet-copper, water-tight, with slightly convex top, so as not to increase its section materially when it dips below the surface, and at the same time prevent the water from remaining on it. The section opposed to the current has an area of 0.078+ square feet or about 11.3 square inches.

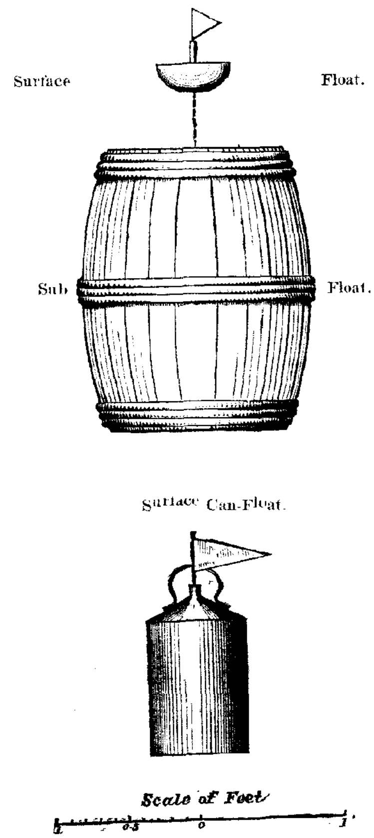
The connecting-wire is the finest piano-wire, with a diameter of 0.022+ of an inch. Even finer wire than this could be used, but with increased care in manipulating it.

The subfloat is a common wooden barrel, without top or bottom; the sinking-weight is fastened at the lower inside edge, so that the barrel shall float upright if left free; to it is added the weight of buoyancy of upper float less the weight of connecting-wire when immersed. The mean diameter of this float is 1.4 feet and its height = 1.89 feet. The area of section exposed to the current is three hundred and eighty-one square inches, giving a ratio to section of surface-float of 35 to 1, and to the latter, combined with the section of sixty feet of connecting-wire, of 14 to 1.

From the above data we may find to what extent the surface-float affects the motion of the subfloat at depths where differences of velocity occur. Taking, for example, an observation at sixty feet depth, and assuming a difference of velocity between surface and subcurrent of 0.5 nautical mile per hour, or 0.8439 foot per second, and computing the impulse on the surface-float due to this velocity by Weisbach's formula for the resistance of floating bodies, we find the theoretical value of an observation made with these floats to be as follows: The retardation (or acceleration) of lower float = 1.8 feet, or a distance slightly in excess of the diameter of the subfloat; the inclination of the connecting-wire is 1° 42′; and the lifting of the subfloat = 0.03 foot, *i. e.*, instead of floating at sixty feet depth it moves at a depth of 59.97 feet.

This result tends to show that very reliable observations can be made with this form of floats without having to make any correction for the influence of the connected surface-float.

A sketch showing the relative sizes of the floats is given below:



Soon after the receipt of the Revy current-meter sent by the Coast Survey Office, I made several ineffectual attempts to obtain its value by direct observations in a small still-water canal at the head of South Pass.

An approximate value was obtained, and I then determined to occupy a station in the axis of the stream in Southwest Pass and observe a vertical curve from top to bottom. Some difficulty was experienced in anchoring boats from which the meter could be kept in a vertical line in the strong current of the pass; but the greatest difficulty was found in manipulating the instrument. After the meter is secured at the required depth, it is then placed in gear by pulling a wire connected with the pivot of the registering-wheels, which raises them towards an endless screw on the propeller-shaft, the propeller being continually in motion so long as the current exists. This is a continual source of uncertainty. The tension on the wire which would be required to place the wheels in gear at ten feet depth is very different from that which would gear them at fifty feet depth, and cannot be ascertained but by repeated readings of the register at the same depth, which entails a great loss of time, as the meter has to be lifted out of the water each time.

Another source of error is found in the possibility of the endless screw catching the teeth of one wheel in advance of those of the other registering-wheel, thereby registering erroneously. This was the case in a few instances. All of these are disqualifications which make the use of this meter so uncertain as to bar it from usefulness in subcurrent-observations in large streams.

A meter registering by means of an electric current, or by some other method directly under one's observation, seems to me to be the only way of obtaining reliable work.

I respectfully submit the above, hoping that the amount of work done during the season, and its quality, may meet your approval.

Very respectfully,

HENRY L. MARINDIN,
Assistant Coast Survey.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey,
Washington, D. C.

APPENDIX No. 10.

DESCRIPTION OF AN OPTICAL DENSIMETER FOR OCEAN WATER.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, October, 1879.

SIR: I submit herewith an account of an instrument which was devised by myself and constructed at this office, for the purpose of determining the density of sea-water by its refractive power. A description of it was presented to the National Academy of Sciences in April, 1878. The observation with this instrument is as readily performed at sea as on shore, while the determination of specific gravity by the hydrometer is rendered difficult and uncertain by the motion of the ship.

In perfecting this device, I have followed the suggestion of Prof. Wolcott Gibbs, made for the voyage of the Hassler in 1871–'72. According to his indication, a hollow prism was mounted on a sextant in the place of the index-glass, a collimating-telescope with a narrow slit attached to the vernier-arm, and an observing-telescope so fixed in the usual place of the horizon-glass, that the image of the slit might be observed in it after two refractions and one internal reflection by the prism, when filled with fresh or saline water. No available results were obtained with this instrument, but this I believe to have been due mainly to the observer not using monochromatic light, so that the image of the slit appeared as a series of ill-defined spectra, instead of a single sharply-defined line. The scale of measurement appears to have been sufficiently large.

Numerous experiments made with the simple instrument herewith submitted give reason to believe that it will prove to be satisfactory to our naval officers.

I am indebted to Mr. J. Homer Lane for designing the details of construction.

Very respectfully,

J. E. HILGARD,
Assistant.

CARLILE P. PATTERSON,
Superintendent United States Coast Survey,
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OPTICAL DENSIMETER FOR OCEAN WATER.

The determination of the density of the ocean in different parts of the world and at various depths is admitted to be an element of the physical condition of our globe which it is important to determine with great precision. As the object of this notice is only to describe a new instrument for finding such densities, there is no occasion to discuss the importance of their ascertainment further than to consider the degree of precision requisite for useful results, and which can be reached by the instrumental means available on ship-board. Account is taken only of the density of ocean-water uninfluenced by the immediate proximity of fresh-water streams. As the sensible effect of such is variable in different seasons and at different stages of the tide, no great precision in any single observation of the density of the water is useful, because the densities will differ sensibly in adjacent threads of the current, and the value can only be obtained by the average of a great number of observations of approximate accuracy. Ordinary hydrometer-floats ranging from the density of fresh water to that of ocean-water, with a stem of three inches graduated from 1.000 to 1.030, will sufficiently serve such experimental purposes.

When, however, we get away from such local conditions and inquire into the general regimen of the ocean, affected in part by the fresh-water outflow from the continents, but mainly by the general thermal circulation, it becomes important to measure the differences of density with the greatest precision that can practically be obtained. These considerations are equally important with regard to the density of ocean-water in different parts of the surface and at various depths. If the specimens secured could be preserved without sensible change until they could be opportunely submitted to a laboratory investigation, the task of the naval officer would be reduced to collecting specimens and hermetically sealing them up, but it is reasonably to be supposed that he would have a desire to ascertain the results for himself.

The want of suitable instruments has been met to a certain degree by hydrometers (which might properly be called "stem-floats") specially adapted to sea-water. This method of ascertaining the density does not, however, admit of great precision on ship-board, because the float partakes of the movements of the vessel, and oscillates between wide limits—wider in proportion to its sensitiveness, and generally unconformable to the oscillations of the ship. Hence it becomes very difficult to read the average position of the float with a sufficient degree of precision, unless the sea be exceptionally calm.

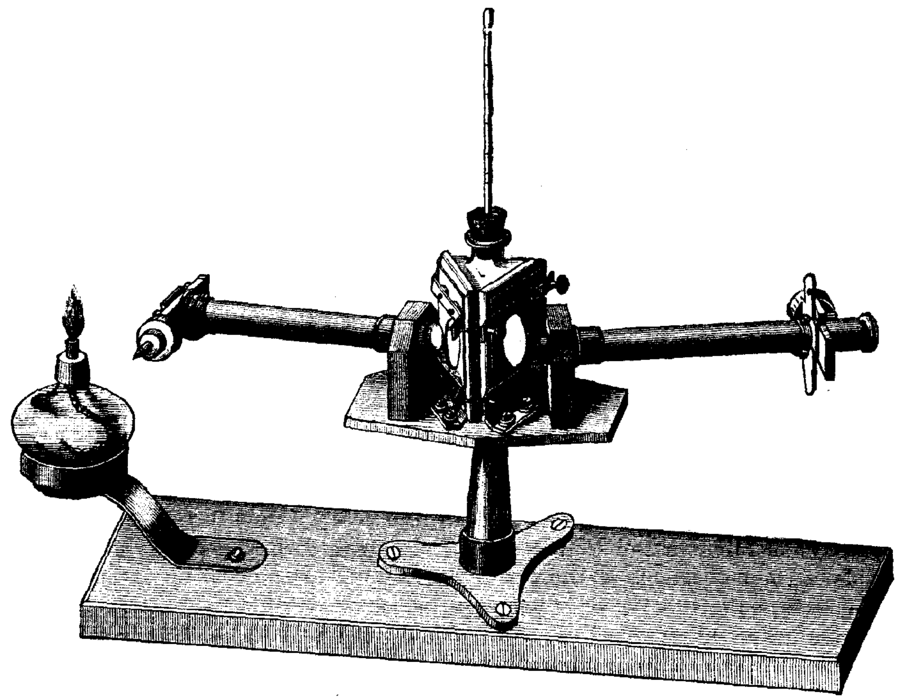
The average density of the ocean properly speaking, unaffected by local causes, will not vary, when reduced to a common temperature, more than one-thousandth part from the average value. It is therefore necessary, in order to obtain any useful result, that the density should be ascertained to at least one-ten-thousandth part of the whole, or practically a unit in the fourth decimal place. Now, a hydrometer or stem-float of that degree of sensibility, while perfectly available on shore, is so susceptible of the movements of the vessel as generally to render observations quite impracticable on ship-board. For this reason it has been deemed advisable to abandon that most direct mode of ascertaining the density, and to resort to other means offered us by physical science.

With this view the Optical Densimeter, described below, has been devised, which obviates all the difficulties arising from the movement of the vessel. The basis of this instrument is the change n the refractive power of a saline solution of greater or less density. The instrument consists iiubstantially of a hollow prism filled with the water under observation, transmitting from a collmating-telescope a line of monochromatic light to an observing-telescope in which the refracted position of that line is read by means of a micrometer. The monochromatic light employed is a sodium flame obtained by adding a small proportion of a solution of common salt to the alcohol of the lamp. The accompanying illustration exhibits the instrument in the proportions that have been found advantageous. The temperature of the liquid under observation is found by means of a thermometer inserted through the neck of the hollow prism, but which is withdrawn when the optical observation is made.

It is obvious that the sensibility of this apparatus is not affected by the movements of the vessel, and that its power of measurement might be increased by either enlarging or increasing the power of the telescopes or by introducing an additional prism. But it will be seen at once that the practical accuracy is limited to the ascertainment of the temperature at which the observation is made.

For, at the average temperature at which such observations would be made—say 68° F. or 20° C.—a change of one degree Fahrenheit causes a change of specific gravity of about 0.0002, and since we cannot expect to ascertain the temperature more correctly than within two or three tenths of a degree Fahrenheit, it is obvious that any attempt to ascertain the density more nearly than 0.00006 would prove futile on that account. The tables given at the end of this article show that a single determination by the Optical Densimeter possesses this degree of accuracy, and any greater degree of refinement would be lost in the uncertainty of the physical conditions of the specimen.

The glass prism rests on three little knobs so as to have a firm support. Attached to the stand carrying the telescopes are two guides, by means of which the prism is made always to occupy exactly the same position, so that all observations are made under the same angle. A small thumb-screw on the side of the prism, not seen in the plate, forces the prism closely into the guides.



The slit in the focus of the collimating-lens is very readily made by drawing a fine line through a black coating (such as engravers' etching-ground) on the inner surface of a glass diaphragm. In the illustration this diaphragm appears mounted on a micrometer slide, which was deemed desirable for general experimental purposes, in order to make the observations under the condition of equal refraction on both faces of the prism; but in the instruments for practical use on board ship the slit will be in a fixed position. The image of the slit in the field of the observing-telescope is a sharply-defined bright-yellow line, which is pointed upon with a fine dark spider line carried by the micrometer.

The relation of the angle of refraction to the density of sea-water having been ascertained experimentally in the office, as well as the temperature-corrections for different degrees of salinity, it is only necessary to determine for each instrument the difference of micrometer-reading between distilled water and sea-water of an ascertained specific gravity, and from this and the ascertained law construct two tables for its use; one giving the reduction to the standard temperature of 60° Fahr., in terms of micrometer-divisions, the other giving the specific gravity for the difference of reduced readings on distilled water and on the specimen of sea-water under observation.

The following experiments recently made with the Optical Densimeter will give a clear idea of its adaptation to the purpose designed, and will also show the degree of reliability attaching to a single determination by its use.

Four samples of water, of different degrees of saltness, were carefully weighed under observed conditions of temperature and barometric pressure, so that the determination of their specific gravities was a matter of simple computation.

The specific gravity of distilled water at 60° Fahr. is taken as unity, or 1.0000, and all specific gravities herein considered are referred to that unit.

The temperature at which the specimens were weighed was 82°.8 Fahr. There being no well determined coefficients for the expansion of salt water, the specific gravities were computed for the temperature of the weighings. Referred to distilled water at 60°, we have thus obtained the following specific gravities at 82°.8 Fahr.:

I. Distilled water	II. Mixture I and III.	III. Sea-water.	IV. Salted sea-water.
0.99722	1.01012	1.02320	1.03638

For each particular instrument it is of course necessary to deduce the value of the micrometer and to determine certain constants from observations upon liquids of known specific gravity.

To determine the value of the micrometer in terms of the specific gravity, it becomes necessary to know the micrometer-readings upon the above liquids. For reasons before stated we cannot reduce the saline solutions to other temperatures than that at which they were weighed. It is also, in general, inconvenient or impracticable to obtain micrometer-readings at exactly this temperature. The first step toward ascertaining the constants of a new densimeter is, therefore, to develop the curve which shall represent the change in micrometer-reading upon a liquid of known specific gravity, due to changes of the temperature of observations.

For this purpose there were made upon each of the samples a series of readings at various temperatures from 45° to 95° Fahr. From three to five readings of the micrometer are taken at each temperature. The following are the mean temperatures and the mean micrometer-readings as observed:

DISTILLED WATER.		MIXTURE.		SEA-WATER.		SALTED SEA-WATER.	
Temperature.	Micrometer.	Temperature.	Micrometer.	Temperature.	Micrometer.	Temperature.	Micrometer.
°		°		°		°	
93.4	187.8	94.5	362.4	94.2	546.7	89.8	748.2
87.9	211.6	90.0	382.3	87.5	575.8	83.7	775.6
83.1	230.6	84.1	406.4	84.2	588.5	79.8	792.9
77.2	252.5	81.4	419.0	78.8	613.0	73.9	815.5
73.9	262.7	76.9	435.2	73.0	632.5	69.2	833.9
70.1	274.3	71.9	452.8	68.2	651.7	64.9	851.2
64.3	291.8	65.8	473.6	63.5	667.4	58.8	871.2
58.9	304.5	62.8	481.8	59.0	680.9	54.0	886.5
53.5	317.7	58.1	496.1	54.1	694.5	49.0	900.7
49.4	324.0	54.0	504.2	49.6	705.1	45.2	910.8
		49.7	515.1	45.2	715.2		
		45.9	520.8				
		44.4	524.7				

If M_0 = micrometer-reading at an assumed temperature, t_0, and M_t = reading at observed temperature, t, we will have for the equation representing M_t the following:

$$M_t = M_0 + A(t - t_0) + B(t - t_0)^2 + C(t - t_0)^3$$

For the present investigation C is infinitesimal and is neglected.

The preceding observations give from ten to thirteen equations of condition for each specimen. Assuming $t_0 = 60°$ Fahr., forming the normal equations, and solving them, we derive the following values for M_0, A, and B:

For distilled water:

$$M_t = 302.4 - 2.41(t - 60°) - 0.031(t - 60°)^2$$

For the mixture:

$$M_t = 489.8 - 2.69(t - 60°) - 0.030(t - 60°)^2$$

For sea-water:

$$M_t = 677.2 - 2.99(t - 60°) - 0.025(t - 60°)^2$$

For salted sea-water:

$$M_t = 867.0 - 3.32(t - 60°) - 0.022(t - 60°)^2$$

We have thus the means of ascertaining what would be the scale-reading of any one of these specimens at any desired temperature.

From these equations we find that the micrometer-readings, at 82°.8 Fahr., would be as follows:

I. Distilled water.	II. Mixture.	III. Sea-water.	IV. Salted sea-water.
231.3	412.9	596.0	779.9

From the weighings we have the following specific gravities:

I. Distilled water.	II. Mixture.	III. Sea-water.	IV. Salted sea-water.
0.99722	1.01012	1.02320	1.03638

From these two tables we get the following differences of micrometer-reading and of specific gravity, from which we deduce the value of one revolution of micrometer expressed in specific gravity, as given in last column.

	Difference micrometer.	Difference specific gravity.	One revolution of micrometer in terms of specific gravity.
	d.		
I to II	181.6	0.01290	0.00710
II to III	183.1	0.01308	714
III to IV	183.9	0.01318	717
I to III	364.7	0.02598	713
II to IV	367.0	0.02626	715
I to IV	548.6	0.03916	0.00714
			0.007138

The direct observations will thus give us immediately the difference of specific gravity between any two specimens observed at any two temperatures, t and t', and their specific gravity as referred to distilled water = 1.0000, at 60° Fahr., results from the preceding equations.

A fair estimate of the trustworthiness of the method may be formed from the observations given above by computing the micrometer-readings for each temperature there given by the general formulæ deduced from them, and comparing the computed with the actually-observed results. We thus have—

DISTILLED WATER.				MIXTURE.				SEA-WATER.				SALTED SEA-WATER.			
Temperature.	Computed.	Observed.	Difference.	Temperature.	Computed.	Observed.	Difference.	Temperature.	Computed.	Observed.	Difference.	Temperature.	Computed.	Observed.	Difference.
°	*d.*	*d.*	*d.*	°	*d.*	*d.*	*d.*	°	*d.*	*d.*	*d.*	°	*d.*	*d.*	*d.*
93.4	187.3	187.8	−0.5	94.5	361.4	362.4	−0.8	94.2	545.7	546.7	−1.0	89.8	748.5	748.2	+0.3
87.9	211.0	211.6	−0.6	90.0	382.1	382.3	−0.2	87.5	576.1	575.8	+0.3	83.7	776.0	775.6	+0.4
83.1	230.2	230.6	−0.4	84.1	407.6	406.4	+1.2	84.2	590.2	588.5	+1.7	79.8	792.6	792.9	−0.3
77.2	251.8	252.5	−0.7	81.4	418.5	419.0	−0.5	78.8	612.1	613.0	−0.9	73.9	816.5	815.5	+1.0
73.9	262.9	262.7	+0.2	76.9	435.8	435.2	+0.6	73.0	634.1	632.5	+1.6	69.2	834.5	833.9	+0.6
70.1	274.9	274.3	+0.6	71.9	453.5	452.8	+0.7	68.2	651.0	651.7	−0.7	64.9	850.2	851.2	−1.0
64.3	291.5	291.8	−0.3	65.8	473.2	473.6	−0.4	63.5	666.4	667.4	−1.0	58.8	871.0	871.2	−0.2
58.9	305.0	304.5	+0.5	62.8	482.0	481.8	+0.2	59.0	680.2	680.9	−0.7	54.0	886.0	886.5	−0.5
53.5	316.8	317.7	−0.9	58.1	494.9	496.1	−1.2	54.1	693.9	694.5	−0.6	49.0	900.8	900.7	+0.1
49.4	324.5	324.0	+0.5	54.0	504.9	504.2	+0.7	49.6	705.6	705.1	+0.5	45.2	911.3	910.8	+0.5
				49.7	514.3	515.1	−0.8	45.2	716.0	715.2	+0.8				
				45.9	521.8	520.8	+1.0								
				44.4	524.5	524.7	−0.2								

In the above table the extreme difference between the computed and observed micrometer-readings is 1.7 divisions, and the average difference is only 0.65 division. Expressed in specific gravity, these differences are respectively 0.000121 and 0.000046. It is thus seen that the uncertainty of a determination by this method is less than the uncertainty, from physical causes, of any one specimen being an average specimen.

The reading of distilled water being a fixed point on the scale of reference, it is not necessary to observe distilled water for every determination. Tests should, however, be frequently made of the constancy of this reading.

The following will serve as an example of record and reduction of observations:

Number of sample.	Latitude and longitude.	Depth, in fathoms.	Date of taking.	Date of observation.	Micrometer-readings.	Temperature, Fahr.	Reduced micrometer-reading.	Difference of micrometer.	Specific gravity at 60° Fahr.
Distilled water.				June 28	274.8				
					75.4				
					75.1	70°			
					76.1				
					275.2				
					275.3		302.5	....	1.00000
28	37¼ N. 72½ W.	100	June 22	June 28	655.0				
					54.6				
					54.3	71°			
					54.8				
					653.9				
					654.5		690.5	388.0	1.02769
29	37¼ N. 72½ W.	50	June 22	June 28	658.0				
					59.1				
					58.2	70°			
					57.3				
					658.1				
					658.3		690.6	388.1	1.02770

APPENDIX No. 11.

AN EXAMINATION OF THREE NEW 20-INCH THEODOLITES. REPORT BY J. E. HILGARD, ASSISTANT.

The three theodolites which form the subject of the following report were made by William Wurdemann, formerly of the Coast Survey, and have recently been received from his workshops in Dresden, Saxony. Theodolite No. 113 arrived a short time before the close of the Centennial Exhibition, and formed a part of the Coast Survey exhibit. It was then brought to Washington, where, for want of proper conveniences, it remained unexamined until March of this year. In January the second one, No. 114, arrived, and a few weeks since the third one was received.

In their general construction these three theodolites are similar to the two 20-inch theodolites made by Mr. Wurdemann for the Coast Survey in 1873. The essential points of difference are—

First, the use of an improved clamp for holding the telescope, the device of Assistant Davidson. Instead of being attached to the axis of the telescope, the clamps, of which two are used on each instrument, are attached to the pillars, and do not change when the telescope is reversed. The clamp acts upon a collar near one end of the axis, and the contact-surfaces are so adjusted as in clamping to exert a slight downward pressure, thus avoiding all risk of lifting the telescope from the Ys.

Second, the use of a shield of sheet-brass which covers the limb, concealing it from view, except for a space of about 10° at one side where an opening in the shield and a pointer permit the setting of any desired reading, or the reading of any pointing. The opening under each microscope being large enough merely to permit their use in reading the subdivisions of the limb the readings are noted by the pointer only, the fractional minutes and seconds being derived from the micrometer. The form of the shield is that of the surface of the frustum of a cone, having its upper base around the axis of the instrument, about three inches above the circle, and extending downward and outward so as to cover and protect, without touching, the limb. The principal object of the shield is to protect the limb from the effect of unequal temperatures in observing. As, in actual field-practice, the light and heat always come from one side, and as the limb remains fixed in position through any one "position" of the instrument, there is a tendency for one side of the instrument to become more heated than the other, and discrepant observations may result. By the use of this shield the heat radiated from the side of the observing-tent or observatory is received upon it instead of falling directly upon the limb and axis of the instrument. They are thus not only protected from the direct radiation, but inasmuch as the shield revolves with the microscopes different portions of it are continually brought to the warmer side of the observing-tent, and the temperature is thereby equalized to a great extent.

Third, and most important, the new theodolites were graduated on a dividing-engine recently perfected by Mr. Wurdemann, and which the examination of the limbs proves to have done very good work.

It was desired to have the illumination of the limb radial, but owing to mechanical difficulties this could not be readily effected. Experience, however, has shown that the most accurate pointings may be made when the limb is illuminated by a hand-lamp held by the observer. The lamp may be so held as to give radial illumination, but it is generally more convenient to hold it a little to one side. This gives oblique illumination, yet, as the obliquity is the same at every reading, no source of error is introduced when the lines are as even as regards depth and width as are the lines on these circles.

The circles were examined

First, with reference to the trisection of the limb by any three division lines 120° apart, and

Second, with reference to periodic errors within 5°, the mechanical construction of the dividing-machine being such that all constant errors would recur with that period.

The trisection of the limb was made by the use of the three filar micrometers attached to the instrument, and in pursuance of the method described in Appendix No. 35, Coast Survey Report for 1860, pp. 357–361, the method being slightly modified to adapt it to the use of three micrometers instead of two, as there used.

The limbs under examination are of 20-inch diameter. They are provided with three filar micrometer-microscopes, at equal angular distances of 120°. The limbs are divided to 5′. In the trisection only every even 5° was read.

It should be borne in mind that it is not claimed for the method of examination by bi- or trisection that it is an absolute test of the accuracy of the graduation. In every trisection the three individual readings are referred each to the mean of the three, and the smallness of the resulting residuals is the criterion of the general accuracy. If we have a limb graduated continuously from 0° to 360°, and if we trisect this limb at various points, and find always that the individual readings closely agree with the mean of the three, it is very strong presumptive evidence of the general accuracy of the division. Yet, as each trisection is entirely independent of every other one, it is evident that we have no check upon the accuracy of the angular space between any two divisions not exactly 120° apart; and thus errors, having a period of 120° or any aliquot part of 120°, will not appear by this method, the principal value of which consists in showing the probable value of accidental errors or of errors having a period not commensurate with 120°.

Of the three theodolites, one, C. S. No. 113, was examined by Mr. J. B. Baylor, and two, Nos. 114 and 115, by Mr. H. W. Blair.

With regard to the periodicity of errors within 5°, No. 114 was examined by Mr. Baylor and No. 115 by Mr. Blair.

Here will be given merely the final results of the examination. The detailed results, and the method of arriving at them, will be given at greater length at the end of this paper.

Examination of 20-inch theodolite C. S. No. 113.

For the purposes of the examination, the theodolite was mounted upon one of the masonry piers in the small observatory in the rear of the Coast Survey building. The door, windows, and slides were all closed and the illumination of the limb was effected by means of a bull's-eye lamp, held in the left hand of the observer. By this means an even and steady light was obtained and the pointings were quickly and readily made. The division-lines upon the limb appeared even and regular, and the adjustment of the distance between the parallel wires of the microscopes to the width of the lines was such as to obtain the most accurate pointings.

The results for this instrument show greater errors of trisection than is observable in the other two. This was noted and mentioned by Mr. Wurdemann when the instrument was sent from Dresden. He ascribes the greater irregularity to unfavorable temperature considerations during the dividing of the limb.

The examination involves the determination of the line of no eccentricity, or the reading, ρ, at which the line through the centers of rotation and of graduation intersects the limb, the eccentricity, ε, the mutual errors of trisection and the mean uncertainty of any one residual.

Three sets of readings were taken in April, 1877, and the following values were obtained:

Value of ρ.

(Readings of line of no eccentricity.)

		°	′
First set,	$\rho =$	48	59
Second set,	$\rho =$	33	16
Third set,	$\rho =$	36	50
Mean,	$\rho =$	39	42

Value of ε.

(Eccentricity.)

		$''$	
First set,	$\varepsilon =$	$-$ 1.45	
Second set,	$\varepsilon =$	$-$ 1.26	
Third set,	$\varepsilon =$	$-$ 1.31	
			Inch.
Mean,	$\varepsilon =$	$-$ 1.34	$= -$ 0.00006

Mean uncertainty of any one residual $= \pm\ 1''.03$

With regard to the sign of the eccentricity, the positive sign indicates that the center of motion is in the direction from the center of graduation to the reading ρ; when negative, that it is in the opposite direction.

Examination of limb of 20-inch theodolite C. S. No. 114.

The three sets of observations upon the limb of this instrument were made on March 28, 29, and 30. The instrument was mounted in the same place and manner as No. 113 and illumination of the limb was effected by the same means. All the conditions, with the exception of the change of the observer, were the same as with No. 113. While the examination shows a somewhat larger eccentricity, it also shows the graduation to be much superior, as is indicated by the very small errors of trisection.

The following are the values obtained:

Value of ρ.

		$\circ$	$'$
First set,	$\rho =$	115	50
Second set,	$\rho =$	119	36
Third set,	$\rho =$	115	25
Mean,	$\rho =$	116	57

Value of ε.

		$''$	
First set,	$\varepsilon =$	$-$ 2.31	
Second set,	$\varepsilon =$	$-$ 2.16	
Third set	$\varepsilon =$	$-$ 2.36	
			Inch.
Mean,	$\varepsilon =$	$-$ 2.28	$= -$ 0.00011

And the center of motion is between the center of graduation and the reading $296^\circ\ 57'$.
Mean uncertainty of any one residual $= \pm\ 0''.44$.

Examination of limb of 20-inch theodolite C. S. No. 115.

This instrument was not received at the office until the latter part of April. The examination was immediately taken up, and the three sets of observations were made on May 1, 2, and 3. The examination was conducted according to the method used in the preceding cases, but the place and manner of mounting were different. The instrument was mounted upon the iron stand belonging to it, and the examination was made in the instrument-room of the fire-proof building adjoining the Coast Survey building. The stand rested upon the floor, and was consequently subject to slight jar as the observer moved around it, but as absolute stability of the stand is not essential to accuracy, no source of error was thereby introduced.

In this instrument the division-lines are much heavier and deeper than on the other two. The edges are beautifully regular and even, and all the lines appear of exactly the same width. Whether or not this deepening of the lines is an advantage, use of the instrument alone will prove. While the limb is new and bright, and the division-lines well blacked, pointings can be made with almost absolute precision.

The following are the resulting values:

Value of ρ.

		°	′
First set,	ρ =	48	01
Second set,	ρ =	72	28
Third set,	ρ =	58	44
Mean,	ρ =	59	44

Value of ε.

		″		Inch.
First set,	ε =	− 0.33		
Second set,	ε =	− 0.41		
Third set,	ε =	− 0.42		
Mean,	ε =	− 0.39	=	− 0.00002

And the center of motion is between the center of graduation and the reading 239° 44′.

Mean uncertainty of any one residual = ± 0″.75.

The exceedingly small value of ε readily accounts for the large range in the value of ρ.

The method pursued in the graduation of these circles was such as to make every even 5° mark a standard line on the circle. The 5° spaces were then subdivided automatically. Any error in the automatic apparatus would thus appear as a periodic error in every 5° space. To ascertain whether or not any such error existed in these instruments an entire space of 5° was measured with the micrometer of one of the reading-microscopes. Portions of the limbs of both No. 114 and No. 115 were thus examined, the former by Mr. Baylor, the latter by Mr. Blair.

The investigation consisted merely in measuring with one of the micrometers each 5′ space for 5°, and comparing directly the resulting value.

To obtain a better mean result two spaces of 5° each were thus measured on each instrument.

Measurement of subdivisions on limb of 20-inch theodolite C. S. No. 114.

The instrument was mounted on its iron stand in the fire-proof building. The value of each 5′ space was measured with the micrometer of microscope A, and the resulting values expressed in turns and divisions (1 turn = 60 divisions). It is evident from the observations that the microscope has an overrun of nearly two seconds, but, as the values are relative and not absolute, this is immaterial. Two pointings were made upon each end of each space measured, that is, in measuring any space, as from 5′ to 10′, a pointing was made upon the 5′ line, then upon the 10′ line, again upon the 10′ line, and back to the 5′. The maximum range in several pointings upon the same line would seldom exceed 0″.5. Below is given a tabular statement of the results for the mean value of a 5′ space for each degree measured.

Measurement of subdivisions of limb of 20-inch theodolite C. S. No. 114, *for* 5°, *from* 24° *to* 29°.

April 28 and 30, 1877. Mean temperature, 65°.7 Fahr.

	°		°		t.	d.
Mean value of 5′ space,	25	to	26	=	4	58.02
	26	to	27	=		58.19
	27	to	28	=		58.25
	28	to	29	=		58.13
	24	to	25	=	4	58.18
Mean,	24	to	29	=	4	58.15

Measurement of subdivisions of limb from 290° to 295°.

May 1, 1877. Mean temperature, 59°.9 Fahr.

	°		°		t.	d.
Mean value of 5′ space,	290	to	291	=	4	58.36
	291	to	292	=		58.55
	292	to	293	=		58.25
	293	to	294	=		58.33
	294	to	295	=	4	58.45
	290	to	295	=	4	58.39

The difference of 0^{d}.24 between the final means of the two sets probably finds its explanation in an altered relation between the microscope and limb. This may be partly due to change of temperature, but the most probable explanation is that the plane of the limb is not absolutely perpendicular to the axis of rotation, in which case the microscopes would be in one position a little nearer to or further from the limb than in another, and by a quantity sufficient to slightly alter the value of the micrometer, without sensibly affecting the focal adjustment.

The value of the micrometer being somewhat different, we can compare the two sets only by reducing them to common terms, which is best effected by expressing the values of a 5′ space in minutes and seconds of arc, the variations being expressed as differences from the mean of each set, not from the mean of the two. We thus have—

		24° to 29°		290° to 295°		Mean.	
		′	″	′	″	′	″
Mean value 5′ space,	1st degree,	4	59.87	4	59.97	4	59.92
	2d degree,	5	00.04	5	00.16	5	00.10
	3d degree,	5	00.10	4	59.86	4	59.98
	4th degree,	4	59.98	4	59.94	4	59.96
	5th degree,	5	00.03	5	00.06	5	00.04

From these we have, by multiplying by 12,

	′	″
Value of 1st degree,	59	59.04
2d degree,		61.20
3d degree,		59.76
4th degree,		59.52
5th degree,	59	60.48

from which we deduce 0″.70 as the mean uncertainty of any one degree. The discrepancies from the mean, however, are so small as to be well within the ordinary accumulation of error in the measurement of so large a quantity. The extreme variation from the mean is 1″.2. Expressed in linear measurement this is equal to 0.00006 inch in sixty revolutions of the micrometer.

Although the measurements on the limb of No. 114 clearly indicated that there was no periodic error of any pronounced magnitude, it was considered desirable to establish the fact more fully by repeating the measurements on the limb of No. 115. This was accordingly done under precisely the same conditions as the former measurements, with the exception of a change of observers, No. 115 being examined by Mr. Blair. Two spaces of 5° were measured, from 0° to 5°, and from 90° to 95°. To ensure the detection of any change in the value of micrometer during a set, the first 5′ space of the set was remeasured at the end of every degree. No appreciable change was observable.

Following is a statement of the resulting mean values of 5′ spaces:

Measurement of subdivisions of limb of 20-inch theodolite C. S. No. 115, from 0° to 5°.

May 15, 1877. Mean temperature, 65°.6 Fahr.

	°	°	t.	d.
Mean value of 5′ space,	0 to 1	=	5	01.31
	1 to 2	=		01.08
	2 to 3	=		01.10
	3 to 4	=		01.01
	4 to 5	=	5	01.05
Mean,	0 to 5	=	5	01.11

Measurement of subdivisions from 90° to 95°.

May 16, 1877. Mean temperature, 70°.3 Fahr.

	°	°	t.	d.
Mean value of 5′ space,	90 to 91	=	5	00.82
	91 to 92	=		00.81
	92 to 93	=		00.75
	93 to 94	=		00.66
	94 to 95	=	5	00.73
Mean,	90 to 95	=	5	00.75

Expressing these values in minutes and seconds of arc (using for each set the mean value of micrometer derived from that set), we have—

	0° to 5° ′	″	90° to 95° ′	″	Mean. ′	″
Mean value of 5′ space, 1st degree,	5	00.20	5	00.07	5	00.13
2d degree,	4	59.97	5	00.06	5	00.01
3d degree,	4	59.99	5	00.00	5	00.00
4th degree,	4	59.90	4	59.91	4	59.90
5th degree,	4	59.94	4	59.98	5	59.96

From which we have, for the degrees, the following:

	′	″
Value of 1st degree,	60	01.56
2d degree,	60	00.12
3d degree,	60	00.00
4th degree,	59	58.80
5th degree,	59	59.52

The extreme discrepancy being 1″.56 = 0.00008 inch in sixty revolutions of the micrometer-screw.

If we combine these values with the ones derived from the examination of No. 114, we will have—

	′	″
Value of 1st degree,	60	00.30
2d degree,	60	00.66
3d degree,	59	59.88
4th degree,	59	59.16
5th degree,	60	00.00

These last values show conclusively that there is no periodic error of any appreciable magnitude in the subdivisions of the 5° spaces.

The preceding part of this paper embodies the substance of the results of the examination of the three 20 inch theodolites. The succeeding portion will be devoted to a description of the method and samples of record, the reductions, and statement of the results of the individual trisections.

The method pursued is substantially the same as that given in Appendix No. 35, Coast Survey Report for 1860, pages 357–361.

The three settings, or nine pointings, for any one trisection, are made in succession, to avoid the risk of possible change in the relative positions of the microscopes, if the settings were made in regular succession from 0° to 360°; that is to say, for the trisection, 0°, 120°, 240°, the pointer was set at 0° and the three micrometers read; then at 120°; and then at 240°; after which it was set successively at 5°, 125°, 245°, &c.

Following is given a sample of the form of record and the derivation of the observed errors of trisection:

Examination of limb of 20-inch theodolite C. S. No. **114.**

COAST SURVEY OFFICE. *Washington, D. C., March* 28, 1877.

Trisection of limb at every even 5°. Temperature at commencement = 61°.

Time.	Circle-readings.					Time.	Circle-readings.					Time.	Circle-readings.				
			r	$r+120°$	$r+240°$				r	$r+120°$	$r+240°$				r	$r+120°$	$r+240°$
	°	′	″	″	″		°	′	″	″	″		°	′	″	″	″
10.40 a. m.	0	00	00	−01	+04	10.55 a. m.	10	00	00	−01	+03	11.11 a. m.	20	00	00	01	03
	120	00	01	00	00				−04	00	00				−05	00	−01
	240	00	−04	−02	00				−07	−03	00				−05	−02	00
			−03	−03	+04				−11	−04	+03				−10	−01	+02
			+2.3	+2.3	−4.6				+7.0	00	−7.0				+7.0	−2.0	−5.0
			+0.8	+0.8	−1.5				+2.3	00	−2.3				+2.3	−0.7	−1.7
10.47 a. m.	5	00	00	−02	+02	11.03 a. m.	15	00	00	+01	+03	11.18 a. m.	25	00	00	00	−02
			−01	00	00				−04	00	−01				−03	00	00
			−05	−02	00				−05	−03	00				−05	−02	00
			−06	−04	+02				−09	−02	+02				−08	−02	−02
			+3.3	+1.3	−4.6				+6.0	−1.0	−5.0				+5.3	−0.7	−4.7
			+1.1	+0.4	−1.5				+2.0	−0.3	−1.7				+1.8	−0.2	−1.6

And so on to 115°, which is the last reading.

In this record the first column notes the times of the observations; the second and third columns give the degrees and minutes of the various readings; and the fourth, fifth, and sixth columns give the seconds. Of these last three columns, the first horizontal line gives the readings of the three microscopes, A, B, C, when the pointer is upon any reading, r. The order of the microscopes is then A, B, C. The second line gives the readings when the pointer is upon the reading $r + 120°$. Microscope A has then moved to the second column, and the order of the microscopes is C, A, B. In the third line the pointer is upon $r + 240°$, A is in the third column, and the order of the microscopes is B, C, A. The fourth line contains the sums of the first, second, and third lines. The mean of the quantities in this line represents the mean reading of the microscopes; and subtracting each quantity from the mean of the three, we have the fifth line. These quantities represent three times the "mutual errors of trisection" (since each angular space on the limb has been measured three times), and, dividing by three, we have the "mutual errors of trisection," which include the effect of eccentricity, of errors of graduation, and errors of pointing.

If, now, we determine the effect of the eccentricity upon any given reading, and correct this reading for it, we will have left the "residual error of graduation and pointing." These two errors it is impossible to separate, but the latter may be practically eliminated by repeating the trisection of the limb several times.

If we designate by α_r, β_r and γ_r the observed errors of trisection corresponding to r, $r + 120°$ and $r + 240°$, and by $[\alpha_r \cos r]$, $[\beta_r \cos (r + 120°)]$, $[\gamma_r \cos (r + 240°)]$, $[\alpha_r \sin r]$, $[\beta_r \sin (r + 120°)]$ and $[\gamma_r \sin (r + 240°)]$, the sums of all the $\alpha_r \cos r$, $\beta_r \sin (r + 120°)$, &c., and by ρ, the reading at which the line through the centers of graduation and of rotation meets the limb, we derive the value of ρ from the formula—

$$\tan \rho = - \frac{[\alpha_r \cos r] + [\beta_r \cos (r + 120°)] + [\gamma_r \cos (r + 240°)]}{[\alpha_r \sin r] + [\beta_r \sin (r + 120°)] + [\gamma_r \sin (r + 240°)]} \qquad (1)$$

To determine ρ, we find each $\alpha_r \cos r$, $\alpha_r \sin r$, $\beta_r \cos (r + 120°)$, &c. This may, of course, be done by actually multiplying out each quantity; but if we reflect that the sines and cosines of any angle may always be expressed in terms of some angle in the first quadrant, this multiplication may be greatly simplified by proceeding in the manner given in Tables I and II in the following reductions. In these tables the first line represents the first quadrant, the second line the second quadrant, &c. Each α_r, β_r, and γ_r is set down under its proper sine and cosine, retaining its sign if the sine or cosine is positive, reversing it if negative. For example, in the sample of record, page 15, we have, corresponding to the reading $r = 5°$, $\alpha_r = + 1''.1$, $\beta_r = + 0''.4$, $\gamma_r = - 1''.5$. In Table I, March 28, we therefore find α_r, under the reading 5°, with the positive sign. β_r corresponds to 125°, which is in the second quadrant. Cos 125° = — cos 55°; hence, $\beta_r \cos 125° = - \beta_r \cos 55°$, and we find β_r in the second line, under the reading 55°, and with its sign changed. γ_r corresponds to 245°. Cos 245° = — cos 65° and $\gamma_r \cos 245° = - \gamma_r \cos 65°$. We therefore place γ_r in the third line, under the reading 65°, and change its sign. The same remarks apply to the formation of Table II, which gives $\alpha_r \sin r$, $\beta_r \sin (r + 120°)$, &c. The fifth, sixth, seventh, and eighth lines of these tables explain themselves. The algebraic addition of the quantities in the eighth line gives the $[\alpha_r \cos r]$, $[\beta_r \sin (r + 120°)]$, &c., and ρ is then derived from the preceding formula.

Knowing ρ, we derive the eccentricity from either of the formulæ—

$$\varepsilon'' = - \frac{[\alpha_r \cos r] + [\beta_r \cos (r + 120°)] + [\gamma_r \cos (r + 240°)]}{\frac{3}{2}\, n \sin \rho} \qquad (2)$$

$$\varepsilon'' = - \frac{[\alpha_r \sin r] + [\beta_r \sin (r + 120°)] + [\gamma_r \sin (r + 240°)]}{\frac{3}{2}\, n \cos \rho} \qquad (3)$$

Where n = number of trisections.

The correction for eccentricity is $= \varepsilon \sin (r - \rho)$, and if α'_r, β'_r, γ'_r represent the "mutual errors of trisection," corrected for eccentricity, or the "residual errors of graduation and pointing," we will have—

$$\alpha'_r = \alpha_r - \varepsilon \sin (r - \rho) \qquad (4)$$

$$\beta'_r = \beta_r - \varepsilon \sin (r + 120° - \rho) \qquad (5)$$

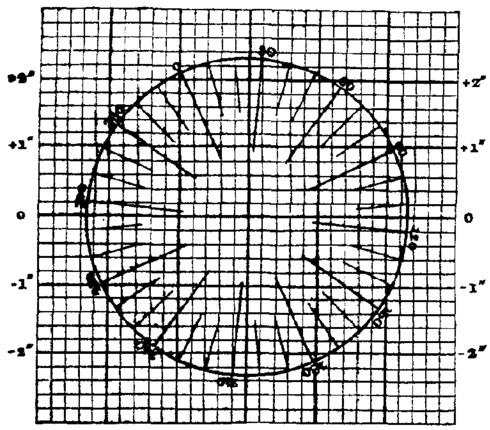
$$\gamma'_r = \gamma_r - \varepsilon \sin (r + 240° - \rho) \qquad (6)$$

These corrections may be separately computed, but a simpler method of arriving at them consists in describing, upon a sheet, ruled in equidistant parallel lines, a circle, with radius equal to the eccentricity, and with the reading of the line of no eccentricity for its initial diameter. Simple inspection thus gives immediately the value of the quantity $\varepsilon \sin (r - \rho)$ for any reading, r. The following diagram illustrates:

Graphic projection of $\varepsilon \sin (r - \rho)$.

March 28, 1877.

$\varepsilon = -2''.31. \qquad \rho = 115^\circ 50'.$



It is readily seen that this gives directly the value of $\varepsilon \sin (r - \rho)$ for every even 10° in the value of r. The intermediate values of r are interpolated.

In Table III the second, fourth, and sixth columns contain the "mutual errors of trisection," uncorrected for eccentricity. These quantities are found in the sixth line in the reduction of observations, sample of which is given on page 120. The third, fifth, and seventh lines contain the corrections for eccentricity, either computed or derived from graphic projection as above. (In the following reductions the graphic method is used.) The eighth, ninth, and tenth columns give the errors of trisection, corrected for eccentricity, or the "residual errors of graduation and reading." Three sets of observations were made upon each instrument, in order to eliminate, in a great degree, the errors of reading, and thus have the final means represent, as nearly as possible, the residual errors of graduation.

Following are the reductions:

Examination of limb of 20-inch theodolite C. S. No. 114.

FIRST SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	+ 0.8	+ 1.1	+ 2.3	+ 2.0	+ 2.3	+ 1.8	+ 3.0	+ 2.3	+ 2.9	+ 2.0
	+ 3.2	+ 2.9	+ 2.8	+ 2.0	+ 2.1	+ 1.3	+ 2.0	+ 0.2	+ 0.7	+ 0.3
		+ 3.9	+ 3.8	+ 3.6	+ 3.1	+ 2.8	+ 2.0	+ 1.4	+ 1.2	+ 0.8
		+ 1.1	+ 1.1	+ 0.6	+ 0.4	+ 0.2	+ 0.3	+ 1.2	+ 0.9	+ 1.8
Sums	+ 4.0	+ 9.0	+10.0	+ 8.2	+ 7.9	+ 6.1	+ 7.3	+ 5.1	+ 5.7	+ 4.9
Logs	0.602	0.954	1.000	0.914	0.898	0.785	0.863	0.708	0.756	0.690
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 4.00	+ 8.95	+ 9.84	+ 7.92	+ 7.43	+ 5.52	+ 6.32	+ 4.18	+ 4.36	+ 3.46

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	+ 1.7	+ 1.6	+ 2.2	+ 1.8	+ 1.9	+ 2.1	+ 1.8	+ 1.4	+ 1.6
		− 1.2	− 0.8	− 0.2	− 0.4	− 0.8	− 0.8	− 0.4	0.0
	+ 1.0	+ 1.6	+ 1.7	+ 1.7	+ 2.3	+ 1.5	+ 1.5	+ 1.9	+ 1.6
		− 1.0	− 0.8	0.0	+ 1.2	+ 1.4	+ 1.4	+ 1.8	+ 1.9
Sums	+ 2.7	+ 1.0	+ 2.3	+ 3.3	+ 5.0	+ 4.2	+ 3.9	+ 4.7	+ 5.1
Logs	0.431	0.000	0.362	0.519	0.699	0.623	0.591	0 672	0.708
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	+ 0.09	+ 0.40	+ 0.86	+ 1.71	+ 1.77	+ 1.95	+ 2.70	+ 3.28

$[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120°)] + [(\gamma_r)\cos(r+240°)] = +74.74$

FIRST SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	+ 0.8	+ 1.1	+ 2.3	+ 2.0	+ 2.3	+ 1.8	+ 3.0	+ 2.3	+ 2.9	+ 2.0
	− 3.2	− 2.9	− 2.8	− 2.0	− 2.1	− 1.3	− 2.0	− 0.2	− 0.7	− 0.3
		+ 3.9	+ 3.8	+ 3.6	+ 3.1	+ 2.8	+ 2.0	+ 1.4	+ 1.2	+ 0.8
		− 1.1	− 1.1	− 0.6	− 0.4	− 0.2	− 0.3	− 1.2	− 0.9	− 1.8
Sums	+ 2.4	+ 1.0	+ 2.2	+ 3.0	+ 2.9	+ 3.1	+ 2.7	+ 2.3	+ 2.5	+ 0.7
Logs	0.602	0.000	0.342	0.477	0.462	0.491	0.431	0.362	0.398	9.845
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	+ 0.09	+ 0.38	+ 0.78	+ 0.99	+ 1.31	+ 1.35	+ 1.32	+ 1.61	+ 0.49

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	+ 1.7	+ 1.6	+ 2.2	+ 1.8	+ 1.9	+ 2.1	+ 1.8	+ 1.4	+ 1.6
		+ 1.2	+ 0.8	+ 0.2	+ 0.4	+ 0.8	+ 0.8	+ 0.4	0.0
	+ 1.0	+ 1.6	+ 1.7	+ 1.7	+ 2.3	+ 1.5	+ 1.5	+ 1.9	+ 1.6
		+ 1.0	+ 0.8	0.0	− 1.2	− 1.4	− 1.4	− 1.8	− 1.9
Sums	+ 2.7	+ 5.4	+ 5.5	+ 3.7	+ 3.4	+ 3.0	+ 2.7	+ 1.9	+ 1.3
Logs	0.431	0.732	0.740	0.568	0.531	0.477	0.431	0.279	0.114
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Products	+ 2.70	+ 5.37	+ 5.41	+ 3.57	+ 3.19	+ 2.72	+ 2.34	+ 1.56	+ 1.00

$[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120°)] + [(\gamma_r)\sin(r+240°)] = +36.18$

$$\tan\rho = -\frac{[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120°)] + [(\gamma_r)\cos(r+240°)]}{[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120°)] + [(\gamma_r)\sin(r+240°)]} = -\frac{74.74}{36.18}$$

$$\therefore \rho = 115° \, 50'$$

$$\epsilon = -\frac{[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120°)] + [(\gamma_r)(\cos r+240°)]}{\frac{3}{2}\, n \sin\beta} = -\frac{74.74}{36 \sin 115° \, 50'} = -2''.31$$

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

FIRST SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		$r + 120°$		$r + 240°$				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	$r + 120°$	$r + 240°$
°	"	"	"	"	"	"	"	"	"
0	+ 0.8	− 2.1	+ 0.8	+ 0.2	− 1.5	+ 1.9	− 1.3	+ 1.0	+ 0.4
5	+ 1.1	− 2.1	+ 0.4	+ 0.4	− 1.5	+ 1.7	− 1.0	+ 0.8	+ 0.2
10	+ 2.3	− 2.2	0.0	+ 0.6	− 2.3	+ 1.6	+ 0.1	+ 0.6	0.7
15	+ 2.0	− 2.3	− 0.3	+ 0.8	− 1.7	+ 1.5	− 0.3	+ 0.5	− 0.2
20	+ 2.3	− 2.3	− 0.7	+ 1.0	− 1.7	+ 1.3	0.0	+ 0.3	− 0.4
25	+ 1.8	− 2.3	− 0.2	+ 1.1	− 1.6	+ 1.1	− 0.5	+ 0.9	− 0.5
30	+ 3.0	− 2.3	− 2.0	+ 1.3	− 1.0	+ 1.0	+ 0.7	− 0.7	0.0
35	+ 2.3	− 2.3	− 1.3	+ 1.5	− 1.0	+ 0.8	0.0	+ 0.2	− 0.2
40	+ 2.9	− 2.2	− 2.1	+ 1.6	− 0.8	+ 0.6	+ 0.7	− 0.5	− 0.2
45	+ 2.0	− 2.1	− 2.0	+ 1.8	− 0.0	+ 0.4	− 0.1	− 0.2	+ 0.4
50	+ 1.6	− 2.1	− 2.8	+ 1.9	+ 1.2	+ 0.2	− 0.5	− 0.9	+ 1.4
55	+ 1.4	− 2.0	− 2.9	+ 2.0	+ 1.4	0.0	− 0.6	− 0.9	+ 1.4
60	+ 1.8	− 1.9	− 3.2	+ 2.1	+ 1.4	− 0.2	− 0.1	− 1.1	+ 1.2
65	+ 2.1	− 1.8	− 3.9	+ 2.2	+ 1.8	− 0.4	+ 0.3	− 1.7	+ 1.4
70	+ 1.9	− 1.6	− 3.8	+ 2.2	+ 1.9	− 0.6	+ 0.3	− 1.6	+ 1.3
75	+ 1.8	− 1.5	− 3.6	+ 2.3	+ 1.8	− 0.8	+ 0.3	− 1.3	+ 1.0
80	+ 2.2	− 1.3	− 3.1	+ 2.3	+ 0.9	− 1.0	+ 0.9	− 0.8	− 0.1
85	+ 1.6	− 1.2	− 2.8	+ 2.3	+ 1.2	− 1.1	+ 0.4	− 0.5	+ 0.1
90	+ 1.7	− 1.0	− 2.0	+ 2.3	+ 0.3	− 1.3	+ 0.7	+ 0.3	− 1.0
95	+ 1.2	− 0.8	− 1.4	+ 2.3	+ 0.2	− 1.5	+ 0.4	+ 0.9	− 1.3
100	+ 0.8	− 0.6	− 1.2	+ 2.2	+ 0.4	− 1.6	+ 0.2	+ 1.0	− 1.2
105	+ 0.2	− 0.4	− 0.8	+ 2.2	+ 0.6	− 1.8	− 0.2	+ 1.4	− 1.2
110	+ 0.4	− 0.2	− 1.6	+ 2.1	+ 1.1	− 1.9	+ 0.2	+ 0.5	+ 0.8
115	+ 0.8	0.0	− 1.9	+ 2.0	+ 1.1	− 2.0	+ 0.8	+ 0.1	− 0.9

For each date the values of ε and ρ were used as determined by the observations of that date and not the mean values of the three dates.

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

SECOND SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	+ 0.7	+ 1.0	+ 1.4	+ 1.9	+ 2.4	+ 2.1	+ 3.0	+ 2.4	+ 2.7	+ 2.3
	+ 3.1	+ 3.1	+ 3.0	+ 2.3	+ 2.3	+ 1.2	+ 1.3	− 0.1	+ 0.6	+ 0.1
		+ 3.3	+ 3.7	+ 2.8	+ 2.9	+ 2.2	+ 1.7	+ 0.9	+ 1.2	+ 0.4
		+ 1.1	+ 0.8	+ 0.2	+ 0.1	− 0.6	+ 0.3	+ 0.8	+ 0.8	+ 1.6
Sums	+ 3.8	+ 8.5	+ 8.9	+ 7.2	+ 7.7	+ 4.9	+ 6.3	+ 4.0	+ 5.3	+ 4.4
Logs	0.580	0.929	0.949	0.857	0.886	0.690	0.799	0.602	0.724	0.643
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 3.80	+ 8.45	+ 8.75	+ 6.95	+ 7.23	+ 4.44	+ 5.46	+ 3.27	+ 4.05	+ 3.10

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	+ 1.3	+ 1.4	+ 2.1	+ 1.2	+ 1.7	+ 2.0	+ 1.9	+ 1.6	+ 2.0
		− 1.4	− 1.1	− 0.2	− 0.8	− 0.8	− 1.0	− 0.7	− 0.1
	+ 1.7	+ 2.2	+ 1.9	+ 1.8	+ 1.6	+ 1.7	+ 1.7	+ 1.9	+ 1.6
		− 1.2	− 0.3	0.0	+ 1.0	+ 1.6	+ 1.2	+ 1.3	+ 2.0
Sums	+ 3.0	+ 1.0	+ 2.6	+ 2.8	+ 3.5	+ 4.5	+ 3.8	+ 4.1	+ 5.5
Logs	0.477	0.000	0.415	0.447	0.544	0.653	0.580	0.613	0.740
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	+ 0.09	+ 0.45	+ 0.72	+ 1.20	+ 1.90	+ 1.90	+ 2.35	+ 3.53

$[(\alpha_r) \cos r] + [(\beta_r) \cos (r + 120°)] + [(\gamma_r) \cos (r + 240°)] = + 67.64$

SECOND SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	+ 0.7	+ 1.0	+ 1.4	+ 1.9	+ 2.4	+ 2.1	+ 3.0	+ 2.4	+ 2.7	+ 2.3
	− 3.1	− 3.1	− 3.0	− 2.3	− 2.3	− 1.2	− 1.3	+ 0.1	− 0.6	− 0.1
		+ 3.3	+ 3.7	+ 2.8	+ 2.9	+ 2.2	+ 1.7	+ 0.9	+ 1.2	+ 0.4
		− 1.1	− 0.8	− 0.2	− 0.1	+ 0.6	− 0.3	− 0.8	− 0.8	− 1.6
Sums	− 2.4	+ 0.1	+ 1.3	+ 2.2	+ 2.9	+ 3.7	+ 3.1	+ 2.6	+ 2.5	+ 1.0
Logs	0.380	9.000	0.114	0.342	0.462	0.568	0.491	0.415	0.398	0.000
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	+ 0.01	+ 0.23	+ 0.57	+ 0.99	+ 1.56	+ 1.55	+ 1.49	+ 1.61	+ 0.71

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	+ 1.3	+ 1.4	+ 2.1	+ 1.2	+ 1.7	+ 2.0	+ 1.9	+ 1.6	+ 2.0
		+ 1.4	+ 1.1	+ 0.2	+ 0.8	+ 0.8	+ 1.0	+ 0.7	+ 0.1
	+ 1.7	+ 2.2	+ 1.9	+ 1.8	+ 1.6	+ 1.7	+ 1.7	+ 1.9	+ 1.6
		+ 1.2	+ 0.3	0.0	− 1.0	− 1.6	− 1.2	− 1.3	− 2.0
Sums	+ 3.0	+ 6.2	+ 5.4	+ 3.2	+ 3.1	+ 2.9	+ 3.4	+ 2.9	+ 1.7
Logs	0.477	0.792	0.732	0.505	0.491	0.462	0.531	0.462	0.230
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Products	+ 3.00	+ 6.17	+ 5.31	+ 3.09	+ 2.91	+ 2.62	+ 2.94	+ 2.37	+ 1.30

$[(\alpha_r) \sin r] + [(\beta_r) \sin (r + 120°)] + [(\gamma_r) \sin (r + 240°)] = + 38.43$

$$\tan \rho = -\frac{[(a_r) \cos r] + [(\beta_r) \cos (r + 120°)] + [(\gamma_r) \cos (r + 240°)]}{[(a_r) \sin r] + [(\beta_r) \sin (r + 120°)] + [(\gamma_r) \sin (r + 240°)]} = -\frac{67.64}{38.43}$$

$$\therefore \rho = 119° \ 36'$$

$$\varepsilon = -\frac{[(a_r) \cos r] + [(\beta_r) \cos (r + 120°)] + [(\gamma_r) \cos (r + 240°)]}{\frac{3}{2} n \sin \rho} = -\frac{67.64}{36 \sin 119° \ 36'} = -2''.16$$

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

SECOND SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		$r + 120°$		$r + 240°$				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	$r + 120°$	$r + 240°$
°	"	"	"	"	"	"	"	"	"
0	+ 0.7	− 1.9	+ 1.0	0.0	− 1.7	+ 1.9	− 1.2	+ 1.0	+ 0.2
5	+ 1.0	− 2.0	+ 0.7	+ 0.2	− 1.7	+ 1.8	− 1.0	+ 0.9	+ 0.1
10	+ 1.4	− 2.0	+ 0.1	+ 0.4	− 1.6	+ 1.7	− 0.6	+ 0.5	+ 0.1
15	+ 1.9	− 2.1	− 0.1	+ 0.6	− 1.8	+ 1.5	− 0.2	+ 0.5	− 0.3
20	+ 2.4	− 2.1	− 0.6	+ 0.7	− 1.9	+ 1.4	+ 0.3	+ 0.1	− 0.5
25	+ 2.1	− 2.1	+ 0.1	+ 0.9	− 2.2	+ 1.2	0.0	+ 1.0	− 1.0
30	+ 3.0	− 2.2	− 1.3	+ 1.1	− 1.7	+ 1.1	+ 0.8	− 0.2	− 0.6
35	+ 2.4	− 2.1	− 1.2	+ 1.2	− 1.2	+ 0.9	+ 0.3	0.0	− 0.3
40	+ 2.7	− 2.1	− 2.3	+ 1.4	− 0.3	+ 0.7	+ 0.6	− 0.9	+ 0.4
45	+ 2.3	− 2.1	− 2.3	+ 1.6	0.0	+ 0.5	+ 0.2	− 0.7	+ 0.5
50	+ 2.0	− 2.0	− 3.0	+ 1.7	+ 1.0	+ 0.4	0.0	− 1.3	+ 1.4
55	+ 1.6	− 1.9	− 3.1	+ 1.8	+ 1.6	+ 0.1	− 0.3	− 1.3	+ 1.7
60	+ 1.9	− 1.9	− 3.1	+ 1.9	+ 1.2	0.0	0.0	− 1.2	+ 1.2
65	+ 2.0	− 1.8	− 3.3	+ 2.0	+ 1.3	− 0.2	+ 0.2	− 1.3	+ 1.1
70	+ 1.7	− 1.7	− 3.7	+ 2.0	+ 2.0	− 0.4	0.0	− 1.7	+ 1.6
75	+ 1.2	− 1.5	− 2.8	+ 2.1	+ 1.6	− 0.6	− 0.3	− 0.7	+ 1.0
80	+ 2.1	− 1.4	− 2.9	+ 2.1	+ 0.8	− 0.7	+ 0.7	− 0.8	+ 0.1
85	+ 1.4	− 1.2	− 2.2	+ 2.1	+ 0.8	− 0.9	+ 0.2	− 0.1	− 0.1
90	+ 1.3	− 1.1	− 1.7	+ 2.2	+ 0.3	− 1.1	+ 0.2	+ 0.5	− 0.8
95	+ 1.4	− 0.9	− 0.9	+ 2.1	− 0.6	− 1.2	+ 0.5	+ 1.2	− 1.8
100	+ 1.1	− 0.8	− 1.2	+ 2.1	+ 0.1	− 1.4	+ 0.3	+ 0.9	− 1.3
105	+ 0.2	− 0.6	− 0.4	+ 2.1	+ 0.2	− 1.5	− 0.4	+ 1.7	− 1.3
110	+ 0.8	− 0.4	− 1.6	+ 2.0	+ 0.8	− 1.6	+ 0.4	+ 0.4	− 0.8
115	+ 0.8	− 0.2	− 1.9	+ 1.9	+ 1.1	− 1.7	+ 0.6	0.0	− 0.6

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

THIRD SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	+ 1.1	+ 1.7	+ 2.0	+ 2.3	+ 2.6	− 2.6	+ 3.4	+ 2.8	+ 2.7	+ 2.2
	+ 3.4	+ 3.1	+ 3.2	+ 2.8	+ 2.3	+ 2.3	+ 1.9	+ 1.1	+ 1.1	+ 0.3
		+ 3.6	+ 3.6	+ 3.1	+ 2.9	+ 2.3	+ 1.4	+ 1.7	+ 1.0	+ 0.9
		+ 0.9	+ 0.7	+ 0.1	0.0	+ 0.3	+ 0.2	0.0	+ 0.8	+ 1.6
Sums	+ 4.5	+ 9.3	+ 9.5	+ 8.3	+ 7.8	+ 7.5	+ 6.9	+ 5.6	+ 5.6	+ 5.0
Logs	0.653	0.968	0.978	0.919	0.892	0.875	0.839	0.748	0.748	0.699
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 4.50	+ 9.25	+ 9.35	+ 8.02	+ 7.33	+ 6.79	+ 5.98	+ 4.58	+ 4.28	+ 3.53

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	+ 1.2	+ 2.3	+ 2.1	+ 1.6	+ 1.4	+ 1.8	+ 1.9	+ 1.9	+ 1.8
		− 1.3	− 1.0	− 0.8	− 0.7	− 0.6	− 0.8	− 0.3	− 0.3
	+ 1.6	+ 1.4	+ 1.4	+ 2.0	+ 2.3	+ 2.0	+ 1.9	+ 1.4	+ 1.3
		− 0.6	− 0.3	+ 0.6	+ 1.4	+ 1.2	+ 1.6	+ 1.8	+ 2.1
Sums	+ 2.8	+ 1.8	+ 2.2	+ 3.4	+ 4.4	+ 4.4	+ 4.6	− 4.8	+ 4.9
Logs	0.447	0.255	0.342	0.531	0.643	0.643	0.663	0.681	0.690
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	+ 0.16	+ 0.38	+ 0.88	+ 1.50	+ 1.86	+ 2.30	+ 2.75	+ 3.15

$[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120^\circ)] + [(\gamma_r)\cos(r+240^\circ)] = +76.59$

THIRD SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	+ 1.1	+ 1.7	+ 2.0	+ 2.3	+ 2.6	+ 2.6	+ 3.4	+ 2.8	+ 2.7	+ 2.2
	− 3.4	− 3.1	− 3.2	− 2.8	− 2.3	− 2.3	− 1.9	− 1.1	− 1.1	− 0.3
		+ 3.6	+ 3.6	+ 3.1	+ 2.9	+ 2.3	+ 1.4	+ 1.7	+ 1.0	+ 0.9
		− 0.9	− 0.7	− 0.1	0.0	− 0.3	− 0.2	0.0	− 0.8	− 1.6
Sums	− 2.3	+ 1.3	+ 1.7	+ 2.5	+ 3.2	+ 2.3	+ 2.7	+ 3.4	+ 1.8	+ 1.2
Logs	0.362	0.114	0.230	0.398	0.505	0.362	0.431	0.531	0.255	0.079
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	+ 0.11	+ 0.30	+ 0.65	+ 1.09	+ 0.97	+ 1.35	+ 1.95	+ 1.16	+ 0.85

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	+ 1.2	+ 2.3	+ 2.1	+ 1.6	+ 1.4	+ 1.8	+ 1.9	+ 1.9	+ 1.8
		+ 1.3	+ 1.0	+ 0.8	+ 0.7	+ 0.6	+ 0.8	+ 0.8	+ 0.3
	+ 1.6	+ 1.4	+ 1.4	+ 2.0	+ 2.3	+ 2.0	+ 1.9	+ 1.4	+ 1.3
		+ 0.6	+ 0.3	− 0.6	− 1.4	− 1.2	− 1.6	− 1.8	− 2.1
Sums	+ 2.8	+ 5.6	+ 4.8	+ 3.8	+ 3.0	+ 3.2	+ 3.0	+ 2.3	+ 1.3
Logs	0.447	0.748	0.681	0.580	0.477	0.505	0.477	0.362	0.114
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Products	+ 2.80	+ 5.57	+ 4.72	+ 3.67	+ 2.82	+ 2.90	+ 2.60	+ 1.88	+ 1.00

$[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120^\circ)] + [(\gamma_r)\sin(r+240^\circ)] = +36.39$

$$\tan\rho = -\frac{[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120^\circ)] + [(\gamma_r)\cos(r+240^\circ)]}{[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120^\circ)] + [(\gamma_r)\sin(r+240^\circ)]} = -\frac{76.59}{36.39}$$

$$\therefore \rho = 115^\circ\ 25'$$

$$\epsilon = -\frac{[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120^\circ)] + [(\gamma_r)\cos(r+240^\circ)]}{\frac{3}{2}\, n \sin\rho} = -\frac{76.59}{36\sin 115^\circ\ 25'} = -2.36$$

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

THIRD SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		*r* + 120°		*r* + 240°				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	*r*	*r* + 120°	*r* + 240°
°	"	"	"	"	"	"	"	"	"
0	+ 1.1	− 2.1	+ 0.8	+ 0.2	− 1.9	+ 1.9	− 1.0	+ 1.0	0.0
5	+ 1.7	− 2.2	+ 0.3	+ 0.4	2.0	+ 1.8	− 0.5	+ 0.7	− 0.2
10	+ 2.0	− 2.3	+ 0.3	+ 0.6	− 2.3	+ 1.7	− 0.3	+ 0.9	− 0.6
15	+ 2.3	− 2.3	− 0.3	+ 0.8	− 2.0	+ 1.5	0.0	+ 0.5	− 0.5
20	+ 2.6	− 2.4	− 1.1	+ 1.0	− 1.4	+ 1.4	+ 0.2	− 0.1	0.0
25	+ 2.6	− 2.4	− 1.1	+ 1.2	− 1.4	+ 1.2	+ 0.2	+ 0.1	− 0.2
30	+ 3.4	− 2.4	− 1.9	+ 1.3	− 1.6	+ 1.1	+ 1.0	− 0.6	− 0.5
35	+ 2.8	− 2.3	− 2.3	+ 1.5	− 0.6	+ 0.8	+ 0.5	− 0.8	+ 0.2
40	+ 2.7	− 2.3	− 2.3	+ 1.6	− 0.3	+ 0.6	+ 0.4	− 0.7	+ 0.3
45	+ 2.2	− 2.2	− 2.8	+ 1.8	+ 0.6	+ 0.4	0.0	− 1.0	+ 1.0
50	+ 1.8	− 2.2	− 3.2	+ 1.9	+ 1.4	+ 0.2	− 0.4	− 1.3	+ 1.6
55	+ 1.9	− 2.1	− 3.1	+ 2.1	+ 1.2	0.0	− 0.2	− 1.0	+ 1.2
60	+ 1.9	− 2.0	− 3.4	+ 2.2	+ 1.6	− 0.2	− 0.1	− 1.2	+ 1.4
65	+ 1.8	− 1.8	− 3.6	+ 2.2	+ 1.8	− 0.4	0.0	− 1.4	+ 1.4
70	+ 1.4	− 1.7	− 3.6	+ 2.3	+ 2.1	− 0.6	− 0.3	− 1.3	+ 1.5
75	+ 1.6	− 1.6	− 3.1	+ 2.3	+ 1.6	− 0.8	0.0	− 0.8	+ 0.8
80	+ 2.1	− 1.4	− 2.9	+ 2.4	+ 0.8	− 1.0	+ 0.7	− 0.5	− 0.2
85	+ 2.3	− 1.2	− 2.3	+ 2.4	0.0	− 1.2	+ 1.1	+ 0.1	− 1.2
90	+ 1.2	− 1.0	− 1.4	+ 2.4	+ 0.2	− 1.3	+ 0.2	+ 1.0	− 1.1
95	+ 1.3	− 0.8	− 1.7	+ 2.3	+ 0.3	− 1.5	+ 0.5	+ 0.6	− 1.2
100	+ 1.0	− 0.7	− 1.0	+ 2.3	0.0	− 1.6	+ 0.3	+ 1.3	− 1.6
105	+ 0.8	− 0.4	− 0.9	+ 2.2	+ 0.1	− 1.8	+ 0.4	+ 1.3	− 1.7
110	+ 0.6	− 0.2	− 1.3	+ 2.2	+ 0.7	− 1.9	+ 0.4	+ 0.9	− 1.2
115	+ 0.6	0.0	− 1.4	+ 2.1	+ 0.9	− 2.1	+ 0.6	+ 0.7	− 1.2

Examination of limb of 20-inch theodolite C. S. No. 114—Continued.

RESIDUAL ERRORS OF GRADUATION AND READING.

r	RESIDUAL ERRORS.											
	FIRST SET.			SECOND SET.			THIRD SET.			MEAN.		
	0°	120°	240°	0°	120°	240°	0°	120°	240°	0°	120°	240°
0	− 1.3	+ 1.0	+ 0.4	− 1.2	+ 1.0	+ 0.2	− 1.0	+ 1.0	0.0	− 1.2	+ 1.0	+ 0.2
5	− 1.0	+ 0.8	+ 0.2	− 1.0	+ 0.9	+ 0.1	− 0.5	+ 0.7	− 0.2	− 0.8	− 0.8	0.0
10	+ 0.1	+ 0.6	− 0.7	− 0.6	+ 0.5	+ 0.1	− 0.3	+ 0.9	− 0.6	− 0.3	+ 0.7	− 0.5
15	− 0.3	+ 0.5	− 0.2	− 0.2	+ 0.5	− 0.3	0.0	+ 0.5	− 0.5	− 0.2	+ 0.5	− 0.3
20	0.0	+ 0.3	− 0.4	+ 0.3	+ 0.1	− 0.5	+ 0.2	− 0.1	0.0	+ 0.2	+ 0.1	0.3
25	− 0.5	+ 0.9	− 0.5	0.0	+ 1.0	− 1.0	+ 0.2	+ 0.1	− 0.2	− 0.1	+ 0.7	− 0.6
30	+ 0.7	− 0.7	0.0	+ 0.8	− 0.2	− 0.6	+ 1.0	− 0.6	− 0.5	+ 0.8	− 0.5	− 0.4
35	0.0	+ 0.2	− 0.2	+ 0.3	0.0	− 0.3	+ 0.5	− 0.8	+ 0.2	+ 0.3	− 0.2	− 0.1
40	+ 0.7	− 0.5	− 0.2	+ 0.6	− 0.9	+ 0.4	+ 0.4	− 0.7	+ 0.3	+ 0.6	− 0.7	+ 0.2
45	− 0.1	− 0.2	+ 0.4	+ 0.2	− 0.7	+ 0.5	0.0	− 1.0	+ 1.0	0.0	− 0.6	+ 0.6
50	− 0.5	− 0.9	+ 1.4	0.0	− 1.3	+ 1.4	− 0.4	− 1.3	+ 1.6	− 0.3	− 1.2	+ 1.5
55	− 0.6	− 0.9	+ 1.4	− 0.3	− 1.3	+ 1.7	− 0.2	− 1.0	+ 1.2	− 0.4	− 1.1	+ 1.4
60	− 0.1	− 1.1	+ 1.2	0.0	− 1.2	+ 1.2	− 0.1	− 1.2	+ 1.4	− 0.1	− 1.2	+ 1.2
65	+ 0.3	− 1.7	+ 1.4	+ 0.2	− 1.3	− 1.1	0.0	− 1.4	+ 1.4	+ 0.2	− 1.5	+ 1.3
70	+ 0.3	− 1.6	+ 1.3	0.0	− 1.7	+ 1.6	− 0.3	− 1.3	+ 1.5	0.0	− 1.5	+ 1.5
75	+ 0.3	1.3	+ 1.0	− 0.3	0.7	+ 1.0	0.0	0.8	+ 0.8	0.0	0.9	+ 0.9
80	+ 0.9	− 0.8	− 0.1	+ 0.7	0.8	+ 0.1	+ 0.7	− 0.5	− 0.2	+ 0.8	0.7	0.1
85	+ 0.4	− 0.5	+ 0.1	+ 0.2	− 0.1	− 0.1	+ 1.1	+ 0.1	− 1.2	− 0.6	0.2	0.4
90	+ 0.7	+ 0.3	− 1.0	+ 0.2	+ 0.5	− 0.8	+ 0.2	+ 1.0	− 1.1	+ 0.4	+ 0.6	− 1.0
95	+ 0.4	+ 0.9	− 1.3	+ 0.5	+ 1.2	− 1.8	+ 0.5	+ 0.6	− 1.2	+ 0.5	+ 0.9	− 1.4
100	+ 0.2	+ 1.0	− 1.2	+ 0.3	+ 0.9	− 1.3	+ 0.3	+ 1.3	− 1.6	+ 0.3	+ 1.1	− 1.4
105	− 0.2	+ 1.4	− 1.2	− 0.4	+ 1.7	− 1.3	+ 0.4	+ 1.3	− 1.7	− 0.1	+ 1.5	− 1.4
110	+ 0.2	+ 0.5	− 0.8	+ 0.4	+ 0.4	− 0.8	+ 0.4	+ 0.9	− 1.2	+ 0.3	+ 0.6	− 0.9
115	+ 0.8	+ 0.1	− 0.9	+ 0.6	0.0	− 0.6	+ 0.6	+ 0.7	− 1.2	+ 0.7	+ 0.3	− 0.9

Examination of limb of 20-inch theodolite C. S. No. 113.

FIRST SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	+ 0.6	+ 0.9	+ 0.3	− 0.8	− 0.7	− 0.8	− 1.9	+ 1.6	+ 0.2	0.0
	− 0.2	− 0.8	− 0.8	− 1.3	+ 0.8	− 0.9	− 1.4	− 0.2	0.0	− 1.6
		+ 2.7	− 0.1	+ 0.8	0.0	+ 2.0	+ 1.7	+ 2.3	− 0.1	+ 0.7
		+ 2.9	+ 0.7	+ 4.0	+ 1.8	+ 4.6	+ 3.0	+ 4.0	+ 2.3	+ 2.9
Sums	+ 0.4	+ 5.7	+ 0.1	+ 4.3	+ 1.9	+ 4.9	+ 1.4	+ 7.7	+ 2.4	+ 2.0
Logs		0.756	0.000	0.633	0.279	0.650	0.146	0.886	0.380	0.301
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 0.40	+ 5.68	+ 0.98	+ 4.15	+ 1.79	+ 4.05	+ 1.21	+ 6.30	+ 1.84	+ 1.41

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	− 1.3	− 2.0	− 2.3	− 2.1	− 1.9	− 1.0	− 2.1	− 0.9	− 1.9
	+ 0.5	+ 2.3	+ 1.9	+ 3.3	+ 1.0	+ 2.1	− 0.2	− 0.2	− 0.7
		− 0.6	− 0.7	+ 0.8	+ 1.0	+ 1.1	+ 0.8	+ 0.8	− 0.3
		− 2.5	− 0.6	− 1.3	+ 1.1	+ 0.1	+ 1.9	+ 3.7	+ 1.8
Sums	− 0.8	− 2.8	− 0.5	+ 0.7	+ 1.2	+ 2.3	− 0.6	+ 3.4	− 1.1
Logs		0.447	9.699	9.845	0.079	0.362	9.778	0.531	0.041
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.0	− 0.24	− 0.09	+ 0.18	+ 0.41	+ 9.73	− 0.30	+ 1.95	− 0.71

$[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120°)] + [(\gamma_r)\cos(r+240°)] = +34.44$

FIRST SET—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	+ 0.6	+ 0.9	+ 0.3	− 0.8	− 0.7	− 0.8	− 1.9	+ 1.6	+ 0.2	0.0
	+ 0.2	+ 0.8	+ 0.8	+ 1.3	− 0.8	+ 0.9	+ 1.4	+ 0.2	0.0	+ 1.6
		+ 2.7	− 0.1	+ 0.8	0.0	+ 2.0	+ 1.7	+ 2.3	− 0.1	+ 0.7
		− 2.9	− 0.7	− 4.0	− 1.8	− 4.6	− 3.0	− 4.0	− 2.3	− 2.9
Sums	+ 0.8	+ 1.5	+ 0.3	− 2.7	− 3.3	− 2.5	− 1.8	+ 0.1	− 2.2	− 0.6
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Logs		0.176	9.477	0.431	0.518	0.400	0.255	9.000	0.342	9.778
Products	0.00	+ 0.13	+ 0.05	− 0.70	− 1.13	− 1.06	− 0.90	+ 0.00	− 1.41	− 0.42

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	− 1.3	− 2.0	− 2.3	− 2.1	− 1.9	− 1.0	− 2.1	− 0.9	− 1.9
	0.5	− 2.3	− 1.9	− 3.3	− 1.0	− 2.1	+ 0.2	+ 0.2	+ 0.7
		− 0.6	− 0.7	+ 0.8	+ 1.0	+ 1.1	+ 0.8	+ 0.8	− 0.3
		+ 2.5	− 0.6	+ 1.3	− 1.1	− 0.1	− 1.9	− 3.7	− 1.8
Sums	− 1.8	− 2.4	− 5.5	− 3.3	− 3.0	− 2.1	− 3.0	− 3.6	− 3.3
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Logs		0.380	0.740	0.518	0.477	0.322	0.477	0.556	0.518
Products	− 1.80	− 2.40	− 5.41	− 3.19	− 2.82	− 1.90	− 2.60	− 2.95	− 2.52

$[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120°)] + [(\gamma_r)\sin(r+240°)] = -30.03$

$$\tan\rho = -\left(\frac{+34.44}{-30.03}\right)$$

$$\therefore\ \rho = +48°\ 59'$$

$$\epsilon = -\frac{34.44}{36\sin 49°} = -1''.45$$

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

FIRST SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		$r + 120°$		$r + 240°$				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	$r + 120°$	$r + 240°$
°	″	″	″	″	″	″	″	″	″
0	+ 0.6	− 1.1	+ 0.2	+ 1.3	− 0.8	− 0.3	− 0.5	+ 1.5	− 1.1
5	+ 0.9	− 1.0	+ 0.2	+ 1.4	− 1.1	− 0.4	− 0.1	+ 1.6	− 1.5
10	+ 0.3	− 0.9	+ 0.7	+ 1.4	− 1.0	− 0.5	− 0.6	+ 2.1	− 1.5
15	− 0.8	− 0.8	+ 1.6	+ 1.4	− 0.8	− 0.6	− 1.6	+ 3.0	− 1.4
20	− 0.7	− 0.7	0.0	+ 1.4	+ 0.7	− 0.7	− 1.4	+ 1.4	0.0
25	− 0.8	− 0.6	+ 0.2	+ 1.4	+ 0.6	− 0.9	− 1.4	+ 1.6	− 0.3
30	− 1.9	− 0.5	+ 1.4	+ 1.4	+ 0.5	− 0.9	− 2.4	+ 2.8	− 0.4
35	+ 1.6	− 0.3	+ 0.9	+ 1.3	− 2.5	− 1.0	+ 1.3	+ 2.2	− 3.5
40	+ 0.2	− 0.2	− 0.8	+ 1.3	+ 0.6	− 1.1	0.0	+ 0.5	− 0.5
45	0.0	− 0.1	+ 1.3	+ 1.2	− 1.3	− 1.2	− 0.1	+ 2.5	− 2.5
50	− 1.9	0.0	+ 0.8	+ 1.2	+ 1.1	− 1.2	− 1.9	+ 2.0	− 0.1
55	− 0.9	+ 0.1	+ 0.8	+ 1.1	+ 0.1	− 1.3	− 0.8	+ 1.9	− 1.2
60	− 2.1	+ 0.3	+ 0.2	+ 1.1	+ 1.9	− 1.3	− 1.8	+ 1.3	+ 0.6
65	− 1.0	+ 0.4	− 2.7	+ 1.0	+ 3.7	− 1.4	− 0.6	− 1.7	+ 2.3
70	− 1.9	+ 0.5	+ 0.1	+ 0.9	+ 1.8	− 1.4	1.4	+ 1.0	− 0.4
75	− 2.1	+ 0.6	− 0.8	+ 0.8	+ 2.9	− 1.4	− 1.5	0.0	+ 1.5
80	− 2.3	+ 0.7	0.0	+ 0.7	+ 2.3	− 1.4	− 1.6	+ 0.7	+ 0.9
85	− 2.0	+ 0.8	− 2.0	+ 0.6	+ 4.0	− 1.4	− 1.2	− 1.4	+ 2.6
90	− 1.3	+ 0.9	− 1.7	+ 0.5	+ 3.0	− 1.4	− 0.4	− 1.2	+ 1.6
95	− 2.3	+ 1.0	− 2.3	+ 0.4	+ 4.6	− 1.4	− 1.3	− 1.9	+ 3.2
100	− 1.9	+ 1.1	+ 0.1	+ 0.2	+ 1.8	− 1.3	− 0.8	+ 0.3	+ 0.5
105	− 3.3	+ 1.2	− 0.7	+ 0.1	+ 4.0	− 1.3	− 2.1	− 0.6	+ 2.7
110	− 1.0	+ 1.2	+ 0.3	0.0	+ 0.7	− 1.2	+ 0.2	+ 0.3	− 0.5
115	− 2.1	+ 1.3	− 0.8	− 0.1	+ 2.9	− 1.2	− 0.8	− 0.9	+ 1.7

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

SECOND SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	− 0.1	− 0.2	+ 0.1	− 1.2	− 0.1	− 0.1	− 0.8	+ 0.9	+ 0.4	− 0.1
	− 1.6	− 0.6	− 1.3	+ 0.5	+ 0.2	− 0.6	− 0.6	+ 1.1	+ 0.1	− 2.4
		+ 1.4	+ 0.6	+ 2.3	− 0.3	+ 1.6	+ 1.2	+ 2.1	+ 0.4	− 0.2
		+ 2.0	+ 1.8	+ 1.9	+ 3.2	+ 4.2	+ 3.4	+ 3.4	+ 1.0	+ 4.3
Sums	1.9	+ 2.6	+ 1.0	+ 3.5	+ 3.0	+ 5.1	+ 3.2	+ 7.5	+ 1.9	+ 1.6
Logs		0.415	0.000	0.544	0.477	0.708	0.505	0.875	0.279	0.204
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	− 1.90	+ 2.59	+ 0.98	+ 3.38	+ 2.81	+ 4.62	+ 2.77	+ 6.13	+ 1.45	+ 1.13
	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°	
	− 2.2	− 1.9	− 1.3	− 2.0	− 1.6	− 2.4	− 2.1	− 2.1	− 3.0	
	+ 0.2	+ 2.1	+ 2.8	+ 2.1	+ 1.9	+ 1.3	− 0.6	− 0.4	− 0.8	
		− 1.2	− 0.2	+ 1.2	+ 0.9	+ 0.2	+ 0.6	+ 0.7	− 0.1	
		− 1.4	− 0.2	+ 0.6	+ 1.7	+ 1.5	+ 0.5	+ 3.9	+ 2.1	
Sums	− 2.0	2.4	+ 1.1	+ 1.9	+ 2.9	+ 0.6	− 1.6	+ 2.1	− 1.8	
Logs		0.380	0.041	0.278	0.462	9.778	0.204	0.322	0.255	
Log cos		8.940	9.240	9.413	9.534	9.626	0.699	9.759	9.808	
Products	0.00	− 0.21	+ 0.19	+ 0.49	+ 0.99	+ 0.25	− 0.80	+ 1.21	− 1.16	

$[(\alpha_r) \cos r] + [(\beta_r) \cos (r + 120°)] + [(\gamma_r) \cos (r + 240°)] = + 24''.92$

SECOND SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	− 0.1	− 0.2	+ 0.1	− 1.2	− 0.1	− 0.1	− 0.8	+ 0.9	+ 0.4	− 0.1
	+ 1.6	+ 0.6	+ 1.3	− 0.5	− 0.2	+ 0.6	+ 0.6	− 1.1	− 0.1	+ 2.4
		+ 1.4	+ 0.6	+ 2.3	− 0.3	+ 1.6	+ 1.2	+ 2.1	+ 0.4	− 0.2
		− 2.0	− 1.8	− 1.9	− 3.2	− 4.2	− 3.4	− 3.4	− 1.0	− 4.3
Sums	+ 1.5	− 0.2	+ 0.2	− 1.3	− 3.8	− 2.1	− 2.4	− 1.5	− 0.3	− 2.2
Logs		9.301	9.301	0.113	0.580	0.322	0.380	0.176	9.477	0.342
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	− 0.02	+ 0.04	− 0.33	− 1.30	− 0.88	− 1.20	− 0.86	− 0.19	− 1.55
	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°	
	− 2.2	− 1.9	− 1.3	− 2.0	− 1.6	− 2.4	− 2.1	− 2.1	− 3.0	
	− 0.2	− 2.1	− 2.8	− 2.1	− 1.9	− 1.3	+ 0.6	+ 0.4	+ 0.8	
		− 1.2	− 0.2	+ 1.2	+ 0.9	+ 0.2	+ 0.6	+ 0.7	+ 0.1	
		+ 1.4	+ 0.2	− 0.6	− 1.7	− 1.5	− 0.5	− 3.9	− 2.1	
Sums	2.4	− 3.8	− 4.1	− 3.5	− 4.3	− 5.0	− 2.4	− 4.9	− 4.4	
Logs		0.580	0.613	0.544	0.633	0.700	0.380	0.690	0.643	
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	
Products	− 2.40	− 3.79	− 4.04	− 3.38	− 4.04	− 4.54	− 2.08	− 4.01	− 3.37	

$[(\alpha_r) \sin r] + [(\beta_r) \sin (r + 120°)] + [(\gamma_r) \sin (r + 240°)] = - 37''.98$

$$\tan \rho = - \left(\frac{+ 24''.92}{- 37.98}\right)$$

$$\therefore \rho = 33° \, 16'$$

$$\epsilon = - \left(\frac{24.92}{36 \sin 33° \, 16'}\right) = - 1''.26$$

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

SECOND SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		*r* + 120°		*r* + 240°				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	*r*	*r* + 120°	*r* + 240°
°	″	″	″	″	″	″	″	″	″
0	− 0.1	− 0.7	+ 0.6	+ 1.3	− 0.6	− 0.6	− 0.8	+ 1.9	− 1.2
5	− 0.2	− 0.6	+ 0.4	+ 1.3	− 0.2	− 0.7	− 0.8	+ 1.7	− 0.9
10	+ 0.1	− 0.5	+ 0.8	+ 1.2	− 0.9	− 0.7	− 0.4	+ 2.0	− 1.6
15	− 1.2	− 0.4	+ 2.4	+ 1.2	− 1.2	− 0.8	− 1.6	+ 3.6	− 2.0
20	− 0.1	− 0.3	− 0.1	+ 1.2	+ 0.2	− 0.9	− 0.4	+ 1.1	− 0.7
25	− 0.1	− 0.2	− 1.1	+ 1.2	+ 1.2	− 1.0	− 0.3	+ 0.1	+ 0.2
30	− 0.8	− 0.1	+ 0.6	+ 1.1	+ 0.2	− 1.1	− 0.9	+ 1.7	− 0.9
35	+ 0.9	0.0	+ 0.6	+ 1.1	− 1.4	− 1.1	+ 0.9	+ 1.7	− 2.5
40	+ 0.4	+ 0.1	− 0.2	+ 1.0	− 0.2	− 1.1	+ 0.5	+ 0.8	− 1.3
45	− 0.1	+ 0.2	− 0.5	+ 0.9	+ 0.6	− 1.2	+ 0.1	+ 0.4	− 0.6
50	− 3.0	+ 0.4	+ 1.3	+ 0.9	+ 1.7	− 1.2	− 2.6	+ 2.2	+ 0.5
55	− 2.1	+ 0.5	+ 0.6	+ 0.8	+ 1.5	− 1.3	− 1.6	+ 1.4	+ 0.2
60	− 2.1	+ 0.6	+ 1.6	+ 0.7	+ 0.5	− 1.3	− 1.5	+ 2.3	− 0.8
65	− 2.4	+ 0.7	− 1.4	+ 0.6	+ 3.9	− 1.3	− 1.7	− 0.8	+ 2.6
70	− 1.6	+ 0.7	− 0.6	+ 0.5	+ 2.1	− 1.2	− 0.9	− 0.1	+ 0.9
75	− 2.0	+ 0.8	− 2.3	+ 0.4	+ 4.3	− 1.2	− 1.2	− 1.9	+ 3.1
80	− 1.3	+ 0.9	+ 0.3	+ 0.3	+ 1.0	− 1.2	− 0.4	+ 0.6	− 0.2
85	− 1.9	+ 1.0	− 1.6	+ 0.2	+ 3.4	− 1.2	− 0.9	− 1.4	+ 2.2
90	− 2.2	+ 1.1	− 1.2	+ 0.1	+ 3.4	− 1.1	− 1.1	− 1.1	+ 2.3
95	− 2.1	+ 1.1	− 2.1	0.0	+ 4.2	− 1.0	− 1.0	− 2.1	+ 3.2
100	− 2.8	+ 1.2	− 0.4	− 0.1	+ 3.2	− 1.0	− 1.6	− 0.5	+ 2.2
105	− 2.1	+ 1.2	+ 0.2	− 0.2	+ 1.9	− 0.9	− 0.9	0.0	+ 1.[illegible]
110	− 1.[illegible]	+ 1.2	+ 0.1	− 0.4	+ 1.8	− 0.9	− 0.7	− 0.3	+ 0.9
115	− 1.3	+ 1.3	− 0.7	− 0.5	+ 2.0	− 0.8	0.0	− 1.2	+ 1.2

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

THIRD SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	+ 0.1	+ 0.1	+ 0.7	− 1.2	+ 0.3	− 1.4	− 1.3	+ 0.2	0.0	− 0.2
	− 0.4	− 1.7	0.0	− 0.4	− 0.3	− 1.2	− 2.3	+ 0.4	+ 0.3	− 1.1
		+ 2.0	+ 0.6	+ 2.1	+ 0.3	+ 1.2	+ 1.2	+ 1.7	+ 0.1	− 0.7
		+ 3.8	+ 1.2	+ 2.7	+ 2.6	+ 5.3	+ 3.4	+ 4.1	+ 0.6	+ 4.2
Sums	− 0.3	+ 4.2	+ 2.5	+ 3.2	+ 2.9	+ 3.9	+ 1.0	+ 6.4	+ 1.0	+ 2.2
Logs		0.623	0.400	0.505	0.462	0.591	0.000	0.806	0.000	0.342
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	− 0.30	+ 4.18	+ 2.47	+ 3.09	+ 2.72	+ 3.58	+ 0.87	+ 5.24	+ 0.77	+ 1.55

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	− 2.2	− 2.9	− 0.3	− 2.1	− 1.6	− 2.0	− 2.2	− 1.7	− 1.0
	− 1.0	+ 3.7	+ 2.4	+ 3.3	+ 0.8	+ 2.6	− 0.4	+ 0.2	− 0.7
		− 1.9	0.0	− 0.1	+ 1.3	− 0.1	+ 0.6	+ 1.2	+ 0.4
		− 1.4	− 0.3	− 0.2	+ 1.0	0.0	+ 1.8	+ 4.0	+ 2.1
Sums	− 3.2	− 2.5	+ 1.8	+ 0.9	+ 1.5	+ 0.5	− 0.2	+ 3.7	+ 0.8
Logs		0.400	0.255	9.954	0.176	9.700	9.301	0.568	9.903
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	− 0.22	+ 0.31	+ 0.23	+ 0.51	+ 0.21	− 0.10	+ 2.12	+ 0.51

$$[(\alpha_r)\cos r] + [(\beta_r)\cos(r+120^\circ)] + [(\gamma_r)\cos(r+240^\circ)] = +27''.69$$

THIRD SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	+ 0.1	+ 0.1	+ 0.7	− 1.2	+ 0.3	− 1.4	− 1.3	+ 0.2	0.0	− 0.2
	+ 0.4	+ 1.7	0.0	+ 0.4	+ 0.3	+ 1.2	+ 2.3	− 0.4	− 0.3	+ 1.1
		+ 2.0	+ 0.6	+ 2.1	+ 0.3	+ 1.2	+ 1.2	+ 1.7	+ 0.1	− 0.7
		− 3.8	− 1.2	− 2.7	− 2.6	− 5.3	− 3.4	− 4.1	− 0.6	− 4.2
Sums	+ 0.5	0.0	+ 0.1	− 1.4	− 1.7	− 4.3	− 1.2	− 2.6	− 0.8	− 4.0
Logs	9.700		9.000	0.146	0.230	0.633	0.079	0.415	9.903	0.602
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	0.00	+ 0.02	− 0.36	− 0.58	− 1.82	− 0.60	− 1.49	− 0.51	− 2.82

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	− 2.2	− 2.9	− 0.3	− 2.1	− 1.6	− 2.0	− 2.2	− 1.7	− 1.0
	+ 1.0	− 3.7	+ 2.4	− 3.3	− 0.8	− 2.6	+ 0.4	− 0.2	+ 0.7
		− 1.9	0.0	− 0.1	+ 1.3	− 0.1	+ 0.6	+ 1.2	+ 0.4
		+ 1.4	+ 0.3	+ 0.2	− 1.0	0.0	− 1.8	− 4.0	− 2.1
Sums	− 1.2	− 7.1	− 2.4	− 5.3	− 2.7	− 4.7	− 3.0	− 4.7	− 2.0
Logs	0.079	0.851	0.380	0.724	0.322	0.672	0.477	0.672	0.301
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Products	− 1.20	− 7.07	− 2.36	− 5.07	− 1.97	− 4.26	− 2.60	− 3.85	− 1.53

$$[(\alpha_r)\sin r] + [(\beta_r)\sin(r+120^\circ)] + [(\gamma_r)\sin(r+240^\circ)] = -38''.07$$

$$\tan\rho = -\left(\frac{27.99}{-38.07}\right)$$

$$\therefore\ \rho = 36^\circ\ 50'$$

$$\epsilon = -\frac{27.69}{36\sin 36.50} = -1''.31$$

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

THIRD SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		r + 120°		r + 240°				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	r + 120°	r + 240°
°	"	"	"	"	"	"	"	"	"
0	+ 0.1	− 0.8	+ 0.4	+ 1.3	− 0.6	− 0.5	− 0.7	+ 1.7	− 1.1
5	+ 0.1	− 0.7	− 0.2	+ 1.3	+ 0.1	− 0.6	− 0.6	+ 1.1	− 0.5
10	+ 0.7	0.6	+ 0.7	+ 1.3	− 1.3	− 0.7	+ 0.1	+ 2.0	− 2.0
15	− 1.2	− 0.5	+ 1.1	+ 1.3	+ 0.1	− 0.8	− 1.7	+ 2.4	− 0.7
20	+ 0.3	− 0.4	− 0.3	+ 1.3	0.0	− 0.9	− 0.1	+ 1.0	− 0.9
25	− 1.4	− 0.3	− 0.4	+ 1.3	+ 1.9	− 1.0	− 1.7	+ 0.9	+ 0.9
30	− 1.3	− 0.1	+ 2.3	+ 1.2	− 1.0	− 1.1	− 1.4	+ 3.5	− 2.1
35	+ 0.2	0.0	+ 1.2	+ 1.1	− 1.4	− 1.1	+ 0.2	+ 2.3	− 2.5
40	0.0	+ 0.1	+ 0.3	+ 1.1	− 0.3	− 1.2	+ 0.1	+ 1.4	− 1.5
45	− 0.2	+ 0.2	+ 0.4	+ 1.0	− 0.2	− 1.2	0.0	+ 1.4	− 1.4
50	− 1.0	+ 0.3	0.0	+ 1.0	+ 1.0	− 1.3	− 0.7	+ 1.0	− 0.3
55	− 1.7	+ 0.4	+ 1.7	+ 0.9	0.0	− 1.3	− 1.3	+ 2.6	− 1.3
60	− 2.2	+ 0.5	+ 0.4	+ 0.8	+ 1.8	− 1.3	− 1.7	+ 1.2	+ 0.5
65	− 2.0	+ 0.6	− 2.0	+ 0.7	+ 4.0	− 1.3	− 1.4	− 1.3	+ 2.7
70	− 1.6	+ 0.7	− 0.6	+ 0.6	+ 2.1	− 1.3	− 0.9	0.0	+ 0.8
75	− 2.1	+ 0.8	− 2.1	+ 0.5	+ 4.2	− 1.3	− 1.3	− 1.6	+ 2.9
80	− 0.3	+ 0.9	− 0.3	+ 0.4	+ 0.6	− 1.3	+ 0.6	+ 0.1	− 0.7
85	− 2.9	+ 1.0	− 1.2	+ 0.3	+ 4.1	− 1.2	− 1.9	− 0.9	+ 2.9
90	− 2.2	+ 1.1	− 1.2	+ 0.2	+ 3.4	− 1.2	− 1.1	− 1.0	+ 2.2
95	− 3.7	+ 1.2	− 1.7	+ 0.1	+ 5.3	− 1.2	− 2.5	− 1.6	+ 4.1
100	− 2.4	+ 1.2	− 0.1	− 0.1	+ 2.6	− 1.1	− 1.2	− 0.2	+ 1.5
105	− 3.3	+ 1.2	+ 0.7	− 0.2	+ 2.7	− 1.1	− 2.1	+ 0.5	+ 1.6
110	− 0.8	+ 1.3	− 0.4	− 0.3	+ 1.2	− 1.0	+ 0.5	− 0.7	+ 0.2
115	− 2.6	+ 1.3	− 1.2	− 0.4	+ 3.8	− 0.9	− 1.3	− 1.6	+ 2.9

Examination of limb of 20-inch theodolite C. S. No. 113—Continued.

RESIDUAL ERRORS OF GRADUATION AND READING.

r	RESIDUAL ERRORS.											
	FIRST SET.			SECOND SET.			THIRD SET.			MEAN		
	0°	120°	240°	0°	120°	240°	0°	120°	240°	0°	120°	240°
°	"	"	"	"	"	"	"	"	"	"	"	"
0	− 0.5	+ 1.5	− 1.1	− 0.8	+ 1.9	− 1.2	− 0.7	+ 1.7	− 1.1	− 0.7	+ 1.7	− 1.1
5	− 0.1	+ 1.6	− 1.5	− 0.8	+ 1.7	− 0.9	− 0.6	+ 1.1	− 0.5	− 0.5	+ 1.5	− 1.0
10	− 0.6	+ 2.1	− 1.5	− 0.4	+ 2.0	− 1.6	+ 0.1	+ 2.0	− 2.0	− 0.3	+ 2.0	− 1.7
15	− 1.6	+ 3.0	− 1.4	− 1.6	+ 3.6	− 2.0	− 1.7	+ 2.4	− 0.7	− 1.6	+ 3.0	− 1.4
20	− 1.4	+ 1.4	0.0	− 0.4	+ 1.1	− 0.7	− 0.1	+ 1.0	− 0.9	− 0.6	+ 1.2	− 0.5
25	− 1.4	+ 1.6	− 0.3	− 0.3	+ 0.1	+ 0.2	− 1.7	+ 0.9	+ 0.9	− 1.1	+ 0.9	+ 0.3
30	− 2.4	+ 2.8	− 0.4	− 0.9	+ 1.7	− 0.9	− 1.4	+ 3.5	− 2.1	− 1.6	+ 2.7	− 1.1
35	+ 1.3	+ 2.2	− 3.5	+ 0.9	+ 1.7	− 2.5	+ 0.2	+ 2.3	− 2.5	+ 0.8	+ 2.1	− 2.8
40	0.0	+ 0.5	− 0.5	+ 0.5	+ 0.8	− 1.3	+ 0.1	+ 1.4	− 1.5	+ 0.2	+ 0.9	− 1.1
45	− 0.1	+ 2.5	− 2.5	+ 0.1	+ 0.4	− 0.6	0.0	+ 1.4	− 1.4	0.0	+ 1.4	− 1.5
50	− 1.9	+ 2.0	− 0.1	− 2.6	+ 2.2	+ 0.5	− 0.7	+ 1.0	− 0.3	− 1.7	+ 1.7	0.0
55	− 0.8	+ 1.9	− 1.2	− 1.6	+ 1.4	+ 0.2	− 1.3	+ 2.6	− 1.3	− 1.2	+ 2.0	− 0.8
60	− 1.8	+ 1.3	+ 0.6	− 1.5	+ 2.3	− 0.8	− 1.7	+ 1.2	+ 0.5	− 1.7	+ 1.6	+ 0.1
65	− 0.6	− 1.7	+ 2.3	− 1.7	− 0.8	+ 2.6	− 1.4	− 1.3	+ 2.7	− 1.2	− 1.2	+ 2.5
70	− 1.4	+ 1.0	+ 0.4	− 0.9	− 0.1	+ 0.9	− 0.9	0.0	+ 0.8	− 1.1	+ 0.3	+ 0.7
75	− 1.5	0.0	+ 1.5	− 1.2	− 1.9	+ 3.1	− 1.3	− 1.6	+ 2.9	− 1.3	− 1.2	+ 2.5
80	− 1.6	+ 0.7	+ 0.9	− 0.4	+ 0.6	− 0.2	+ 0.6	+ 0.1	− 0.7	− 0.5	+ 0.5	0.0
85	− 1.2	− 1.4	+ 2.6	− 0.9	− 1.4	+ 2.2	− 1.9	− 0.9	+ 2.9	− 1.3	− 1.2	− 2.6
90	− 0.4	− 1.2	+ 1.6	− 1.1	− 1.1	+ 2.3	− 1.1	− 1.0	+ 2.2	− 0.9	− 1.1	+ 2.0
95	− 1.3	− 1.9	+ 3.2	− 1.0	− 2.1	+ 3.2	− 2.5	− 1.6	+ 4.1	− 1.7	− 1.9	+ 3.5
100	− 0.8	+ 0.3	+ 0.5	− 1.6	− 0.5	+ 2.2	− 1.2	− 0.2	+ 1.5	− 1.2	0.0	+ 1.4
105	− 2.1	− 0.6	+ 2.7	− 0.9	0.0	+ 1.0	− 2.1	+ 0.5	+ 1.6	− 1.7	0.0	+ 1.8
110	+ 0.2	+ 0.3	− 0.5	− 0.7	− 0.3	+ 0.9	+ 0.5	− 0.7	+ 0.2	0.0	− 0.2	+ 0.3
115	− 0.8	− 0.9	+ 1.7	0.0	− 1.2	+ 1.2	− 1.3	− 1.6	+ 2.9	− 0.7	− 1.2	+ 1.9

Examination of limb of 20-inch theodolite C. S. No. 115.

FIRST SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	− 1.2	− 1.3	− 0.7	− 1.3	− 1.2	0.0	− 0.9	− 1.6	− 0.9	− 0.7
		+ 2.1	− 1.4	+ 0.3	− 0.4	0.4	+ 0.2	+ 0.7	− 0.8	+ 0.3
	+ 0.7	+ 2.3	1.0	+ 1.2	+ 1.3	+ 1.8	0.9	+ 1.6	1.4	+ 1.6
		− 0.6	+ 0.6	+ 0.4	+ 0.2	+ 0.1	+ 0.8	1.2	1.3	+ 1.4
Sums	0.5	+ 2.5	− 0.5	+ 0.6	0.1	+ 1.5	+ 1.0	+ 1.9	1.0	− 2.6
Logs	9.699	0.398	9.699	9.778	9.000	0.176	0.000	0.279	0.000	0.415
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	− 0.50	+ 2.49	− 0.49	+ 0.58	0.09	+ 1.36	+ 0.87	+ 1.56	+ 0.77	1.84

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	+ 0.1	+ 0.6	0.0	− 0.2	+ 0.3	+ 0.4	− 0.7	+ 0.2	− 0.9
		− 1.4	− 1.2	− 1.1	− 1.6	− 0.1	0.4	− 0.3	− 0.3
	− 1.1	− 0.7	− 0.4	− 1.7	− 0.3	− 1.0	− 0.8	− 0.4	− 2.1
		+ 1.1	+ 0.4	+ 1.0	− 0.6	+ 1.9	+ 1.3	+ 1.8	+ 0.7
Sums	− 1.0	− 0.4	− 1.2	− 2.0	− 2.2	+ 1.2	− 0.6	+ 1.3	+ 1.6
Logs	0.000	9.602	0.079	0.301	0.342	0.079	9.778	0.114	0.204
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	− 0.03	− 0.21	− 0.52	− 0.75	+ 0.51	0.30	+ 0.75	+ 1.03

$[\alpha \cos r] + [\beta \cos (r + 120°)] + [\gamma \cos (r + 240°)] = + 8.87$

FIRST SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	− 1.2	− 1.3	− 0.7	− 1.3	− 1.2	0.0	− 0.9	− 1.6	− 0.9	− 0.7
		− 2.1	+ 1.4	− 0.3	+ 0.4	+ 0.4	− 0.2	− 0.7	+ 0.8	− 0.3
	+ 0.7	+ 2.3	+ 1.0	+ 1.2	+ 1.3	+ 1.8	+ 0.9	+ 1.6	+ 1.4	+ 1.6
		+ 0.6	− 0.6	− 0.4	− 0.2	− 0.1	− 0.8	− 1.2	− 1.3	− 1.4
Sums	− 0.5	− 0.5	+ 1.1	− 0.8	+ 0.3	+ 2.1	1.0	− 1.9	0.0	− 0.8
Logs	9.699	9.699	0.041	9.903	9.477	0.322	0.000	0.279		9.903
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	− 0.04	+ 0.19	− 0.21	+ 0.10	+ 0.89	− 0.50	− 1.09	0.00	− 0.56

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	+ 0.1	+ 0.6	0.0	− 0.2	+ 0.3	+ 0.4	− 0.7	+ 0.2	− 0.9
		+ 1.4	+ 1.2	+ 1.1	+ 1.6	+ 0.1	+ 0.4	+ 0.3	+ 0.3
	− 1.1	− 0.7	− 0.4	− 1.7	− 0.3	− 1.0	− 0.8	− 0.4	+ 2.1
		− 1.1	− 0.4	− 1.0	+ 0.6	− 1.9	− 1.3	− 1.8	− 0.7
Sums	− 1.0	+ 0.2	+ 0.4	− 1.8	+ 2.2	− 2.4	− 2.4	− 1.7	+ 0.8
Logs	0.000	9.301	9.602	0.255	0.342	0.380	0.380	0.230	9.903
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884
Products	− 1.00	+ 0.20	+ 0.39	− 1.74	+ 2.06	− 2.17	− 2.08	− 1.39	+ 0.61

$[\alpha \sin r] + [\beta \sin (r + 120°)] + [\gamma \sin (r + 240°)] = - 6.34$

$$\tan \rho = \frac{-8.87}{-6.34}$$

$$\rho = 48° \ 01'$$

$$\epsilon = - \frac{8.87}{36 \sin 48° \ 01'} = - 0''.33$$

Examination of limb of 20-inch theodolite C. S. No. 115—Continued.

FIRST SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		r + 120°		r + 240°				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	r + 120°	r + 240°
°	"	"	"	"	"	"	"	"	"
0	− 1.2	− 0.2	+ 0.4	+ 0.3	+ 0.8	− 0.1	− 1.4	+ 0.7	+ 0.7
5	− 1.3	− 0.2	+ 0.3	+ 0.3	+ 1.0	0.1	− 1.5	+ 0.6	+ 0.9
10	− 0.7	− 0.2	+ 0.3	+ 0.3	+ 0.3	− 0.1	− 0.9	+ 0.6	+ 0.2
15	− 1.3	− 0.2	− 0.3	+ 0.3	− 1.7	− 0.2	− 1.5	0.0	+ 1.5
20	− 1.2	− 0.2	+ 0.8	+ 0.3	− 0.4	− 0.2	− 1.4	+ 1.1	+ 0.2
25	0.0	− 0.1	− 0.7	+ 0.3	+ 0.7	− 0.2	− 0.1	− 0.4	+ 0.5
30	− 0.9	− 0.1	− 0.2	+ 0.3	+ 1.1	− 0.2	− 1.0	+ 0.1	+ 0.9
35	− 1.6	− 0.1	+ 0.4	+ 0.3	+ 1.1	− 0.2	− 1.7	+ 0.7	+ 0.9
40	− 0.9	0.0	+ 0.4	+ 0.3	− 0.4	− 0.3	− 0.9	+ 0.7	+ 0.1
45	− 0.7	0.0	− 0.3	+ 0.3	+ 1.0	− 0.3	− 0.7	0.0	+ 0.7
50	− 0.9	0.0	+ 1.4	+ 0.3	− 0.6	− 0.3	− 0.9	+ 1.7	− 0.9
55	+ 0.2	0.0	− 2.1	+ 0.3	+ 1.9	− 0.3	+ 0.2	− 1.8	+ 1.6
60	− 0.7	+ 0.1	− 0.7	+ 0.2	+ 1.3	− 0.3	− 0.6	− 0.5	+ 1.1
65	+ 0.4	+ 0.1	− 2.3	+ 0.2	+ 1.8	− 0.3	+ 0.5	− 2.1	+ 1.6
70	+ 0.3	+ 0.1	− 1.0	+ 0.2	− 0.7	− 0.3	+ 0.4	− 0.8	+ 0.4
75	− 0.2	+ 0.1	− 1.2	+ 0.2	+ 1.4	− 0.3	− 0.1	− 1.0	+ 1.1
80	0.0	+ 0.2	− 1.3	+ 0.2	+ 1.3	− 0.3	+ 0.2	− 1.1	+ 1.0
85	+ 0.6	+ 0.2	− 1.8	+ 0.1	+ 1.2	− 0.3	+ 0.8	− 1.7	+ 0.9
90	+ 0.1	+ 0.2	− 0.9	+ 0.1	+ 0.8	− 0.3	+ 0.3	− 0.8	+ 0.5
95	+ 1.4	+ 0.2	− 1.6	+ 0.1	− 0.1	− 0.3	+ 1.6	− 1.5	− 0.2
100	+ 1.2	+ 0.3	− 1.4	+ 0.1	+ 0.2	− 0.3	+ 1.5	− 1.3	− 0.1
105	+ 1.1	+ 0.3	− 1.6	+ 0.1	+ 0.4	− 0.3	+ 1.4	− 1.5	+ 0.1
110	+ 1.6	+ 0.3	− 2.1	0.0	+ 0.6	− 0.3	+ 1.9	− 2.1	+ 0.3
115	+ 0.1	+ 0.3	+ 0.4	0.0	− 0.6	− 0.3	+ 0.4	+ 0.4	− 0.9

Examination of limb of 20-inch theodolite C. S. No. 115—Continued.

SECOND SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	− 0.8	− 0.8	− 0.3	− 1.4	− 1.0	− 0.4	− 0.6	− 1.4	− 0.8	− 0.7
		− 2.0	− 1.2	0.0	− 0.2	− 0.2	+ 0.6	+ 0.8	− 0.7	+ 0.1
	+ 1.6	+ 2.1	+ 0.4	+ 1.6	+ 2.0	+ 2.0	+ 1.3	+ 1.8	+ 1.8	+ 1.8
		− 1.2	+ 0.4	+ 0.6	+ 0.2	+ 0.2	+ 1.3	+ 1.3	+ 2.0	+ 1.8
Sums	+ 0.8	+ 2.1	− 0.7	+ 0.8	+ 1.0	+ 1.6	+ 2.6	+ 2.5	+ 2.3	+ 3.0
Logs	9.903	0.322	9.845	9.903	0.000	0.204	0.415	0.398	0.362	0.477
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 0.80	− 2.09	− 0.69	+ 0.77	− 0.94	+ 1.45	+ 2.25	+ 2.05	+ 1.76	+ 2.12
	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°	
	0.0	+ 0.7	0.0	− 0.2	− 0.1	+ 0.6	− 0.6	+ 0.3	− 0.8	
		− 1.6	− 1.6	− 1.2	− 1.4	− 0.8	− 0.6	− 0.1	0.0	
	− 1.1	− 1.2	− 0.3	− 1.6	− 0.3	− 0.9	− 0.2	− 0.4	+ 1.9	
		+ 1.2	+ 0.6	− 0.7	− 0.4	+ 1.7	+ 2.1	+ 1.6	+ 0.6	
Sums	− 1.1	− 0.9	− 1.3	− 3.5	− 2.2	+ 0.6	+ 0.7	− 1.6	+ 1.7	
Logs	0.041	9.954	0.114	0.544	0.342	9.779	9.845	0.204	0.230	
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	
Products	0.00	− 0.08	− 0.23	− 0.91	− 0.75	+ 0.25	+ 0.35	+ 0.92	+ 1.09	

$$[\alpha \cos r] + [\beta \cos (r + 120^\circ)] + [\gamma \cos (r + 240^\circ)] = + 14.18$$

SECOND SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	− 0.8	− 0.8	− 0.3	− 1.4	− 1.0	− 0.4	− 0.6	− 1.4	− 0.8	− 0.7
		− 2.0	+ 1.2	0.0	+ 0.2	+ 0.2	− 0.6	− 0.8	+ 0.7	− 0.1
	+ 1.6	+ 2.1	+ 0.4	+ 1.6	+ 2.0	+ 2.0	+ 1.3	− 1.8	+ 1.8	+ 1.8
		+ 1.2	− 0.4	− 0.6	− 0.2	− 0.2	− 1.3	− 1.3	− 2.0	− 1.8
Sums	+ 0.8	+ 0.5	+ 0.9	− 0.4	+ 1.0	+ 1.6	− 1.2	− 1.7	0.3	− 0.8
Logs	9.903	9.699	9.954	9.602	0.000	0.204	0.079	0.230	9.477	9.903
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	+ 0.04	+ 0.16	− 0.10	+ 0.34	+ 0.68	− 0.60	− 0.97	− 0.19	− 0.56
	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°	
	0.0	+ 0.7	0.0	− 0.2	− 0.1	+ 0.6	− 0.6	+ 0.3	− 0.8	
		+ 1.6	+ 1.6	+ 1.2	+ 1.4	+ 0.8	+ 0.6	− 0.1	0.0	
	− 1.1	− 1.2	− 0.3	− 1.6	− 0.3	− 0.9	− 0.2	− 0.4	+ 1.9	
		− 1.2	− 0.6	+ 0.7	+ 0.4	− 1.7	− 2.1	− 1.6	− 0.6	
Sums	− 1.1	− 0.1	+ 0.7	+ 0.1	+ 1.4	− 1.2	− 2.3	− 1.8	+ 0.5	
Logs	0.041	9.000	9.845	9.000	0.146	0.079	0.362	0.255	9.699	
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	
Products	− 1.10	− 0.10	+ 0.69	+ 0.10	+ 1.31	− 1.09	− 2.00	− 1.47	+ 0.38	

$$[\alpha \sin r] + [\beta \sin (r + 120^\circ)] + [\gamma \sin (r + 240^\circ)] = - 4.48$$

$$\tan \rho = \frac{-14.18}{-4.48}$$

$$\rho = 72^\circ\ 28'$$

$$\epsilon'' = -\frac{14.18}{36 \sin 72^\circ\ 28'} = -0''.41$$

Examination of limb of 20-inch theodolite C. S. No 115—Continued.

SECOND SET.—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		r + 120°		r + 240°				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	r + 120°	r + 240°
°	"	"	"	"	"	"	"	"	"
0	− 0.8	− 0.4	+ 0.6	+ 0.3	+ 0.2	+ 0.1	− 1.2	+ 0.9	+ 0.3
5	− 0.8	− 0.4	− 0.1	+ 0.3	+ 0.9	+ 0.1	− 1.2	+ 0.2	+ 1.0
10	− 0.3	− 0.4	0.0	+ 0.3	+ 0.3	0.0	− 0.7	+ 0.3	+ 0.3
15	− 1.4	− 0.4	− 0.1	+ 0.4	+ 1.6	0.0	− 1.8	+ 0.3	+ 1.6
20	− 1.0	− 0.3	+ 0.7	+ 0.4	+ 0.3	− 0.1	− 1.3	+ 1.1	+ 0.2
25	− 0.4	− 0.3	− 0.8	+ 0.4	+ 1.2	− 0.1	− 0.7	− 0.4	+ 1.1
30	− 0.6	− 0.3	− 0.6	+ 0.4	+ 1.1	− 0.1	− 0.9	− 0.2	+ 1.0
35	− 1.4	− 0.2	+ 0.2	+ 0.4	+ 1.2	− 0.2	− 1.6	+ 0.6	+ 1.0
40	− 0.8	− 0.2	+ 0.2	+ 0.4	+ 0.6	0.2	1.0	+ 0.6	+ 0.4
45	0.7	− 0.2	0.0	+ 0.4	+ 0.7	− 0.2	− 0.9	+ 0.4	+ 0.5
50	− 0.8	− 0.2	+ 1.2	+ 0.4	− 0.4	− 0.3	− 1.0	+ 1.6	− 0.7
55	+ 0.3	− 0.1	− 2.0	+ 0.4	+ 1.7	0.3	+ 0.2	− 1.6	+ 1.4
60	− 0.6	− 0.1	− 1.6	+ 0.4	+ 2.1	− 0.3	− 0.7	− 1.2	+ 1.8
65	+ 0.6	− 0.1	− 2.1	+ 0.4	+ 1.6	− 0.3	+ 0.5	− 1.7	+ 1.3
70	− 0.1	0.0	− 0.4	+ 0.4	+ 0.6	− 0.4	− 0.1	0.0	+ 0.2
75	− 0.2	0.0	− 1.6	+ 0.3	+ 1.8	− 0.4	− 0.2	− 1.3	+ 1.4
80	0.0	+ 0.1	2.0	+ 0.3	+ 2.0	− 0.4	+ 0.1	− 1.7	+ 1.6
85	+ 0.7	+ 0.1	− 2.0	+ 0.3	+ 1.3	− 0.4	+ 0.8	− 1.7	+ 0.9
90	0.0	+ 0.1	− 1.3	+ 0.3	+ 1.3	− 0.4	+ 0.1	− 1.0	+ 0.9
95	+ 1.6	+ 0.2	− 1.8	+ 0.3	+ 0.2	− 0.4	+ 1.8	− 1.5	− 0.2
100	+ 1.6	+ 0.2	− 1.8	+ 0.2	+ 0.2	− 0.4	+ 1.8	− 1.6	− 0.2
105	+ 1.2	+ 0.2	− 1.8	+ 0.2	+ 0.6	− 0.4	+ 1.4	− 1.6	+ 0.2
110	+ 1.4	+ 0.2	− 1.9	+ 0.2	+ 0.4	− 0.4	+ 1.6	− 1.7	0.0
115	+ 0.8	+ 0.3	+ 0.4	+ 0.1	− 1.2	− 0.4	+ 1.1	+ 0.5	− 1.6

Examination of limb of 20-inch theodolite C. S. No. 115—Continued.

THIRD SET.—TABLE I.

	Cos 0°	Cos 5°	Cos 10°	Cos 15°	Cos 20°	Cos 25°	Cos 30°	Cos 35°	Cos 40°	Cos 45°
	— 0.7	— 0.7	— 0.7	— 1.3	— 1.2	— 0.2	— 0.6	— 0.9	— 0.9	— 0.6
		+ 1.4	— 0.7	+ 0.2	+ 0.2	+ 0.2	+ 0.6	+ 0.9	— 0.4	0.0
	+ 1.4	+ 1.3	+ 1.4	+ 1.2	+ 1.4	+ 1.3	+ 1.6	+ 1.3	+ 1.4	+ 2.0
		— 1.1	+ 0.6	+ 0.3	— 0.1	0.0	+ 1.4	+ 1.3	+ 1.6	+ 1.8
Sums	+ 0.7	+ 0.9	+ 0.6	+ 0.4	+ 0.3	+ 1.3	+ 3.0	+ 2.6	+ 1.7	+ 3.2
Logs	9.845	9.954	9.779	9.602	9.477	0.114	0.477	0.415	0.230	0.505
Log cos		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.884	9.849
Products	+ 0.70	+ 0.90	+ 0.59	+ 0.39	+ 0.28	+ 1.18	+ 2.60	+ 2.13	+ 1.30	+ 2.26

	Cos 90°	Cos 85°	Cos 80°	Cos 75°	Cos 70°	Cos 65°	Cos 60°	Cos 55°	Cos 50°
	+ 0.1	0.0	— 0.1	— 0.6	+ 0.6	0.0	— 0.8	— 0.1	— 0.7
		— 1.3	— 1.6	— 1.7	— 1.6	— 0.6	— 0.3	— 0.3	— 0.3
	- 1.1	— 1.1	— 0.8	— 1.3	— 0.3	— 0.3	— 0.3	— 0.6	+ 2.1
		+ 1.1	+ 1.1	+ 0.8	0.0	+ 1.6	+ 2.2	+ 1.3	+ 0.9
Sums	— 1.0	— 1.3	— 1.4	— 2.8	— 1.3	+ 0.7	+ 0.8	+ 0.3	+ 2.0
Logs	0.000	0.114	0.146	0.447	0.114	9.845	9.903	9.477	0.301
Log cos		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808
Products	0.00	— 0.11	— 0.24	— 0.72	— 0.45	+ 0.30	+ 0.40	+ 0.17	+ 1.28

$[\alpha \cos r] + [\beta \cos (r + 120°)] + [\gamma \cos (r + 240°)] = + 12''.96$

THIRD SET.—TABLE II.

	Sin 0°	Sin 5°	Sin 10°	Sin 15°	Sin 20°	Sin 25°	Sin 30°	Sin 35°	Sin 40°	Sin 45°
	— 0.7	— 0.7	— 0.7	— 1.3	— 1.2	— 0.2	— 0.6	— 0.9	— 0.9	— 0.6
		— 1.4	+ 0.7	— 0.2	— 0.2	— 0.2	— 0.6	— 0.9	+ 0.4	0.0
	+ 1.4	+ 1.3	+ 1.4	+ 1.2	+ 1.4	+ 1.3	+ 1.6	+ 1.3	+ 1.4	+ 2.0
		+ 1.1	— 0.6	— 0.3	+ 0.1	0.0	— 1.4	— 1.3	— 1.6	— 1.8
Sums	+ 0.7	+ 0.3	+ 0.8	— 0.6	+ 0.1	+ 0.9	— 1.0	— 1.8	— 0.7	— 0.4
Logs	9.846	9.477	9.903	9.779	9.000	9.954	0.000	0.255	9.845	9.602
Log sin		8.940	9.240	9.413	9.534	9.626	9.699	9.759	9.808	9.849
Products	0.00	+ 0.03	+ 0.14	— 0.16	+ 0.03	+ 0.38	— 0.50	— 1.03	— 0.45	— 0.28

	Sin 90°	Sin 85°	Sin 80°	Sin 75°	Sin 70°	Sin 65°	Sin 60°	Sin 55°	Sin 50°
	+ 0.1	0.0	— 0.1	— 0.6	+ 0.6	0.0	— 0.8	— 0.1	— 0.7
		+ 1.3	+ 1.6	+ 1.7	+ 1.6	+ 0.6	+ 0.3	+ 0.3	+ 0.3
	— 1.1	— 1.1	— 0.8	— 1.3	— 0.3	— 0.3	— 0.3	— 0.6	+ 2.1
		— 1.1	— 1.1	— 0.8	0.0	— 1.6	— 2.2	— 1.3	— 0.9
Sums	— 1.0	— 0.9	— 0.4	— 1.0	+ 1.9	— 1.3	— 3.0	— 1.7	+ 0.8
Logs	0.000	9.954	9.602	0.000	0.279	0.114	0.477	0.230	9.903
Log sin		9.998	9.993	9.985	9.973	9.957	9.938	9.913	9.984
Products	— 1.00	— 0.90	— 0.39	— 0.97	+ 1.79	— 1.18	— 2.60	— 1.39	+ 0.61

$[\alpha \sin r] + [\beta \sin (r + 120°)] + [\gamma \sin (r + 240°)] = - 7.87$

$$\tan \rho = - \frac{12.96}{7.87}$$

$$\rho = 58° \ 44'$$

$$\varepsilon = - \frac{12.96}{36 \sin 58° \ 44'} = - 0''.42$$

Examination of limb of 20-inch theodolite C. S. No. 115—Continued.

THIRD SET—TABLE III.

r	Mutual errors of trisection.						Residual errors of graduation and reading.		
	r		$r + 120°$		$r + 240°$				
	Error.	Correction.	Error.	Correction.	Error.	Correction.	r	$r + 120°$	$r + 240°$
°	"	"	"	"	"	"	"	"	"
0	− 0.7	− 0.4	+ 0.3	− 0.3	+ 0.3	+ 0.1	− 1.1	+ 0.6	+ 0.4
5	− 0.7	− 0.4	+ 0.3	+ 0.3	+ 0.3	+ 0.1	− 1.1	+ 0.6	+ 0.4
10	− 0.7	− 0.4	+ 0.3	+ 0.3	+ 0.3	+ 0.1	− 1.1	+ 0.6	+ 0.4
15	− 1.3	− 0.3	0.0	+ 0.4	+ 1.3	0.0	− 1.6	+ 0.4	+ 1.3
20	− 1.2	− 0.3	+ 0.4	+ 0.4	+ 0.8	− 0.1	− 1.5	+ 0.8	+ 0.7
25	− 0.2	− 0.3	− 0.9	+ 0.4	+ 1.1	− 0.1	− 0.5	− 0.5	+ 1.0
30	− 0.6	− 0.3	− 0.6	+ 0.4	+ 1.1	− 0.1	− 0.9	− 0.2	+ 1.0
35	− 0.9	− 0.2	− 0.2	+ 0.4	+ 1.1	− 0.2	− 1.1	+ 0.2	+ 0.9
40	− 0.9	− 0.2	− 0.2	+ 0.4	+ 1.1	− 0.2	− 1.1	+ 0.2	+ 0.9
45	− 0.6	− 0.2	− 0.2	+ 0.4	+ 0.8	− 0.2	− 0.8	+ 0.2	+ 0.6
50	− 0.7	− 0.2	+ 0.7	+ 0.4	0.0	− 0.3	− 0.9	+ 1.1	− 0.3
55	− 0.1	− 0.2	− 1.4	+ 0.4	+ 1.6	− 0.3	− 0.3	− 1.0	+ 1.3
60	− 0.8	− 0.1	− 1.4	+ 0.4	+ 2.2	− 0.3	− 0.9	− 1.0	+ 1.9
65	0.0	0.0	− 1.3	+ 0.4	+ 1.3	− 0.3	0.0	− 0.9	+ 1.0
70	+ 0.6	0.0	− 1.4	+ 0.4	+ 0.9	− 0.4	+ 0.6	− 1.0	+ 0.5
75	− 0.6	0.0	− 1.2	+ 0.4	+ 1.8	− 0.4	− 0.6	− 0.8	+ 1.4
80	− 0.1	+ 0.1	− 1.4	+ 0.3	+ 1.6	− 0.4	0.0	− 1.1	+ 1.2
85	0.0	+ 0.1	− 1.3	+ 0.3	+ 1.3	− 0.4	+ 0.1	− 1.0	+ 0.9
90	+ 0.1	+ 0.1	− 1.6	+ 0.3	+ 1.4	− 0.4	+ 0.2	− 1.3	+ 1.0
95	+ 1.3	+ 0.2	− 1.3	+ 0.3	0.0	− 0.4	+ 1.5	− 1.0	− 0.4
100	+ 1.6	+ 0.2	− 1.4	+ 0.2	− 0.1	− 0.4	+ 1.8	− 1.2	− 0.5
105	+ 1.7	+ 0.2	− 2.0	+ 0.2	+ 0.3	− 0.4	+ 1.9	− 1.8	− 0.1
110	+ 1.6	+ 0.2	− 2.1	+ 0.2	+ 0.6	− 0.4	+ 1.8	− 1.9	+ 0.2
115	+ 0.6	+ 0.3	+ 0.6	+ 0.1	− 1.1	− 0.4	+ 0.9	+ 0.7	− 1.5

Examination of limb of 20-*inch theodolite C. S. No.* 115—Continued.

RESIDUAL ERRORS OF GRADUATION AND READING.

r	RESIDUAL ERRORS.											
	FIRST SET.			SECOND SET.			THIRD SET.			MEAN.		
	α′	β′	γ′	α′	β′	γ′	α′	β′	γ′	α′₀	β′₀	γ′₀
°	″	″	″	″	″	″	″	″	″	″	″	″
0	− 1.4	+ 0.7	+ 0.7	− 1.2	+ 0.9	+ 0.3	− 1.1	+ 0.6	+ 0.4	− 1.2	− 0.7	+ 0.5
5	− 1.5	+ 0.6	+ 0.9	− 1.2	+ 0.2	+ 1.0	− 1.1	+ 0.6	+ 0.4	− 1.3	+ 0.5	+ 0.8
10	− 0.9	+ 0.6	+ 0.2	− 0.7	+ 0.3	+ 0.3	− 1.1	+ 0.6	+ 0.4	− 0.9	+ 0.5	+ 0.3
15	− 1.5	0.0	+ 1.5	− 1.8	+ 0.3	+ 1.6	− 1.6	+ 0.4	+ 1.3	− 1.6	+ 0.2	+ 1.5
20	1.4	+ 1.1	+ 0.2	− 1.3	+ 1.1	+ 0.2	− 1.5	+ 0.8	− 0.7	− 1.4	+ 1.0	+ 0.4
25	− 0.1	− 0.4	+ 0.5	− 0.7	− 0.4	+ 1.1	− 0.5	− 0.5	+ 1.0	− 0.4	− 0.4	+ 0.9
30	− 1.0	+ 0.1	+ 0.9	− 0.9	− 0.2	+ 1.0	− 0.9	− 0.2	+ 1.0	− 0.9	0.1	+ 1.0
35	− 1.7	+ 0.7	+ 0.9	− 1.6	+ 0.6	+ 1.0	− 1.1	+ 0.2	+ 0.9	− 1.5	+ 0.5	+ 0.9
40	− 0.9	+ 0.7	+ 0.1	− 1.0	+ 0.6	+ 0.4	− 1.1	+ 0.2	+ 0.9	− 1.0	+ 0.5	+ 0.5
45	− 0.7	0.0	+ 0.7	− 0.9	+ 0.4	+ 0.5	− 0.8	+ 0.2	+ 0.6	− 0.8	+ 0.2	+ 0.6
50	− 0.9	+ 1.7	− 0.9	− 1.0	+ 1.6	− 0.7	− 0.9	+ 1.1	− 0.3	− 0.9	+ 1.5	− 0.6
55	+ 0.2	− 1.8	+ 1.6	+ 0.2	− 1.6	+ 1.4	− 0.3	− 1.0	+ 1.3	0.0	− 1.5	+ 1.4
60	− 0.6	− 0.5	+ 1.1	− 0.7	− 1.2	+ 1.8	− 0.9	− 1.0	+ 1.9	− 0.7	− 0.9	+ 1.6
65	+ 0.5	− 2.1	+ 1.6	+ 0.5	− 1.7	+ 1.3	0.0	− 0.9	+ 1.0	+ 0.3	− 1.6	+ 1.3
70	+ 0.4	− 0.8	+ 0.4	− 0.1	0.0	+ 0.2	+ 0.6	− 1.0	+ 0.5	+ 0.3	− 0.6	+ 0.4
75	− 0.1	− 1.0	+ 1.1	− 0.2	− 1.3	+ 1.4	− 0.6	− 0.8	+ 1.4	− 0.3	− 1.0	+ 1.3
80	+ 0.2	− 1.1	+ 1.0	+ 0.1	− 1.7	+ 1.6	0.0	− 1.1	+ 1.2	+ 0.1	− 1.3	+ 1.3
85	+ 0.8	− 1.7	+ 0.9	+ 0.8	− 1.7	+ 0.9	+ 0.1	− 1.0	+ 0.9	+ 0.6	− 1.5	+ 0.9
90	+ 0.3	− 0.8	+ 0.5	+ 0.1	− 1.0	+ 0.9	+ 0.2	− 1.3	+ 1.0	+ 0.2	− 1.0	+ 0.8
95	+ 1.6	− 1.5	− 0.2	+ 1.8	− 1.5	− 0.2	+ 1.5	− 1.0	− 0.4	+ 1.6	− 1.3	− 0.3
100	+ 1.5	− 1.3	− 0.1	+ 1.8	− 1.6	− 0.2	+ 1.8	− 1.2	− 0.5	+ 1.7	− 1.4	− 0.3
105	+ 1.4	− 1.5	+ 0.1	+ 1.4	− 1.6	+ 0.2	+ 1.9	− 1.8	− 0.1	+ 1.6	− 1.6	+ 0.1
110	+ 1.9	− 2.1	+ 0.3	+ 1.6	− 1.7	0.0	+ 1.8	− 1.9	+ 0.2	+ 1.8	− 1.9	+ 0.2
115	+ 0.4	+ 0.4	− 0.9	+ 1.1	+ 0.5	− 1.6	+ 0.9	+ 0.7	− 1.5	+ 0.8	+ 0.5	− 1.3

Examination of limbs of 20-inch theodolites with reference to periodicity of errors within 5°.

The design of these observations, and their general results, are given before—pages 117 to 119 of this report. The following differs from what has already been given only in being more full and giving the individual results for each 5′ space measured.

The design of the observer in measuring from 24° to 29°, instead of from 25° to 30°, does not appear. As it is a question of comparison of even 5° spaces, we must consider the degree between 24° and 25° as corresponding to that between 29° and 30°. It is, therefore, called the 5th degree, and from 25° to 26° is considered the 1st degree.

The examination consisted merely in measuring with one of the micrometers each 5′ space for 5° and comparing the results directly. Each measurement consisted of two pointings upon each end of each 5′ space. In measuring any space, as from 5′ to 10′, a pointing was made upon the 5′ line, then upon the 10′, upon the 10′ again, and back to the 5′. The range in the readings in several pointings upon the same line very rarely exceeded 0.5 division.

It will be noticed that the mean value of micrometer is somewhat different on the different dates of observation. The presumed explanation of this difference is given on pages 10 and 11. In expressing the values of the 5′ spaces, the 5° spaces are assumed to be equal to 5°, and the value of the 5′ spaces are expressed according to their differences from the mean micrometer value of the 5′ space for that set.

Following is a specimen of record of observations:

Examination of limb of 20-inch theodolite C. S. No. 114.

COAST SURVEY OFFICE, *May* 1, 1877.

Measurement of equality of subdivisions. Observations with micrometer A. Measurement of 5′ spaces from 290° to 295°. Temp., 59°.5 F.

Time.	°	′	*d*	*d*	Value of 5′ space.	Time.	°	′	*d*	*d*	Value of 5′ space.	Time.	°	′	*d*	*d*	Value of 5′ space.
					t. d.						*t. d.*						*t. d.*
10.20 a. m.	290	00	16. 2	15. 0		10.30 a. m.	290	20	21. 5	20. 4		10.40 a. m.	290	40	46. 2	45. 0	
			16. 8	16. 4					22. 0	20. 0					48. 0	46. 4	
			16. 50	15. 70	4 59. 20				21. 75	20. 20	4 58. 45				47. 10	45. 70	4 58. 60
	290	05	13. 7	12. 5			290	25	28. 3	26. 8			290	45	46. 9	44. 8	
			14. 8	12. 2					29. 2	27. 5					46. 5	45. 0	
			14. 25	12. 35	4 58. 10				28. 75	27. 15	4 58. 40				46. 70	44. 90	4 58. 20
	290	10	37. 2	35. 2			290	30	34. 5	33. 0			290	50	39. 0	37. 2	
			37. 0	35. 0					34. 7	33. 3					38. 5	37. 2	
			37. 10	35. 10	4 58. 00				34. 60	33. 15	4 58. 55				38. 75	37. 20	4 58. 45
	290	15	24. 6	23. 0			290	35	37. 0	35. 3							
			24. 5	22. 8					36. 8	34. 5							
			24. 55	22. 90	4 58. 35				36. 90	34. 90	4 58. 00						

The entire 5° was measured in this manner. For Theodolite C. S. No. 114 we have then the following results:

Measurement of limb from 24° to 29°. April 28, 1877.

	25° to 26°		26° to 27°		27° to 28°		28° to 29°		24° to 25°	
′ ′	t.	d.	t.	d.	t.	d.	t.	d.	t.	d.
0 to 5	4	57.95	4	58.90	4	58.25	4	59.30	4	58.00
5 to 10		57.75		57.85		58.35		57.55		58.25
10 to 15		58.40		58.70		57.20		58.45		58.05
15 to 20		57.50		57.20		58.25		57.25		58.05
20 to 25		58.60		58.75		58.40		58.20		58.55
25 to 30		57.07		57.40		57.95		59.75		58.10
30 to 35		59.35		59.45		58.80		58.90		58.15
35 to 40		56.60		59.45		57.70		57.10		57.55
40 to 45		59.35		57.65		59.25		58.20		58.20
45 to 50		58.40		56.60		57.85		57.65		58.40
50 to 55		57.85		58.30		58.25		58.50		58.10
55 to 60	4	57.45	4	58.00	4	58.05	4	56.65	4	58.70
	4	58.02	4	58.19	4	58.25	4	58.13	4	58.18

Measurement of limb from 290° to 295°. May 1, 1877.

	290° to 291°		291° to 292°		292° to 293°		293° to 294°		294° to 295°	
′ ′	t.	d.	t.	d.	t.	d.	t.	d.	t.	d.
0 to 5	4	59.20	4	58.05	4	58.75	4	59.80	4	57.90
5 to 10		58.10		59.20		58.00		57.75		58.05
10 to 15		58.00		58.85		58.20		59.75		57.85
15 to 20		58.35		58.30		57.65		57.60		58.10
20 to 25		58.45		58.55		58.55		58.00		58.50
25 to 30		58.40		58.55		58.20		57.95		58.25
30 to 35		58.55		59.60		58.05		59.20		59.65
35 to 40		58.00		58.00		57.80		58.10		57.75
40 to 45		58.60		59.10		58.45		58.40		57.95
45 to 50		58.20		57.90		57.15		58.50		59.45
50 to 55		58.45		58.75		59.75		57.15		58.65
55 to 60	4	58.00	4	58.75	4	58.50	4	57.80	4	59.25
	4	58.36	4	58.55	4	58.25	4	58.33	4	58.45

From the preceding we have, from the first set—

	°		°		t.	d.
Mean value of 5′ space,	25	to	26	=	4	58.02
	26	to	27	=		58.19
	27	to	28	=		58.25
	28	to	29	=		58.13
	24	to	25	=	4	58.18
	24	to	29	=	4	58.15

And from the second set—

	°		°		t.	d.
Mean value of 5′ space,	290	to	291	=	4	58.36
	291	to	292	=		58.55
	292	to	293	=		58.25
	293	to	294	=		58.33
	294	to	295	=	4	58.45
	290	to	295	=	4	58.39

To compare the two sets we must reduce them to common terms. Expressing them in minutes and seconds (using for each set the mean value of micrometer derived from that set), we have—

	First set.		Second set.		Mean.	
	′	″	′	″	′	″
Mean value of 5′ space, 1st degree....	4	59.87	4	59.97	4	59.92
2d degree....	5	00.04	5	00.16	5	00.10
3d degree....	5	00.10	4	59.86	4	59.98
4th degree....	4	59.98	4	59.94	4	59.96
5th degree....	5	00.03	5	00.06	5	00.04

And from these mean values we have—

	′	″
Value of 1st degree =	59	59.04
2d degree =		61.20
3d degree =		59.76
4th degree =		59.52
5th degree =	59	60.48

Probable error of any one degree = $\pm 0''.70 = 0^{in}.000035$ in sixty revolutions of the micrometer screw, a quantity well within the ordinary accumulation of error in the measurement of so large a quantity.

After examination of its limb by trisection, the limb of the 20-inch theodolite No. 115 was subjected to the preceding examination. Two spaces of 5° were measured—from 0° to 5° and from 90° to 95°—the first on May 15, the second on May 16, 1877.

Following are the individual results:

Measurement of limb from 0° to 5°. May 15, 1877. Mean temperature 65°.6 F.					
	0° to 1°	1° to 2°	2° to 3°	3° to 4°	4° to 5°
′ ′	*t.* *d.*	*t.* *d.*	*t.* *d.*	*t.* *d.*	*t.* *d.*
0 to 5	5 00.6	5 01.3	5 00.5	5 01.4	5 00.2
5 to 10	01.0	01.0	01.3	00.6	01.9
10 to 15	00.9	01.0	00.8	00.3	00.9
15 to 20	01.6	01.2	00.9	5 02.1	01.8
20 to 25	01.0	00.8	00.8	4 59.8	00.5
25 to 30	01.1	01.7	01.7	5 01.7	01.0
30 to 35	01.9	00.3	00.4	01.1	00.9
35 to 40	01.3	01.3	01.5	00.8	01.2
40 to 45	01.2	00.8	01.5	00.8	01.0
45 to 50	01.8	01.0	01.1	01.3	01.0
50 to 55	02.0	00.1	00.8	00.6	00.7
55 to 60	5 01.4	5 02.4	5 01.9	5 01.6	5 01.5
	5 01.31	5 01.08	5 01.10	5 01.01	5 01.05

Measurement of limb from 90° to 95°. May 16, 1877. Mean temperature, 70°.3 F.					
	90° to 91°	91° to 92°	92° to 93°	93° to 94°	94° to 95°
′ ′	*t.* *d.*	*t.* *d.*	*t.* *d.*	*t.* *d.*	*t.* *d.*
0 to 5	5 00.9	5 01.1	5 00.9	5 00.6	5 01.3
5 to 10	00.3	00.9	4 59.5	00.8	00.7
10 to 15	01.0	00.1	5 01.5	00.3	00.5
15 to 20	00.6	01.5	01.1	00.8	01.2
20 to 25	00.3	01.2	00.9	00.6	00.7
25 to 30	01.5	00.8	00.6	00.2	00.9
30 to 35	01.6	00.4	00.8	00.9	5 00.9
35 to 40	00.7	00.6	00.5	00.3	4 59.2
40 to 45	00.3	01.1	00.9	01.1	5 01.6
45 to 50	00.7	5 00.8	00.4	01.0	00.3
50 to 55	00.9	4 59.8	00.8	00.7	00.6
55 to 60	5 01.0	5 01.4	5 00.9	5 00.6	5 00.9
	5 00.82	5 00.81	5 00.75	5 00.66	5 00.73

From the preceding we have, from the first set—

	°		°		*t.*	*d.*
Mean value of 5′ space,	0	to	1	=	5	01.31
	1	to	2	=		01.08
	2	to	3	=		01.10
	3	to	4	=		01.01
	4	to	5	=	5	01.05
	0	to	5	=	5	01.11

And from the second set—

	°		°		*t.*	*d.*
Mean value of 5′ space,	90	to	91	=	5	00.82
	91	to	92	=		00.81
	92	to	93	=		00.75
	93	to	94	=		00.66
	94	to	95	=	5	00.73
	90	to	95	=	5	00.75

Expressing these results in minutes and seconds of arc (using for each set the mean micrometer-value derived from that set), we have—

	First set.	Second set.	Mean.
	′ ″	′ ″	′ ″
Mean value of 5′ space, 1st degree....	5 00.20	5 00.07	5 00.13
2d degree....	4 59.97	5 00.06	5 00.01
3d degree....	4 59.99	5 00.00	5 00.00
4th degree....	4 59.90	4 59.91	4 59.90
5th degree....	4 59.94	4 59.98	4 59.96

And from these mean values we have—

	′	″
Value of 1st degree =	60	01.56
2d degree =	60	00.12
3d degree =	60	00.00
4th degree =	59	58.80
5th degree =	59	59.52

from which we deduce 0″.68, as the mean uncertainty of one degree.

If we combine these results with those from No. 114, we will have—

	No. 114.		No. 115.		Mean.	
	′	″	′	″	′	″
Value of 1st degree	59	59.04	60	01.66	60	00.30
2d degree	60	01.20	60	00.12	60	00.66
3d degree	59	59.76	60	00.00	59	59.88
4th degree	59	59.52	59	58.80	59	59.16
5th degree	60	00.48	59	59.52	60	00.00

from which it appears that either there is no periodic error, or, if any exists, it is so small as not to be at all well defined.

APPENDIX No. 12.

COMPARISON OF AMERICAN AND BRITISH STANDARD YARDS. REPORT BY J. E. HILGARD, ASSISTANT.

UNITED STATES COAST AND GEODETIC SURVEY OFFICE,
Washington, D. C., July 10, 1880.

SIR: A year ago I submitted to you a statement concerning the relation of the lawful standards of measure of the United States to those of Great Britain and France, which by your direction was printed with the Coast Survey Report for 1876 as Appendix No. 22. That statement, which was also separately printed and widely distributed, has elicited numerous expressions of satisfaction from various quarters, because it set at rest doubts which had arisen from various causes as to the identity of the British and American standards of length.

It appears to be useful to publish through the same channel the details of the observations upon which rest the relations at present assigned to different standards of length in order to fully substantiate the statements of this office, and likewise to bring to the knowledge of those interested in the maintenance of standards the variations which have taken place in time, influenced probably by changes of temperature, in the relative length of bars, not only of different but even of the same material, at least when that material is an alloy of metals of widely different chemical and mechanical properties, as is the alloy of the British standards. With this view, I submit to you this concise record for publication in the Coast Survey Report for 1877.

I am indebted to Assistant O. H. Tittmann for editing the material, as well as for the part he has taken in some of the comparisons; to the late J. Homer Lane for the critical discussion of the coefficient of expansion of the British bronze bars, which I present in full as a model for treating such investigations; and to Subassistant H. W. Blair for the efficient part he has taken in the comparisons made at this office as well as for the discussion of the standard temperature of the Troughton scale.

The present amplified account, preceded by a repetition of last year's condensed statement slightly modified by more explicit information in some instances and in others by minute changes in assigned values resulting from recent discussions, is arranged under the following separate heads:

1. Relation of the lawful standards of measure of the United States to those of Great Britain and France.
2. Description of the Troughton 86-inch scale.
3. Description of British standard yards, bronze No. 11 and iron No. 57.
4. Discussion of coefficients of expansion.
5. Comparisons of bronze yard No. 11 with iron yard No. 57.
6. Comparisons of bronze yard No. 11 with the Imperial yard and other British standards.
7. Comparisons of Troughton scale with British standard yard No. 11.
8. Concluding statements.

Very respectfully,

J. E. HILGARD,
Assistant Coast and Geodetic Survey,
In charge of Verifications of Standards.

CARLILE P. PATTERSON, *Superintendent.*

1. RELATION OF THE LAWFUL STANDARDS OF MEASURE OF THE UNITED STATES TO THOSE OF GREAT BRITAIN AND FRANCE.

This publication is designed to give trustworthy information concerning the relation of American standards of measure to British and French standards.

In regard to all standards of measure in customary use in the United States, it should be observed that they have been inherited by our ancestors from England together with the common law. No enactment by Congress has ever been made declaring particular measures in the keeping of the government as standards except the standard troy pound of the Mint of the United States at Philadelphia, procured in 1827, which is an exact copy of the Imperial troy pound of Great Britain.

The principal facts may be stated as follows:

1st. There is at this time no difference between the standards of weight of Great Britain and those of the United States.

2d. The standards of volume or capacity in the United States are the same as those lawful in Great Britain prior to 1826.

3d. There is at this time no difference between the standards of length of Great Britain and those of the United States.

4th. The relation of the American and British standards to the French metric standards is not determined with extreme precision, but the legal enactments (see Annex II) will suffice for all purposes, except those of great scientific accuracy.

MEASURE OF WEIGHT.

Elaborate comparisons, made at various times from the year 1855 up to the present date, of this *troy* pound, containing 5,760 grains, and of the commercial or *avoirdupois* pound, containing 7,000 grains, derived from the former, with copies of similar weights derived from the standard pound of Great Britain, have shown that there is not so much as one-thousandth of a grain outstanding between the money standards of the two countries.

MEASURE OF CAPACITY.

Of the measures of capacity, which are not measures of great precision, it is only necessary to say that the old British wine-gallon of 231 cubic inches, and the old Winchester bushel, containing 2,150.4 cubic inches, are the recognized standards in the United States, as they were the lawful standards before the separation of the colonies from Great Britain, no subsequent enactment having been made.

MEASURE OF LENGTH.

The measure of length, which is the yard of 36 inches, is legally in the same condition as the measures of capacity. The standard yard of Great Britain was lawful in the colonies before 1776. By the Constitution of the United States the Congress is charged with fixing the standard of weights and measures (Art. I, sec. 8); but no such enactment has ever been made by Congress, and therefore that yard which was standard in England previous to 1776 remains the standard yard of the United States to this day; the same being also true of the commercial or avoirdupois pound and of the gallon and bushel, as above stated.

It must not be supposed that this is a matter which, in view of the great questions of public policy engrossing the attention of Congress in early years, had remained without due consideration. The journals of both houses of Congress show that committees were early appointed for the consideration of the subject. A Senate committee reported on March 1, 1791, that "it would not be eligible at present to introduce any alteration in the measures and weights which are now used in the United States." Other reports were made from time to time, and in January, 1820, a committee of the House of Representatives presented their conclusions, which were: "That little should be done; that standards conformed to those in most common use among us should be accurately made and carefully preserved at the seat of government; that correct models should be placed in different districts of the country; and that the proportions and relations between these should be ascertained."

Again, on March 11, 1822, a committee report was submitted to the same body, making recommendations for rendering "uniform and stable the measures and weights which we at present possess."

Thus, after full consideration for thirty years, it was agreed that the matter was in a satisfactory shape, in virtue of our inheritance and traditions, and that no legislation was advisable.

Finally, in 1836, an act was passed directing the Secretary of the Treasury to cause copies of the weights and measures adopted by the department as standards, for the use of custom-houses, to be supplied to each State, "to the end that a uniform standard of weights and measures may be established throughout the United States." (Annex I.) The standards so "adopted" were those of Great Britain, as before related.

The actual standard of length used was a bronze scale of 82 inches, subdivided on silver to tenths of inches, which had been prepared for the Coast Survey of the United States by Troughton, of London. The 36 inches comprised between the 27th and 63d inches, found equal to the average of the whole scale, were taken as the standard yard, and the temperature at which this was considered to be a standard, that is to say, equal to the British Standard Yard, was presumed to be 62° F. It had, however, never been directly compared with that standard, but was simply copied from Troughton's own scale without subsequent verification.

In England, the old standard yard, known as Bird's Standard of 1760, had in the mean time been found to be inadequate in definition for the increasing requirements of science, and a new set of standards of length, weight, and capacity was constructed between 1816 and 1826 of such finished workmanship and precise definition as was required by the science of the time, and every effort was made to reproduce, with the greatest possible exactness, the old standard pound and yard.

Not long after this important work had been accomplished, the standards so constructed were destroyed by the burning of the Parliament buildings in 1834. They have since been reproduced by reference to all of the former accredited standards with which they had been originally compared, and are now known as the "Imperial Standards." Some fifty copies of these standards were constructed and intercompared, and certain of these have been sent to the United States. The avoirdupois pound of 7,000 grains is found to agree within one-thousandth of a grain with the avoirdupois pound of the United States, derived from the Mint-pound heretofore mentioned—an agreement which leaves no question outstanding as to the identity of the units of weight of Great Britain and the United States.

The comparison of the Troughton scale heretofore mentioned with the Bronze Standard Yard No. 11, received from Great Britain in 1856, shows the former to be longer by nearly one-thousandth of an inch in the yard, or, more precisely, 0.00092 inch. By very recent comparisons, however, made by myself at the British Standards Office between the standard Imperial yard and Bronze No. 11, the latter was found to be 0.000088 inch shorter than the former, which may be stated in the form that it is of standard length at a temperature of 62°.25 F. Hence we infer that at 62° the Troughton scale is too long by 0.00083 inch, or that it is standard at 59.6 F. instead of 62° as formerly assumed; and this correction will apply to all measures that have been derived from it. This change, although sensible in operations of extreme scientific precision, is really of no consequence in ordinary practice, as it amounts only to the 1:40,000th part of the whole length—a degree of accuracy which is seldom required. The correction does not exceed the thickness of one of the lines that define the yards supplied to the States.

Extreme accuracy in this matter is beset with great difficulties, for in addition to that of ascertaining for each particular bar the rate of dilatation by temperature, there is an uncertainty in regard to permanence in the length of the bars themselves. Of the two standard yards presented to the United States, one is of bronze (No. 11), and the other of Low-Moor wrought iron (No. 57). These are found to have changed their relative length by 0.00025 inch in twenty-five years; the bronze bar being now relatively shorter by that amount. This subject is undergoing further investigation.

RELATION OF YARD TO METER.

Statements in regard to this relation have varied excessively, comparison between the two standards being subject to two great difficulties: first, their different nature and definition, and second, their incommensurability in length. The meter is a platinum bar, cut to length (an *end-measure*), and standard at the temperature of melting ice (32° F.). The length of the yard is defined by lines drawn on a bronze bar, standard at a temperature of 62° F. The difficulty of making accurate comparisons of lengths so differently defined is at once apparent; moreover, as their relative length is such that the meter is something longer than 39.37 inches, it is necessary first to derive the latter length from the yard of 36 inches by minute subdivision into a scale of equal parts, and the addition of the odd amount, a process which involves so many successive operations that the probable error of the result is largely increased by an accumulation of uncertainties.

From these circumstances have arisen the differences in statements of the length of a meter expressed in inches. One of the earliest trustworthy comparisons was that made by Kater, giving the value, generally quoted, of 39.37079 inches. This comparison was made with one of the earlier British standards. A more recent determination is that made by Clarke, at office of the British Ordnance Survey, between a number of the new British standards and several well-accredited copies of the meter, which give, very accordantly, a value of 39.37043 inches. It appears that in the latter observations the coefficients of expansion of the bars used were more accurately ascertained than in the former, and as between these two values the latter probably deserves the preference.

It must be observed, that since both yard and meter are material things, no legislative declaration in regard to their relative value can have any force other than to define what shall be considered lawful equivalents. This circumstance being recognized, when the metric standards were made optional in the United States, Congress, instead of stating the equivalents with excessive minuteness, as was done in Great Britain, merely defined the relation which shall be held lawful, to a degree of precision sufficient for practical purposes; thus we find in the table annexed that the lawful equivalent of a meter is 39.37 inches.

In the United States, Professor Hassler, first Superintendent of the Coast Survey, made very careful comparisons between one of the original iron meters and the Troughton 82-inch scale. The records of his experiments are not now extant, having been destroyed by fire in 1843, but he has published his results, viz: One meter = 39.38092 inches of the bronze yard, reduced to 32° F. He made use of a coefficient of expansion resulting from some experiments made by himself upon a brass wire, which value is much too large; but we cannot now correct his reduction, because we do not know the actual temperatures of comparison. Using Mr. Hassler's rate of expansion, viz, 0.0003783 inch in one yard, for 1° F., and reducing his result to the standard temperature of the yard (62° F.), his successor, Professor Bache, found the value of the meter to be 39.36851 inches of the Troughton scale, then the only accredited standard in our possession. When, however, we apply to the latter the correction of 0.00083 inch in a yard, found as above stated, and ascribe to it the rate of expansion of other bronze alloys—for instance, that found by Airy, from Sheepshank's observations, for the bronze of which the new Imperial standards are made, viz: 0.000342 inch per yard—we find one meter = 39.37050 inches, as follows:

Hassler's value of meter, reduced to 62°	39.36851
Correction for difference in rate of expansion	+ 0.00109
Correction for excess of Troughton scale in one meter	+ 0.00090
Hassler's comparisons, corrected reduction	39.37050

a value which differs very little from that obtained by Clarke, although it cannot be claimed to possess the same degree of trustworthiness. In fact, if we substitute in above reduction the rate of expansion for the bronze of the British standards recently determined by Fizeau, viz, 0.000351 inch per yard, we shall get 39.37023.

The value 39.3685 inches, derived as above mentioned from Mr. Hassler's comparisons, was used in the Coast Survey for stating the equivalents in yards of distances known in meters, and it has been so employed, as stated in the respective places, in various lists of geographical positions and tables for projections in the Coast Survey Reports, from 1851 to 1868. Since that time it has been deemed advisable to employ the value obtained by Clarke, viz, 39.3704 inches. The conversion is readily made with very sufficient accuracy, by increasing the distances in yards by their 1:20000th part. A table of equivalents is given below (Annex III).

It is not practicable to attain greater precision in comparison until after the completion of the new international meters now in course of construction at the International Bureau of Weights and Measures in Paris. When the construction of these shall have been perfected, and when they shall have been thoroughly intercompared, it will be useful once more to attempt to arrive at a closer comparison of the yard and meter than we now possess.

In order to make such a comparison with the least number of successive operations, I have devised the following scheme: Divide a yard into four parts by successive bisections; dividing again the sum of three of these parts into eight equal parts by successive bisections, one of these eighths added to the yard will give the length of the meter with a degree of precision readily within the reach of any comparator; that is to say, the length will be 39.375 inches. Two bars correspondingly divided have been prepared for this purpose, and intercomparison is in progress.

ANNEX I.

RESOLUTION OF CONGRESS PROVIDING FOR THE DISTRIBUTION OF WEIGHTS AND MEASURES.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Treasury be, and he hereby is, directed to cause a complete set of all the weights and measures adopted as standards, and now either made, or in progress of manufacture, for the use of the several custom-houses, and for other purposes, to be delivered to the governor of each State in the Union, or such person as he may appoint, for the use of the States respectively, to the end that a uniform standard of weights and measures may be established throughout the United States.

Approved June 14, 1836.

ANNEX II.

AN ACT to authorize the use of the metric system of weights and measures.

Be it enacted by the Senate and House of Representatives of the United States in Congress assembled, That from and after the passage of this act it shall be lawful throughout the United States of America to employ the weights and measures of the metric system, and no contract or dealing, or pleading in any court, shall be deemed invalid or liable to objection because the weights or measures expressed or referred to therein are weights or measures of the metric system.

SEC. 2. *And be it further enacted*, That the tables in the schedule heretofore annexed shall be recognized in the construction of contracts, and in all legal proceedings, as establishing, in terms of the weights and measures now in use in the United States, the equivalents of the weights and measures expressed therein in terms of the metric system; and said tables may be lawfully used for computing, determining, and expressing in customary weights and measures the weights and measures of the metric system.

Measures of length.

Metric denominations and values.		Equivalents in denominations in use.
Myriameter	10,000 meters.	6.2137 miles.
Kilometer	1,000 meters.	0.62137 mile, or 3,280 feet 10 inches.
Hectometer	100 meters.	328 feet 1 inch.
Dekameter	10 meters.	393.7 inches.
Meter	1 meter.	39.37 inches.
Decimeter	1-10 of a meter.	3.937 inches.
Centimeter	1-100 of a meter.	0.3937 inch.
Millimeter	1-1000 of a meter.	0.0394 inch.

Measures of surface.

Metric denominations and values.		Equivalents in denominations in use.
Hectare	10,000 square meters.	2.471 acres.
Are	100 square meters.	119.6 square yards.
Centare	1 square meter.	1,550 square inches.

Measures of capacity.

Metric denominations and values.			Equivalents in denominations in use.	
Names.	Number of liters.	Cubic measure.	Dry measure.	Liquid or wine measure.
Kiloliter or stere	1 000	1 cubic meter	1.308 cubic yards	264.17 gallons.
Hectoliter	100	1-10 of a cubic meter	2 bushels and 3.35 pecks	26.417 gallons.
Dekaliter	10	10 cubic decimeters	9.08 quarts	2.6417 gallons.
Liter	1	1 cubic decimeter	0.908 quart	1.0567 quarts.
Deciliter	1-10	1-10 of a cubic decimeter	6.1022 cubic inches	0.845 gill.
Centiliter	1-100	10 cubic centimeters	0.6102 cubic inch	0.338 fluid ounce.
Milliliter	1-1000	1 cubic centimeter	0.061 cubic inch	0.27 fluid dram.

Weights.

Metric denominations and values.			Equivalents in denominations in use.
Names.	Number of grams.	Weight of what quantity of water at maximum density.	Avoirdupois weight.
Millier or tonneau	1 000 000	1 cubic meter	2204.6 pounds.
Quintal	100 000	1 hectoliter	220.46 pounds.
Myriagram	10 000	10 liters	22.046 pounds.
Kilogram or kilo	1 000	1 liter	2.2046 pounds.
Hectogram	100	1 deciliter	3.5274 ounces.
Dekagram	10	10 cubic centimeters	0.3527 ounce.
Gram	1	1 cubic centimeter	15.432 grains.
Decigram	1-10	1-10 of a cubic centimeter	1.5432 grains.
Centigram	1-100	10 cubic millimeters	0.1543 grain.
Milligram	1-1000	1 cubic millimeter	0.0154 grain.

Approved July 28, 1866.

ANNEX III.

COMPARISON OF YARDS AND METERS.

1 metre = 1.093623 yard = 39.37043 inches.

Meters.	Yards.	Yards.	Meters.
1	1.093623	1	0.914392
2	2.187246	2	1.828784
3	3.280869	3	2.743175
4	4.374492	4	3.657567
5	5.468116	5	4.571959
6	6.561739	6	5.486351
7	7.655362	7	6.400743
8	8.748985	8	7.315134
9	9.842608	9	8.229526

2. DESCRIPTION OF THE TROUGHTON 86-INCH SCALE.

The Troughton scale is a bronze bar, with an inlaid silver scale, made for the survey of the coast of the United States, by Troughton, of London (see House Doc. No. 299, Twenty-second Congress, first session, and also Am. Phil. Society Trans., vol. 2, new series). The bar is nearly 86 inches long, 2½ inches wide, and one-half inch thick. A thin strip of silver a little more than 0.1 inch wide is inlaid with its surface flush with that of the brass, midway the width of the bar. It extends the whole length of the bar save where it is interrupted by two perforations, one near each end. Two parallel lines about 0.1 inch apart are ruled longitudinally on the silver. The space between them is divided transversely into tenths of inches.

The zero mark of the graduation is about 3.2 inches from one end of the bar. Immediately over it is engraved an eagle surmounted by the motto *E pluribus Unum*, and thirteen stars. Below the 38 to 42 inch divisions is engraved "Troughton, London, 1814." The bar is also perforated by a hole above the scale and near the 40-inch division, and by one below it between the words "Troughton" and "London."

The bar is placed in a wooden box into which it is fitted edgewise and in this position it is usually maintained, and since 1872 is kept in a room the temperature of which does not vary more than between 60° and 80° Fahr.

The yard of 36 inches comprised between the 27th and 63d inch of the Troughton scale, which was found by Hassler's comparison to be equal to the average 36 inches of the scale, is the actual standard yard of the United States, having been adopted by the Treasury Department as such, in 1832, on the recommendation of Mr. Hassler (Weights and Measures Report, Washington, 1857). As it was the intention that this yard should be equivalent to the English yard, its standard temperature depends on its relation to the Imperial yard.

3. DESCRIPTION OF BRITISH STANDARD YARDS, BRONZE No. 11 AND IRON No. 57.

Copies of the new British standards of length and weight were presented to the United States by the British Government through G. B. Airy, esq., Astronomer Royal. They were received in 1856, and are accompanied by the following statement:

"Copies of the British standards of length and weight, inclosed in box No. 10 and addressed to the United States of America.

"Bronze standard of length No. 11.

"Malleable iron standard of length No. 57.

"At the bottom of each of the two holes near the extremities of each bar is a gold pin, upon which are drawn three transversal lines and two longitudinal lines. The length of one English yard is defined by the distance from the middle transversal line in one hole to the middle transversal line in the other hole, using the parts of those lines which are central between the longitudinal lines, the temperature of the bronze bar No. 11 being 61°.79 Fahr. and that of the iron bar No. 57 being 62°.58 Fahr.

"The expansion of the bronze bar is 0.000342 and that of the iron bar 0.000221 inch for each degree of Fahrenheit.

"Standard weight No. 5.

"This weight is heavier than the (commercial) British pound of 7,000 grains by 0.008 grain.

"G. B. AIRY.

"DECEMBER 21, 1855."

Each standard of length is a solid bar 38 inches long and 1 inch square in transverse section. One inch from each extremity a cylindrical well, one-half inch in diameter, is sunk one-half inch below the surface. At the bottom of the wells in each bar is a gold pin about 0.1 inch in diameter, upon which are drawn three transversal and two longitudinal lines. The wells are protected by metal caps. The length of one English yard at a specified temperature is defined by the distance from the middle transversal line in one well to the middle transversal line in the other, using the parts of those lines which are midway between the longitudinal lines. The spaces between the longitudinal lines of No. 11 are greater than between those of No. 57, being in both between 0.02 inch and 0.03 inch.

The distance between any two transverse lines is about 0.01 inch (Airy, Phil. Trans., 1857, vol. 75, p. 692), but actual measurements show that the lines of No. 57 are not so far apart as those of No. 11. The lines of No. 11 are much finer than those of No. 57.

No. 11 is of bronze and bears the following inscription:

"Copper, 16 oz.
"Tin, $2\frac{1}{2}$
"Zinc, 1 } Mr. Baily's metal No. 11. Standard yard at 61°.79 F. Cast in 1845. Troughton & Simms, London."

No. 57 is of iron and bears the following inscription:

"No. 57. Low Moor iron A. Standard yard at 62°.58 Fahr."

4. COEFFICIENT OF EXPANSION OF THE BRITISH STANDARD YARD BAR, BRONZE No. 11.

BEING A NEW DISCUSSION OF THE EXPERIMENTS OF SHEEPSHANKS AND OF CLARKE.

BY J. HOMER LANE.

There is reason to believe that the coefficient attributed to this bar is too small. The following is an extract from Professor Airy's "Account" of the experiments made by Mr. Sheepshanks, upon which this coefficient appears to depend (Lond. Phil. Trans., 1857, vol. 75, pp. 667–669):

"In the winter of 1849–'50 Mr. Sheepshanks made a series of experiments for the thermometric expansions of bronze, brass, and Low Moor iron. The different temperatures were given to the bars by pouring in water at different temperatures into the external box; this, I believe, was the first occasion on which it was so used. The quantity of water employed at once was 11 gallons. The corrections to the thermometers L and R were still obtained, I believe, from old thermometers; but as the comparison of L and R with new original thermometers followed closely, I am not quite certain on this point. Each number below is the mean of about thirty comparisons.

$1^r = 0^{in}.003587$

The relative expansion of bronze 12 and Low Moor iron.

Date.	Temperature.	Reading for bronze 12.	Reading for Low Moor iron.
Nov. 30, 1849..	68.76	201.5598	201.2976
	64.41	201.0627	200.9355
Dec 1, 1849..	51.50	199.8867	200.1899
	58.88	200.5319	200.5998
	57.16	200.3766	200.4895
Dec. 3, 1849..	67.65	201.3903	201.1642
Dec. 5, 1849..	78.81	202.5139	201.9086
Dec. 6, 1849..	54.82	200.2089	200.4075
	61.15	200.7820	200.7572
Dec. 8, 1849..	48.46	199.6225	200.0354
	75.45	202.1283	201.6404
Dec. 10, 1849..	68.92	201.5656	201.2943
	64.13	201.0967	200.9797

"From these the excess of expansion of 36 inches of bronze above iron for 1° Fahr. was inferred to be $0^r.03318$.

"For absolute expansion of low moor iron, Mr. Sheepshanks compared the higher and lower temperatures on each of the following days:

"November 30, December 1, December 6, December 8, December 10, as given in the last table.

"From these he obtained for 1 Fahr.—

"Absolute expansion of 36 inches of low moor iron $= 0^r.06095$

For absolute expansion of bronze 12 and brass 2.

Date.	Temperature.	Reading for bronze 12.	Reading for brass 2.
	°		
Jan. 24, 1850..	36.06	198.8437	198.8780
	51.75	200.3481	200.4152
	67.82	201.8598	201.9467
Jan. 25, 1850..	70.14	202.0599	202.1320
	45.85	199.7360	199.7850
Jan. 26, 1850..	41.95	199.2963	199.3419
	70.46	202.0152	202.0959
May 4, 1850..	54.23	200.0187	200.0701
	65.87	201.1187	201.1719

"From these were obtained for 1° Fahr.—

"Absolute expansion of 36 inches of bronze = $0^r.09507$
"Absolute expansion of 36 inches of brass = $0^r.09601$

"And by combining the absolute expansion of bronze with the excess of expansion of bronze above iron—

"Absolute expansion of 36 inches of iron = $0^r.06189$."

The number here given ($0^{in}.000341$) for the absolute expansion of bronze 12 is equivalent, sensibly, to the expansion $0^{in}.000342$ attributed to bronze 11 in possession of the United States Government. It does not appear that there was any independent determination of the latter. By way of verification I have recomputed the absolute expansion from the printed numbers of the comparisons, using the method of least squares. The following is the process of computation:

t'_1, t'_2, temperatures — 68°.76, 64°.41, — of comparisons, November 30, 1849.
m', their mean

t''_1, t''_2, t''_3, temperatures for December 1.
m'', their mean

t'''_1, t'''_2, temperatures for December 6.
m''', their mean,
&c.

$0^r.095 + y$ = expansion of 36 inches, bronze 12;

x' = true reading on November 30 for bronze 12 at temperature m'
x'' = true reading on December 1 for bronze 12 at temperature m''
x''' = true reading on December 6 for bronze 12 at temperature m'''
&c.

Equations of condition.

$$(1)\left\{\begin{array}{l} x' + (t'_1 - m')\ (0.095 + y) - 201.5598 = 0 \\ x' + (t'_2 - m')\ (0.095 + y) - 201.0627 = 0 \\ \\ x'' + (t''_1 - m'')\ (0.095 + y) - 199.8867 = 0 \\ x'' + (t''_2 - m'')\ (0.095 + y) - 200.5319 = 0 \\ x'' + (t''_3 - m'')\ (0.095 + y) - 200.3766 = 0 \\ \&c. \end{array}\right.$$

(the quantities $(0.095 + y)$ and 201.5598 are marked r.)

$$(1)'\left\{\begin{array}{l} (t'_1 - m')\ y - n'_1 = 0 \\ (t'_2 - m')\ y - n'_2 = 0 \\ \\ (t''_1 - m'')\ y - n''_1 = 0 \\ (t''_2 - m'')\ y - n''_2 = 0 \\ (t_3 - m'')\ y - n''_3 = 0 \\ \&c. \end{array}\right.$$

Normal equations:

$$(2)\ x' = \tfrac{1}{2}\,(201^r.5598 + 201^r.0627),\ x'' = \tfrac{1}{3}\,(199^r.8867 + 200^r.5319 + 200^r.3766),\ \&c.$$

$$(3)\ y = \frac{[(t-m)\,n]}{[(t-m)^2]}$$

Equation (1)′ expresses the result of substituting the values of x', x'', &c., in (1). The following table exhibits the reductions of these formulæ:

Date.	Temperature.	Reading for bronze 12.	$t-m$	n	$(t-m)^2$	$(t-m)\,n$	Residuals. I.	Residuals. II.
	°	r	°	r			r	
Nov. 30, 1849..	68.76	201.5598	+ 2.175	+ 0.0419	4.73	+ 0.0911	— 0.0427	
	64.41	201.0627	— 2.175	— 0.0419	4.73	+ 0.0911	+ 0.0427	
Dec. 1, 1849..	51.50	199.8867	— 4.35	+ 0.0349	18.92	— 0.1518	— 0.0334	
	58.88	200.5319	+ 3.03	— 0.0210	9.18	— 0.0636	+ 0.0199	
	57.16	200.3766	+ 1.32	— 0.0139	1.74	— 0.0183	+ 0.0134	
Dec. 6, 1849..	54.82	200.2089	— 3.165	+ 0.0141	10.02	— 0.0446	— 0.0130	
	61.15	200.7820	+ 3.165	— 0.0141	10.02	— 0.0446	+ 0.0130	
Dec. 8, 1849..	48.46	199.6225	— 13.495	+ 0.0291	182.12	— 0.3928	— 0.0244	
	75.45	202.1283	+ 13.495	— 0.0291	182.12	— 0.3928	+ 0.0244	
Dec. 10, 1849..	68.92	201.5656	+ 2.395	+ 0.0069	5.74	+ 0.0165	— 0.0077	
	64.13	201.0967	— 2.395	— 0.0069	5.74	+ 0.0165	+ 0.0077	
Jan. 24, 1850..	36.06	198.8437	— 15.82	— 0.0039	250.27	+ 0.0617	+ 0.0094	+ 0.0003
	51.75	200.3481	— 0.12	+ 0.0090	0.04	— 0.0011	— 0.0090	— 0.0090
	67.82	201.8598	+ 15.94	— 0.0050	254.09	— 0.0797	— 0.0006	+ 0.0087
Jan. 25, 1850..	70.14	202.0599	+ 12.145	+ 0.0082	147.50	+ 0.0996	— 0.0125	— 0.0054
	45.85	199.7360	— 12.145	— 0.0082	147.50	+ 0.0996	+ 0.0125	+ 0.0054
Jan. 26, 1850..	41.95	199.2963	— 14.255	— 0.0052	203.21	+ 0.0741	+ 0.0137	+ 0.0019
	70.46	202.0152	+ 14.255	+ 0.0052	203.21	+ 0.0741	— 0.0137	— 0.0019
May 4, 1850..	54.23	200.0187	— 5.82	+ 0.0029	33.87	— 0.0169	— 0.0009	— 0.0042
	65.87	201.1187	+ 5.82	— 0.0029	33.87	— 0.0169	+ 0.0009	+ 0.0042

For brass 2.

Date.	Reading for brass 2.	n	$(t-m)\,n$	Residuals. II.
				r
Jan. 24, 1850..	198.8780	— 0.0324	+ 0.5126	+ 0.0085
	200.4152	+ 0.0133	— 0.0017	— 0.0135
	201.9467	+ 0.0191	+ 0.3044	+ 0.0049
Jan. 25, 1850..	202.1320	+ 0.0197	+ 0.2393	— 0.0014
	199.7850	— 0.0197	+ 0.2393	+ 0.0014
Jan. 26, 1850..	199.3419	— 0.0228	+ 0.3250	+ 0.0013
	202.0959	+ 0.0228	+ 0.3250	— 0.0013
May 4, 1850..	200.0701	+ 0.0020	— 0.0116	— 0.0108
	201.1719	— 0.0020	— 0.0116	+ 0.0108

Taking together all the numbers in the foregoing table, including both the November-December series and the January-May series, we have—

$$[(t-m)\,n] = -\ \ 0.5988$$
$$[(t-m)^2] = 1708.59$$
$$y = -\ 0^r.000350$$

or—

$$\text{Absolute expansion of 36 inches} = 0^r.094650$$

and the corresponding residuals are given in column I of residuals.

Excluding the November-December series, the January-May series alone gives—

$$[(t - m)\, n] = + \quad 0.2945$$
$$[(t - m)^2] = \quad 1273.53$$
$$y = + \quad 0^r.000231$$

or—

$$\text{Absolute expansion of 36 inches} = 0^r.095231$$

and the corresponding residuals are given in column II of residuals.

The large magnitude of the residuals in the November-December series confirms the construction naturally borne by the words of Airy's account, that the number there given for the absolute expansion of 36 inches of bronze, viz:

$$0^r.09507$$

was derived wholly from the January-May series, and it would further appear that this was on account of some superiority in the circumstances of that series. There appears to be no statement of the temperature to which this expansion of $0^r.09507$ appertains.

When the coefficient of expansion has been determined, as if a constant, by the least squares, from a series of readings made in independent pairs, calling t_1 and t_2 the temperatures of any one pair, it is readily shown that the true temperature appertaining to the deduced coefficient is that which, used as a zero of temperature, will make $[\frac{1}{2}(t_2 + t_1)(t_2 - t_1)^2] = 0$, the brackets being, as before, the symbol of summation. When, as on January 24, a triplet of readings occurs, the third near the middle temperature of the triplet is without sensible influence on the temperature appertaining to the deduced coefficient. Hence the temperature for the coefficient

$$0^r.095231$$

above found from the printed numbers of the January and May series is—

$$\frac{500 \times 52^\circ + 300 \times 58^\circ + 400 \times 56^\circ + 68 \times 60^\circ}{500 + 300 + 400 + 68} = 55^\circ$$

The number $0^r.09507$ is palpably too small for the printed numbers of the data in the January-May series, if it be understood, as apparently it is, to apply to the resultant temperatures of the comparisons, viz, 55°. In order to elucidate, if possible, the origin of the discrepancy, the coefficient of brass 2 was also recomputed, as follows:

$$[(t - m)\, n] = + \quad 1.9207$$
$$[(t - m)^2] = \quad 1273.53$$
$$y = + \quad 0^r.00151$$

Absolute expansion of 36 inches brass 2	= 0.09651
Discrepancy in the case of bronze 12	= 0.00016
Discrepancy in the case of brass 2	= 0.00050

These largely *different* mere discrepancies in *calculation* cannot be accounted for by any single cause, unless it were the inadvertent omission of part of the data from the published account. It seems at any rate most judicious to receive the published number

$$0^r.09507 \; (= 0^{in}.000341)$$

as the result of Mr. Sheepshanks's experiments, unless, indeed, we may suppose that the somewhat, but not materially, larger number $0^{in}.000342$, certified for bronze 11, is a *recomputation* from the same data, with which it sufficiently well agrees.

If the value be, as we have reason to believe, too small, the cause of this must of course be sought in the circumstances of Mr. Sheepshanks's experiments. The details of these experiments are not all given. In reference, however, to experiments upon "relative expansions" afterwards made by Mr. Sheepshanks in 1853, Professor Airy informs us, in the same "account" (Phil. Trans., vol. 75, p. 676), that when the temperature had been altered by pouring in hot water, &c., no observations were made until six or more hours after the alteration. If the experiments in 1850 were similarly conducted in this respect, as it seems necessary to suppose, so that a considerable interval of time always elapsed between readings taken at low and high temperatures, then the expansion of the bar may have been in a very sensible degree offset by expansion of the stone slab "D." This slab was the main element in maintaining the interval from microscope to microscope, and that edge of it towards the microscopes, or inner edge as we may call it, was in the near vicinity of the "external trough" of hot water, and not only the edge surface of the slab, but its under surface for a considerable distance back from the edge, would be exposed to the influence of radiation, and perhaps of convection by the air. The inner edge of the slab, therefore, may well have undergone elevation of temperature unless extraordinary measures were taken to prevent it, and it does not appear that this was done in the series here in question, January-May, 1850.

I find only a general statement, apparently referring to the above-mentioned experiments of 1853, that, "In some cases, the trough was wrapped in blankets during the night." But even if such a wrapping of the trough was used in the series of January-May, 1850, it is very doubtful whether it would suffice to cut off the access of heat to the stone slab. And expansion of the inner edge of the slab would be magnified in its effect upon the interval between the microscopes by the circumstance of the outer edge of the slab not partaking of the expansion. In this way it seems possible to account for an error greater than can be attributed to a difference between the elevation of the temperature in the bar and the elevation of temperature indicated by the thermometers.

This source of error or uncertainty was completely guarded against in the determinations made by Captain Clarke in 1865 of the absolute expansions of the Indian 10-foot standards. (Comparisons of Standards of Length made at the Ordnance Survey Office, 1866, p. 180.)

One of these is made of Baily's bronze, of the same given proportions as the standard yards, viz, copper 16, tin $2\frac{1}{2}$, zinc 1. The coefficient obtained by him for the 10-foot Indian bronze bar, it will be seen, very considerably exceeds that found by Mr. Sheepshanks for the British yard bronze 12.

As Mr. Clarke, in the reductions of his observations, has not taken into account the increase of the coefficient with elevation of temperature, I have thought it well to calculate the temperature to which his coefficient, as deduced, applies, and to ingraft upon his residuals the result they will give for the rate of increase of the coefficient with rising temperature. The expansions were measured by comparing, as immediately as possible, the length of the bronze 11-foot bar at one temperature with the length of the steel 10-foot bar at a different temperature, varying the temperature in one bar and the other alternately. There were two series of experiments. The first series was in four groups; both bars cold; bronze hot—steel cold; bronze cold—steel hot; both bars hot. The second series was in three groups; both bars cold; bronze hot—steel cold; bronze cold—steel hot. For valid reasons stated by him, Captain Clarke has used the first-mentioned group alone (both bars cold), consisting of thirteen comparisons in the first series and six comparisons in the second series, to give the absolute difference of length between the two bars at a certain temperature, determined in the first series to be 43°.75 Fahr.

This determined difference was applied to the remaining groups of the series, and thus gave for the first series the equations of condition (19) found at page 209, each of which is of the form

$$t\,y - t'\,y' + n = o \quad . \quad . \quad . \quad (19)$$

where y is the increment in millionths of a yard in the length of the bronze bar for 1° Fahr., and y' the same for the steel bar, and $43°.75 + t$ is the temperature in degrees Fahr., of the bronze bars, and $43°.75 + t'$ the same for the steel bar. From these equations of condition the values of y and y', considered as constant, were deduced by Captain Clarke by the method of least squares. In the first series the values thus found were

$$y = 32.9566$$
$$y' = 21.1938$$

In place of these supposed constant values let us assume as the true values for any temperature $43^\circ.75 + t$,

$$32.9566 + \delta y + (t - 23.25)\, v$$
$$21.1938 + \delta y' + (t - 24.00)\, v'$$

forms in which δy and $\delta y'$ will come out small quantities. Then the increment in length of the bronze bar in passing from $43^\circ.75$ to $43^\circ.75 + t$, and that of the steel bar in passing from $43^\circ.75$ to $43^\circ.75 + t'$, will be, respectively,

$$32.9566\, t + t\, \delta y + \tfrac{1}{2}\, t\, (t - 46.5)\, v \quad . \quad . \quad . \quad (A)$$
$$21.1938\, t' + t'\, \delta y' + \tfrac{1}{2}\, t'\, (t' - 48.0)\, v' \quad . \quad . \quad . \quad (B)$$

For deducing satisfactorily the variation of the coefficient for brass, it was found necessary, in the case of the first series at least, partly in order that the observations with both bars hot might be brought into account, and partly in consequence of the relations existing between the temperatures used, to resort to a complete analysis embracing all the four constants v, v', δy, $\delta y'$. Putting the expressions (A) and (B) in the place of $t\, y$ and $t'\, y'$ in Clarke's equations of condition (19), above referred to, those equations reduce to the following, formed with the residuals n', which he gives at the top of page 211. These I have verified with the exception of — 3.55, which is evidently a misprint for — 3.65, and the latter has been substituted.

$$(19)' \quad -2.56\, \delta y - 41.41\, \delta y' + \tfrac{1}{2}(-2.56)(-2.56 - 46.5)\, v - \tfrac{1}{2}(41.41)(41.41 - 48.0)\, v' - 4.12 = 0$$
$$-3.34\, \delta y - 44.57\, \delta y' + \tfrac{1}{2}(-3.34)(-3.34 - 46.5)\, v - \tfrac{1}{2}(44.57)(44.57 - 48.0)\, v' - 1.23 = 0$$

&c., &c.

General form:

$$(19') \quad . \quad . \quad . \quad t\, \delta y - t'\, \delta y' - \tfrac{1}{2}\, t\, (t - 46.5)\, v - \tfrac{1}{2}\, t'\, (t' - 48.0)\, v' + n' = 0$$

Since it was known that the values of δy and $\delta y'$ as well as those of v and v' would be very small, the several coefficients, t, t', $\tfrac{1}{2}\, t\, (t - 46.5)$, $\tfrac{1}{2}\, t'\, (t' - 48.0)$, have been taken only to the nearest whole number, a, b, c, d. There being more risk in assuming the two sums $[a\, n']$ and $[b\, n']$ to be like $[t\, n']$ and $[t'\, n']$ equal to nothing, the sums $[(a - t)\, n']$ and $[(b - t')\, n']$ were, for security roughly taken in making up the normal equations, though proving to be insignificant. In this way were obtained the normal equations given below. In the following table are given the coefficients a, b, c, d, of the equations of condition, to the nearest whole number, Clarke's residuals n', and the residuals n'' resulting from the normal equations given below. In the first column is given the number of the comparisons.

No.	a	b	c	d	n'	n''	No.	a	b	c	d	n'	n''
9	− 3	+ 41	+ 63	− 136	− 4.12	− 0.40	37	+ 37	+ 1	− 169	− 25	0.06	3.12
6	− 3	+ 45	+ 83	− 76	− 1.23	+ 1.75	17	+ 45	0	− 33	+ 2	− 2.90	− 4.43
7	3	+ 45	+ 79	− 74	− 2.27	+ 0.61	22	+ 49	+ 3	+ 55	− 64	− 1.02	− 0.02
8	3	45	+ 76	− 72	− 3.65	− 0.86	19	+ 49	+ 2	+ 68	− 41	+ 1.18	+ 1.97
11	1	+ 50	+ 18	+ 42	− 0.23	− 0.44	20	+ 50	+ 2	+ 77	− 43	+ 2.83	+ 3.78
10	1	+ 51	+ 23	+ 75	+ 0.34	− 0.38	21	+ 50	− 2	+ 78	− 57	+ 2.50	+ 3.72
5	− 4	+ 51	101	+ 76	+ 4.65	+ 5.23	18	+ 52	+ 1	+ 140	− 29	7.55	− 5.88
15	1	+ 52	− 15	116	+ 1.47	− 0.64	35	+ 52	+ 1	+ 151	− 21	− 9.49	− 7.79
4	− 4	+ 53	+ 106	+ 121	+ 5.11	+ 4.97	36	+ 53	+ 1	+ 185	− 24	− 5.06	− 2.78
14	0	53	− 11	+ 123	+ 1.06	− 1.08	33	+ 55	0	+ 235	− 11	+ 1.11	+ 3.91
12	0	+ 54	1	+ 171	3.05	5.86	34	+ 55	+ 1	+ 239	− 13	− 0.24	+ 2.67
13	0	+ 55	− 2	+ 188	+ 2.18	− 0.98	16	+ 55	− 1	+ 246	+ 23	− 0.18	+ 2.19
27	+ 30	+ 3	245	− 58	+ 5.29	+ 1.76	40	+ 38	+ 36	− 164	214	− 5.95	− 5.38
26	+ 30	+ 3	− 244	57	7.52	+ 3.99	41	+ 36	+ 35	− 187	230	+ 0.98	+ 1.50
23	+ 31	+ 2	− 243	55	+ 6.28	2.70	42	+ 36	+ 35	− 183	226	− 2.38	− 1.86
24	+ 31	+ 2	− 241	55	+ 5.93	+ 2.36	43	+ 48	+ 47	+ 28	− 30	+ 3.56	+ 3.75
25	+ 31	+ 2	− 238	56	+ 7.12	+ 3.63	44	+ 45	+ 45	− 41	− 78	+ 1.11	+ 1.10
38	+ 37	+ 1	− 173	− 24	+ 4.10	+ 0.96	45	+ 44	+ 44	− 54	− 80	− 3.01	− 3.17
39	+ 37	+ 1	172	25	+ 0.86	− 2.25							

The following are the normal equations:

$$
\begin{aligned}
48423\,\delta y - 10192\,\delta y' - 3457\,r + 58049\,r' + 3.10 &= 0 \\
-10192\,\delta y + 39562\,\delta y' - 1104\,r - 666\,r' - 4.04 &= 0 \\
-3457\,\delta y - 1104\,\delta y' + 797899\,r - 174540\,r' - 9761.59 &= 0 \\
58049\,\delta y - 666\,\delta y' - 174540\,r + 350000\,r' - 2243.75 &= 0
\end{aligned}
$$

These equations have been reduced in such a manner as directly to bring out the weights of r and r' with their values. Since the expansion per 1° Fahr. changes with the temperature, its weight will likewise change, since the error of r or r' is involved in it. The probable error of the expansion per 1° Fahr. of the bronze bar is, at the temperature 43°.75 + 23°.25 + m°, the probable error of the function ($\delta y + m\,r$). This has been computed by the formula given in Chauvenet's Practical Astronomy, vol. ii, Appendix, section 50, p. 541. The values of δy, $\delta y'$, r, r' are

$$
\begin{aligned}
\delta y &= -\ 0.0214 \\
\delta y' &= -\ 0.0047 \\
r &= +\ 0.01607, \text{ weight } 693400 \\
r' &= +\ 0.01797, \text{ weight } 241000
\end{aligned}
$$

The sum of the squares of the new residuals, n'', is 396.18, whence we have for the new value of r, the probable error of a single comparison,

$$r = 0.6745\sqrt{\frac{396.18}{37-4}} = \pm\ 2.3371$$

The probable error of $(\delta y + m\,r) = \pm\ \frac{r}{100}\sqrt{0.2764 + 0.0144\,(m - 0.69)^2}$

$$= \pm\ \frac{1}{100}\sqrt{1.510 + 0.0787\,(m - 0.69)^2}$$

The probable error of $r = \frac{r}{\sqrt{693400}}$, of $r' = \frac{r}{\sqrt{241000}}$

Hence we have at T° Fahr.—

Expansion, $\frac{d\,l}{d\,t}$, of bronze bar $= 32.9352 + 0.01607\ (\mathrm{T} - 67)$

Probable error, $= \pm\ \frac{1}{100}\sqrt{1.510 + 0.0787\ (\mathrm{T} - 67.69)^2}$

Increase, $\frac{d^2\,l}{d\,t^2}$, of $\frac{d\,l}{d\,t}$ for 1° F. $= +\ 0.01607$

Probable error, $= \pm\ 0.00281$

For steel bar, $\frac{d^2\,l}{d\,t^2} = +\ 0.01797$

Probable error, $= \pm\ 0.00476$

Multiplying these quantities by 0.0000003, we have their expression as fractions of the bar's length, and in this form their numerical values from 47°.69 to 87°.69 Fahr. are given for the bronze bar in the following tabular statement:

Temperature.	47°.69	57°.69	67°.69	77°.69	87°.69
Coeff. exp. $\frac{d\,l}{l\,d\,t}$	0.0000097875	0.0000098357	0.0000098839	0.0000099321	0.0000099803
Probable error..	± 0172	± 0092	± 0037	± 0092	± 0172
$\frac{d^2\,l}{l\,d\,t^2}$			+ 0.00000000482		
Probable error..			± 00084		

I proceed to apply the above process to the second series of experiments. In this series, Captain Clarke has followed the same plan as in the first with certain changes in the details of the apparatus, one of which was made with a view to greater uniformity in the temperature of the hot bar. The determined temperature for which the absolute difference of length between the bronze bar and the steel bar is fixed by the group, both bars cold, is 56°.84, and the values of y and y' deduced by Captain Clarke in the same way as in the first series are:

$$y = 32.7591$$
$$y' = 21.1594$$

Using the same notation as before, let us assume as the true values for any temperature $56°.84 + t$.

$$32.7591 + \delta y + (t - 16.84)\, r$$
$$21.1594 + \delta y' + (t - 16.01)\, r'$$

Then the increments in length of the two bars respectively will be

$$32.7591\, t + t\, \delta y + \tfrac{1}{2}\, t\, (t - 33.68)\, r \quad (A)'$$
$$21.1594\, t' + t'\, \delta y' + \tfrac{1}{2}\, t'\, (t' - 32.02)\, r' \quad (B)'$$

Putting these expressions in the place of $t\, y$ and $t'\, y'$, in Clarke's equations of condition (27), page 214 of the volume referred to, we obtain equations of condition of the general form

$$t\, \delta y - t'\, \delta y' + \tfrac{1}{2}\, t\, (t - 33.68)\, r - \tfrac{1}{2}\, t'\, (t' - 32.02)\, r' + n' = 0$$

in which n' stands for Clarke's residuals −1.23, −1.60, &c., given on page 215, and which I have duly verified. Treating these equations of condition in the same manner substantially as we have done those of the first series the normal equations below were obtained. In the following table are given, under the same notation as before, the coefficients a, b, c, d, of the equations of condition, Clarke's residuals n', and new residuals n''.

No.	a	b	c	d	n'	n''	No.	a	b	c	d	n'	n''
1	0	+ 18	− 6	− 127	− 1.23	− 0.45	11	+ 19	+ 4	− 140	− 56	+ 3.82	+ 0.83
2	0	+ 18	− 6	− 127	− 1.60	− 0.82	12	+ 19	+ 4	− 139	− 55	+ 2.09	− 0.88
3	0	+ 18	− 6	− 126	− 2.17	− 1.39	13	+ 19	+ 1	− 140	− 16	+ 3.11	− 0.17
4	0	+ 18	− 6	− 126	+ 0.94	+ 1.71	14	+ 19	+ 1	− 139	− 16	+ 2.75	− 0.50
5	− 3	+ 28	+ 48	− 57	− 2.03	− 0.43	15	+ 24	+ 1	− 114	− 16	+ 4.65	+ 2.00
6	− 3	+ 28	+ 47	− 55	+ 0.08	+ 1.64	16	+ 24	+ 1	− 114	− 16	+ 2.22	− 0.43
7	− 1	+ 39	+ 13	+ 141	− 0.69	− 1.35	17	+ 39	+ 1	+ 111	− 9	+ 0.89	+ 3.63
8	− 1	+ 39	+ 12	+ 139	+ 1.49	+ 0.82	18	+ 39	+ 1	+ 111	− 10	− 3.98	− 1.23
9	0	+ 39	+ 6	+ 141	+ 0.53	− 0.30	19	+ 38	+ 1	+ 81	− 14	− 4.08	− 2.03
10	0	+ 39	+ 4	+ 138	+ 1.24	+ 0.38	20	+ 38	+ 1	+ 84	− 15	− 3.08	− 0.95

Normal equations.

$$8633\, \delta y - 157\, \delta y' - 1456\, r + 5272\, r' + 0.97 = 0$$
$$- 157\, \delta y + 9017\, \delta y' - 2359\, r + 9000\, r' + 1.33 = 0$$
$$- 1456\, \delta y - 2359\, \delta y' + 147115\, r - 21708\, r' - 3410.60 = 0$$
$$+ 5272\, \delta y + 9000\, \delta y' - 21708\, r + 156198\, r' - 583.93 = 0$$

$$\delta y = - 0.0004$$
$$\delta y' = - 0.0009$$
$$r = + 0.02422, \text{ weight } 143881$$
$$r' = + 0.00717, \text{ weight } 141483$$

The sum of the squares of the new residuals, n'', is here 36.9752. Hence

$$r = 0.6745\sqrt{\frac{36.97}{20 - 4}} = \pm 1.025$$

$$\text{Probable error of } (\delta\, y + m\, v) = \pm \frac{r}{100} \sqrt{1.186 + 0.0695\,(m + 0.09)^2}$$

$$= \pm \frac{1}{100} \sqrt{1.248 + 0.0731\,(m + 0.09)^2}$$

This last is, at the temperature now of 56°.84 + 16°.84 + m°, the probable error of the expansion per 1° F. of the bronze bar.

The probable error of $e = \frac{r}{\sqrt{113881}}$, of $e' = \frac{r}{\sqrt{141483}}$

Hence we have at T° Fahr.—

Expansion, $\frac{d\,l}{d\,t^1}$ of bronze bar $= 32.7587 + 0.02422\,(\mathrm{T} - 73.68)$

Probable error, $= \pm \frac{1}{100} \sqrt{1.248 + 0.0731\,(\mathrm{T} - 73.6)^2}$

Increase $\frac{d^2\,l}{d\,t^2}$ of $\frac{d\,l}{d\,t^1}$ for 1° F. $= + 0.02422$

Probable error, $= \pm\ 0.00270$

For steel bar, $\frac{d^2\,l}{d\,t^2}$ $= + 0.00717$

Probable error, $= \pm\ 0.00272$

The numerical values of these quantities, expressed as fractions of the bar's length, from 53°.6 to 93°.6, are given for the bronze bar in the following tabular statement:

Temperature.	53°.6	63°.6	73°.6	83°.6	93°.6
Coeff. exp. $\frac{d\,l}{l\,d\,t}$	0.0000096817	0.0000097544	0.0000098270	0.0000098997	0.0000099724
Probable error..	± 0166	± 0088	± 0034	± 0088	± 0166
$\frac{d^2\,l}{l\,d\,t^2}$			0.0000000727		
Probable error..			± 00081		

The difference between the value of $\frac{d^2\,l}{l\,d\,t^2}$ as given in the first series and its value as given in the second series is much greater than is spanned by the calculated probable error of the two results, and still more is this the case with the two values $\frac{d\,l}{l\,d\,t}$. If the difference between the two determinations be denoted by D and their respective probable errors by r_1 and r_2, it is known that, according to the probability curve always assumed,

$$t = \frac{0.477\ \mathrm{D}}{\sqrt{r_1^2 + r_2^2}}$$

is the argument with which we may take from a table of values of $\frac{2}{\sqrt{\pi}} \int_0^t e^{-t^2}\,dt$ the probability of the accidental occurrence of a difference not less than D. The difference between the two determinations of $\frac{d^2\,l}{l\,d\,t^2}$ is 0.00245, and their respective probable errors 0.00084 and 0.00081. This gives $t = 1$, and the probability of the accidental occurrence of so large a difference in the two results more than one-seventh.

When, however, we apply the same test to the two determinations of $\frac{d\,l}{l\,d\,t}$, the probability against the accidental nature of the difference between the two is enormous, and, admitting the absence of change in the actual value of the coefficient, the difference must be due to something special in the conditions of the two series. This is probably connected with the fact that only two thermometers were used to indicate the mean temperature of the 10-foot bar, and with the changes which Captain Clarke made after the first series with a view to reduce the large residual errors of that series. It seems not likely to have been caused by the friction of the rollers under their changed mode of support in the second series, since the residuals became in fact much smaller in that series, and no reason appears why the friction of the rollers should take effect in a systematic direction.

The non-accidental character of the difference between the two determinations of $\frac{d\,l}{l\,d\,t}$ throws greater doubt upon the value of $\frac{d^2\,l}{l\,d\,t^2}$ than would be justified by the comparison of these alone with each other and with their probable errors, for they give increased reason to apprehend that the deduced values of $\frac{d^2\,l}{l\,d\,t^2}$ may be in part the mere expression of the conditions of the experiments. In fact both values of $\frac{d^2\,l}{l\,d\,t^2}$ exceed, and that of the second series is nearly double, the equivalent $+\ 0.00000000370$ of the value found by Fizeau for the brass used in the United States yards and meters.

I will now express in a formula the mean result of the two series, giving equal weights to the two. It being known that the chief error in it is an unknown systematic one, it is fruitless to attempt a numerical statement of the probable value of that error. In the first series 67°.69, and in the second 73°.6, is the temperature at which the deduced value of $\frac{d\,l}{l\,d\,t}$ has its greatest calculated weight. The mean of its value at 67°.69 in the first series and its value at 73°.6 in the second is, therefore, assumed to be the best value for 70°.645, the mean of these temperatures, and to remain* the best, as a result of these two series, at that temperature, when any change of the

---

* That this assumption cannot be materially in error in the present case is shown as follows: In the first series our expressions for the coefficients of expansion of the ten-foot bronze and iron bars in millionths of a yard are, respectively,

$$(a)\ 32.9566 + \delta\,y + (t - 23.25)\,r$$
$$21.1938 + \delta\,y' + (t - 24.00)\,r'$$

and in the second series—

$$32.7591 + \delta\,y + (t - 16.84)\,r$$
$$21.1594 + \delta\,y' + (t - 16.01)\,r'$$

If r and r' were known or assumed, we should be limited to the first two of our four normal equations in either series, from which two we find in the first series—

$$\delta\,y = +\ 0.08\,r - 1.26\,r',$$

which value of $\delta\,y$, substituted in (a), gives for the value, at the temperature $(43.75 + t)^\circ$, of the coefficient in the bronze bar,

$$(b)\ 32.9566 + (t - 23.17)\,r - 1.26\,r'$$

Here the temperature (43°.75 + 23°.17), or 66°.92, at which the coefficient of r disappears, differs less than 1° from the temperature stated as that at which we find the maximum weight, or minimum probable error of (b), when such weight or probable error is calculated upon the theory of r and r' being both functions, exclusively, of the observations of the series, viz, the functions given by the normal equations.

Again (b) also shows that the temperature at which the coefficient takes the value of Clarke's coefficient is but little affected by any values which we can attribute to r and r', and differs but a trifle from the other two temperatures here defined.

For we have in this case—

$$(t - 23.17) = 1.26\,\frac{r'}{r}$$

and it is quite safe to say that $\frac{r'}{r}$ will not greatly exceed a unit. The mean values of r and r' derived from these two series give $\frac{r'}{r} = 0.62$.

In the second series the value of the coefficient at the temperature $(56.84 + t)^\circ$ is found in the same way to be—

$$32.7591 + (t - 16.67)\,r - 0.63\,r'$$

and the like remarks apply as in the first series.

value of $\frac{d^2 l}{l\,d\,t^2}$ may be brought in from other sources. In other words, any such change in this last element alone will take effect upon that part only of the value of $\frac{d\,l}{l\,d\,t}$, which has (T − 70) for its factor nearly enough. The mean of the two values of $\frac{d^2 l}{l\,d\,t^2}$, as resulting from these series, is + 0.00000000604.

We find, then, the expansion for the coefficient, $\frac{d\,l}{l\,d\,t}$, as follows:

	Temp.	$\frac{d\,l}{l\,d\,t}$
	°	
By first series, at	67.69	0.0000098839
By second series, at	73.6	0.0000098270
Mean, at	70.645	0.00000985545
Difference, for	0.645	003896
Mean, at	70.00	0.0000098516

$$\text{Coefficient expansion bronze at T° Fahr.} = 0.0000098516 + 0.00000000604\ (T - 70)$$

$$0.0000098839 + 0.00000000604\ (73.6 - 67.69) = 0.0000099176$$
$$98270$$

$$\text{Coefficient in first series—coefficient in second} = 0.0000000926$$

as drawn from results of the two series alone.

The following is a collation of the results of the above reductions, with the reduction made by Captain Clarke on the assumption of a constant value of the coefficient:

	First series.	Second series.
Sum of squares of Clarke's residuals	592. 95	124. 38
Sum of squares of new residuals	396. 18	36. 98
Probable error of one comparison as resulting from Clarke's reduction	± 2. 77	± 1. 772
Probable error of one comparison as resulting from new reduction	± 2. 34	± 1. 025
Mean value of Clarke's residuals when steel bar alone is hot	2. 44	1. 20
Mean value of Clarke's residuals when bronze bar alone is hot	3. 75	3. 07
Mean value of Clarke's residuals when both bars are hot	2. 83	....
Mean value of new residuals when steel bar alone is hot	1. 93	0. 93
Mean value of new residuals when bronze bar alone is hot	3. 15	1. 26
Mean value of new residuals when both bars are hot	2. 79	....

RECAPITULATION.

1st. The certified expansion of the British standard yard bronze 11 (Baily's bronze) for 1° Fahr., 0.000342 inch, reduced to the fraction of the whole length is 0.0000094722, and agrees sensibly with the number found by Mr. Sheepshanks for the yard bronze 12, from which it seems to have been adopted.

2d. There is reason to believe this coefficient too small, the cause of which, it is conjectured, may have been an undetected heating of the stone slab of the microscope beam compass used by Mr. Sheepshanks.

3d. The mean of the coefficients of Captain Clarke, deduced, without taking into consideration the variation with temperature, from two independent series of experiments, for another bar of Baily's bronze, viz, one of the 10-foot Indian standards, is 0.0000098573.

4th. The mean of the two values of the coefficient, regarded as a linear function of the temperature, deduced from the same two series of Captain Clarke's experiments, is, at the temperature T° Fahr., 0.0000098516 + Q (T − 70), and this expression of the deduced value is nearly correct with whatever assumed value of Q the deduction may be made.

5th. The mean of the values of Q, deduced from Captain Clarke's experiments, is 0.0000000060.

6th. The value of Q, found by Fizeau for Hassler's brass, is 0.0000000037.

ADDENDUM BY O. H. TITTMAN, ASSISTANT.

Since the foregoing investigation was made by Mr. J. H. Lane, the results of M. Fizeau's determination of the coefficient of expansion of Baily's bronze have been published (12th Annual Report of the Warden of the Standards, page 7, London, 1878).

As there given the expansion—

$$\text{from } 0^\circ \text{ to } t^\circ,\ C = 0.000017972 - 0.0000000137\left(40^\circ - \frac{t}{2}\right)$$

accordingly we obtain the expansion of 36 inches, according to Fizeau = $0^{in}.0003507$ for 1° F. at 62°; according to Clarke = $0^{in}.0003518$, for 1° F. at 62°; and we adopt the mean = $0^{in}.000351$ as the expansion of bronze No. 11 for 1° Fahr. at 62°.

According to Mr. Airy's account (Phil. Trans., 1857, vol. 75, p. 676), the absolute expansion of the wrought iron used in the construction of No. 57 was deduced from its relative expansion with bronze No. 6 (No. 28 old). The relative expansion being 0.000121 inch for 1° Fahr., we obtain for the absolute expansion of No. 57, at 62° Fahr., 0.000351 − 0.000121 = 0.000230 inch for 1° Fahr.

5. RELATIVE LENGTHS OF BRONZE YARD No. 11 AND IRON YARD No. 57.

In 1872 there were compared at the Coast Survey Office, on the line and end comparator, two brass-end yards, known as transfer yards A and B, with bronze No. 11. In the same year two brass-end yards, No. 6 and No. 7, made by the office of Weights and Measures for the Lake Survey, were compared by General C. B. Comstock, superintendent United States Lake Survey, with the transfer yards A and B on Saxton's pyrometer at the Coast Survey Office.

The result of these and other comparisons is given by General Comstock as follows, in a letter dated Detroit, April 20, 1876:

" * * * The resulting values at 62° Fahr., of Nos. 6 and 7, were—

	Inch.
No. 6 =	36.00002
No. 7 =	36.00133

"There are the following checks on this work: No. 6–7 has since been carefully determined here and agrees with the above value within 0.00002 inch; my comparisons gave indirectly—

$$A - B = 0.00094 \text{ inch},$$

"while your direct and precise ones gave 0.00089 inch. No. 6 has been carefully compared with two end measure yards, whose values were found by Colonel Clarke by comparisons with the ordnance survey standard; there results—

$$\text{No. } 6 = 35.99956 \text{ inch}$$

"as the mean derived from the two Clarke yards, the separate results differing by 0.00005 inch.

"The value of No. 6 is then 0.00046 inch longer when derived from your transfer yards A and B than when derived from the Clarke yards."

As a first step towards tracing this discrepancy, a series of comparisons was instituted between bronze No. 11 and iron No. 57. The relation between No. 11 and No. 57 had hitherto been assumed to be that assigned in the Astronomer Royal's statement accompanying the yards, as the comparisons between No. 11 and No. 57, spoken of in the Weights and Measures Report of 1856, were never completed.

The first set of comparisons was made in May, 1876, on the Saxton dividing-machine, room 6, Coast Survey building. They were merely experimental, and no special precautions were taken to protect the bars against the influence of the observer's presence. The observations were made by A. H. Scott.

In the reduction of these and the subsequent comparisons between No. 11 and No. 57, the relative expansion is taken as equal to 0.000121 inch for 1° F.

Experimental comparisons on the dividing-machine.

Date.	No. of comparisons.	Observed difference— No. 11–No. 57.	Observed temperature. (Fahrenheit.)	At 68°.38— No. 11–No. 57.
1876.		*Inch.*	°	*Inch.*
May 10, a. m	3	+ 0.00090	70.45	+ 0.00065
10, p. m	3	0.00090	70.23	68
11, a. m	3	0.00067	66.55	89
11, p. m	3	0.00056	66.55	78
11, p. m	3	0.00056	66.82	75
12, a. m	3	0.00060	67.72	68
12, p. m	3	0.00065	68.93	58
12, p. m	3	0.00060	69.80	43
Means.....			68.38	+ 0.00068

$$\text{Hence, at } 68^\circ.38 \text{ Fahr., No. } 11 = \text{No. } 57 + 0.00068 \text{ Inch.}$$
$$\text{Reduced to } 62^\circ \text{ Fahr., No. } 11 = \text{No. } 57 - 0.00009$$

According to the Astronomer Royal's statement, however, we should have—

$$\text{at } 62^\circ \text{ F., No. } 11 = \text{No. } 57 + 0.000200 \text{ Inch.}$$

The foregoing tentative observations having established the fact of a relative change, the bars were removed to the "line and end comparator" mounted in the basement of the Butler building adjoining the Coast Survey Office. The line and end comparator was used by Mr. J. H. Lane in the comparisons between No. 11 and the transfer yards A and B. It was damaged by the falling of the east wall of room No. 6, but at the date of the following comparisons it had been repaired, and was as nearly identical with its condition before the accident as possible.

The value of the micrometers was deduced from the 0.02 inch interval between the transverse lines in the wells of No. 11. The temperature was derived from the indications of four thermometers of known value. During the observations the bars were shifted so that each was alternately nearest the observer. The time occupied by three comparisons was about thirteen minutes. The observations were made by A. H. Scott.

Comparisons on line and end comparator.

Date.	No. of comparisons.	Observed difference— No. 11–No. 57.	Observed temperature. (Fahrenheit.)	At 67°.10— No. 11–No. 57.
1876.		*Inch.*	°	*Inch.*
May 27, a. m	3	+ 0.000527	66.44	+ 0.000607
29, a. m	3	536	66.92	558
30, a. m	3	576	67.91	478
31, a. m	3	538	67.44	497
June 1, a. m	3	+ 0.000547	66.81	+ 0.000582
Means	......	......	67.10	+ 0.000544

Inch.
Hence, at 67°.10 Fahr., No. 11 = No. 57 + 0.000544
Reduced to 62° Fahr., No. 11 = No. 57 − 0.000073

Early in May, 1877, comparisons were again made between these yards by a different observer, and with another apparatus, in the basement of the Butler building.

The arrangement for comparing was as follows:

Along one side of a wooden trestle a brass beam-compass extended. To this were fastened two microscopes, which could be clamped at any required distance apart. The microscopes were held on horizontal arms, which projected sufficiently to allow the bars to be brought under them. By means of a screw at one end of the beam-compass a longitudinal motion could be given to it. By this means the right-hand micrometer was made to read, as nearly as possible, the same for both bars, and nearly all the difference was measured on the left-hand micrometer.

The bars were placed parallel to each other about $\frac{1}{4}$ inch apart, and were supported about 9 inches from the ends on brass rollers about $\frac{3}{16}$ inch in thickness. These in turn rested on a wooden slide, which could be moved transversely to the beam backward and forward, stops being so adjusted as to arrest its motion when one or the other bar was under the microscopes. The temperature at which the comparisons were made was obtained by two thermometers, one laid on the surface of each bar. After the comparisons of May 2 the microscopes were transposed. The bars were shifted three times to bring them alternately next to the observer. A box made of thick paper, through which the microscopes projected, screened the bars and thermometers from the influence of the observer's person. The time occupied in making three comparisons was about ten minutes Light was obtained by artificial illumination.

The observations were made by Mr. H. W. Blair.

Comparisons on the beam compass comparator.

Date.		No. of comparisons.	Observed difference— No. 11 – No. 57.		Observed temperature. (Fahrenheit.)	At 61°.94— No. 11 – No. 57.	
1877.				*Inch.*	°		*Inch.*
Apr.	30, a. m	3	+	0.000013	62.45	−	0.000049
	30, m	3	+	006	62.90		110
	30, p. m	3	+	032	62.70		059
May	1, a. m	3	−	072	61.75		048
	1, m	3	−	033	61.85		022
	1, p. m	3	−	072	61.80		055
	2, a. m	3	−	305	60.35		113
	2, m	3	−	260	60.75		115
	2, p. m	3	−	247	60.80		109
	15, p. m	3	−	072	61.60		032
	16, a. m	3	+	039	62.55		035
	16, m	3	−	006	62.75		104
	16, p. m	3	+	0.000032	63.00		0.000096
Means		......		......	61.94	−	0.000073

Inch.
Hence, at 61°.94 F., No. 11 = No. 57 − 0.000073

and

Reduced to 62°.0 F., No. 11 = No. 57 − 0.000066

Shortly after these comparisons No. 11 was taken to Ottawa, Canada, and compared with standards in keeping there in May and June, 1877: an account of these comparisons is given further on.

Upon its return to this office it was again compared in March, 1878, with No. 57.

These comparisons were made by Mr. H. W. Blair, in the same place and manner as those made by him in April and May, 1877, excepting that different micrometers were attached to the apparatus.

The parallel lines in the microscopes were far enough apart to admit of a well-defined line of light on each side of the defining lines of No. 57. The temperature was noted by two Casella thermometers, Nos. 13135 and 13136, whose corrections were determined by comparison with two thermometers made by James Green, which, in turn, had been carefully compared with Coast Survey Kew standards. The correction to the mean of the two thermometers − 0°.01 was neglected as inappreciable.

During the comparisons, which occupied ten or twelve minutes, the thermometers genrally rose from 0°.3 to 0°.5; as they probably felt the heat of the observer's body sooner than the bars, the temperature first read was adopted for the comparisons. The bars were twice shifted in position to bring them alternately to the side next the observer.

Comparisons on the beam-compass comparator.

Date.	No. of comparisons.	Observed difference—No. 11 − No. 57.	Observed temperature (Fahr.)	At 61°.50—No. 11 − No. 57.
1878.		*Inch.*	°	*Inch.*
March 11, a. m.	3	− 0.000147	61.0	− 0.000086
11, p. m.	3	− 105	61.5	105
12, a. m.	3	− 056	62.7	089
12, p. m.	3	− 014	62.0	075
13, a. m.	3	259	60.4	126
13, p. m.	3	140	60.9	067
14, p. m.	3	084	62.1	157
15, p. m.	3	0.000112	61.4	0.000100
Means			61.50	− 0.000101

Inch.
Hence, at 61°.50, No. 11 = No. 57 − 0.000101

and

Reduced to 62°.0, No. 11 = No. 57 − 0.000040

In July, 1878, No. 11 was taken to England for comparison with the Imperial standard and others (see page 174), and after its return comparisons were again instituted between it and No. 57.

These comparisons were made in January and February, 1879, in room No. 6, Coast Survey building. The apparatus was that described in the account of the comparisons in 1877 and 1878, given above, but different micrometers were used. The manner of observing was, however, different. The bars were successively brought under the microscopes, and the micrometer-threads in each were moved until the central line in each well appeared midway between the parallel micrometer-threads.

The bulbs of the two mercurial thermometers made by James Green, New York, rested about midway on the bronze and iron bars, respectively. They had been compared with the Coast Survey Kew standards, and were compared with each other after the observations. The yards and the bulbs of the thermometers were covered over with cotton, and so was the brass bar to which the microscopes were attached. The whole arrangement was then screened from the radiation of heat of the observers by means of a wooden box. The values of the micrometers were deduced from the first millimeter of a Bruner centimeter scale in the possession of the office, and from the 0.01 inch intervals in the wells of No. 11, both giving practically identical values.

The time of each half day's comparisons was about ten minutes. The illumination used was artificial.

To vary the circumstances three sets of observations were taken.

In the first set No. 57 was nearest the observers.

In the second set the bars were turned end for end and No. 11 was placed nearest the observers.

In the third the arrangement was like to that in the first set.

The observations were made by Assistant O. H. Tittmann and Subassistant H. W. Blair, simultaneously and according to this scheme, Tittmann on the right and Blair on the left, then Blair on the right and Tittman on the left, bringing out the independent differences of micrometer-readings by Tittmann and by Blair.

Comparisons on the beam-compass comparator.

Date.	No. of comparisons. T + B	Observed temperature. (Fahr.)	Obs. diff., No. 11 − No. 57. Tittmann.	Obs. diff., No. 11 − No. 57. Blair.	No. 11 − No. 57 at 61°.11. Tittmann.	No. 11 − No. 57 at 61°.11. Blair.
1879.		°	*Inch.*	*Inch.*	*Inch.*	*Inch.*
Jan. 24, a. m......	6	63.55	+ 0.000131	+ 0.000149	− 0.000164	0.000146
24, p. m......	6	63.75	+ 033	+ 065	286	254
25, a. m......	6	64.15	+ 100	+ 151	178	217
25, p. m......	6	64.90	+ 163	+ 213	296	246
27, a. m......	6	58.95	− 472	− 422	211	161
27, p. m......	6	59.95	− 264	− 404	124	264
28, p. m......	6	66.80	+ 440	+ 416	248	272
29, a. m......	6	67.35	+ 505	+ 520	250	235
30, a. m......	6	66.10	+ 558	+ 517	046	087
30, p. m......	6	65.45	+ 380	+ 279	145	246
31, a. m......	6	62.55	+ 081	+ 050	093	124
31, p. m......	6	62.60	+ 033	+ 015	147	165
Feb. 1, a. m......	6	60.90	− 131	− 255	112	236
3, a. m......	6	51.15	− 1339	− 1304	134	099
3, p. m......	6	51.85	− 1247	− 1232	127	112
4, a. m......	6	53.80	− 953	− 921	078	036
5, a. m......	6	55.90	− 757	− 716	127	086
5, p. m......	6	57.10	− 668	− 636	183	151
7, p. m......	6	59.95	− 300	− 314	160	174
8, a. m......	6	61.80	− 101	− 086	184	169
8, p. m......	6	61.85	− 107	− 068	197	158
11, a. m......	6	60.90	− 255	− 214	220	189
11, p. m......	6	61.20	− 137	− 154	148	165
12, a. m......	6	62.80	+ 014	+ 009	190	195
12, p. m......	6	62.30	− 0.000024	− 0.000039	− 0.000168	− 0.000183
		61.11			− 0.000169	− 0.000175

Inch.

Hence, at 61°.11 F., No. 11 = No. 57 − 0.000172

and

Reduced to 62° F., No. 11 = No. 57 − 0.000064

The magnifying power of the microscopes used in the comparisons was about forty diameters.

The results obtained in different years under the varying circumstances described are, therefore, as follows:

Date.	Observers.	Apparatus.	No. of comparisons.	Observed temperature.	No. 11–No. 57.	
					At observed temperature.	At 62°.
				°	*Inch.*	*Inch.*
1876	A. H. S	Line and end comparator	15	67.10	+ 0.000544	− 0.000073
1877	H. W. B	Beam-compass comparator	39	61.94	− 0.000073	− 0.000066
1878	H. W. B	do	24	61.50	− 0.000101	− 0.000040
1879	O. H. T. and H. W. B	do	150	61.11	− 0.000172	− 0.000064
Arithmetical mean						− 0.000061

We therefore have, as the final result of these comparisons—

$$\text{No. } 11 = \text{No. } 57 - 0.000061 \text{ inch at } 62° \text{ F.}$$

COMPARISON OF BRITISH BRONZE YARD No. 11 WITH THE IMPERIAL YARD AND OTHER STANDARDS OF GREAT BRITAIN.

1. *Comparisons with standards of the Dominion of Canada.*

The comparisons made in 1876 and 1877 between No. 11 and No. 57 having established, beyond doubt, that a different relation at present exists between the lengths of these standards than is given in the statement accompanying them, it became important to ascertain which one had changed, or whether the change was partly in both. It was therefore determined, as a preliminary step, to compare No. 11 with the standard of the Dominion of Canada.

Deposited with the Commissioner of Internal Revenue, at Ottawa, are four yards of the same material as, and similar in construction to, No. 11. They are known as Bronze No. 16 and Dominion Standards A, B, and C. Bronze No. 16 is one of the copies of the Imperial Standard Yard made by the Standards Commission and sent to Canada in 1857. From previous comparisons with the Imperial standard, its assigned standard temperature is 61°.94 F. A, B, and C were compared in England in 1874 with No. 6, known as the "Generator," or "accessible representative of the National standard," and A was found standard at 61°.91 F. For an account of the Dominion standards see "Second Report of the Commissioner of Inland Revenue on the Inspection of Weights, Measures, and Gas," Ottawa, 1875.

In the latter part of May, 1877, No. 11 was taken to Ottawa for comparison with the standards there in keeping. For this purpose A and No. 16 were selected. The comparisons were made in the basement of the Parliament buildings with the new micrometric comparing apparatus constructed for the Dominion by Troughton & Simms. (See the report cited above.)

Comparisons were begun on May 26, and continued from day to day until June 1, being made by Messrs. Hilgard, Brunel, Russell, and Wright. The illumination was obtained sometimes by daylight, sometimes by the use of lamps. The manner of illuminating appears to have had no marked effect on the results, and though generally noted it is not regarded. The temperature was very uniform throughout the observations. The bars being all of the same material, shape, and size, the variations of temperature, though recorded, are not taken into account in the reductions. The temperature is so near that at which the bars are standard that a slight difference in their coefficient of expansion is not appreciable in the reductions.

The observations of May 26 are rejected, the sun having shone on the apparatus for some time in the early morning, and the observations being intended as merely experimental and for practice.

The values of the micrometers used were determined from the spaces of 0.01 inch on the gold pins at the bottom of the wells of Bronze 11. The observations give—

1 division of micrometer A = 0.0000202 + inch
1 division of micrometer B = 0.0000203 − inch

In the following abstract each comparison is the result of three pointings by the micrometers on each bar.

Abstract of comparisons between No. 11 and No. 16.

Date.	Observer.	No. of comparisons.	Temperature, Fahr.	No. 16 – No. 11. micro. div.	Remarks.
1877.			°		
May 27, 9.15 a. m	Hilgard	2	62.8	– 4.7	
9.22 a. m	Brunel	2	....	7.7	
9.40 a. m	Hilgard	2	62.9	5.5	
4.30 p. m	....do	4	61.9	1.3	
5.00 p. m	Brunel	2	....	2.3	
5.20 p. m	....do	2	....	8.2	
5.30 p. m	Hilgard	2	62.3	+ 1.6	
					Bars interchanged.
May 28, 11.00 a. m	Hilgard	4	62.2	– 3.6	
11.27 a. m	Brunel	4	....	+ 0.2	
	Hilgard	2	....	+ 1.0	
3.35 p. m	....do	2	63.2	1.0	
3.45 p. m	Brunel	2	....	0.6	
8.00 p. m	Hilgard	2	61.9	+ 2.7	
	Brunel	2	....	5.4	
May 31, 8.40 p. m	....do	4	63.3	3.2	
9.05 p. m	Hilgard	4	63.5	+ 3.2	
					Bars interchanged
June 1, 10.10 a. m	Hilgard	2	63.8	+ 6.2	
10.39 a. m	....do	2	....	3.7	
10.50 a. m	....do	2	....	4.0	
11.02 a. m	....do	2	....	4.7	
11.18 a. m	Brunel	2	....	5.8	
11.30 a. m	....do	2	64.5	+ 5.5	

Weighting the results according to the number of comparisons, we obtain—

$$\text{No. } 16 = \text{No. } 11 + \overset{\text{Div.}}{2.81} = \text{No. } 11 + \overset{\text{Inch.}}{0.000057} \text{ at } 62^{\circ}.73 \text{ F.} \quad (1)$$

Abstract of comparisons between No. 11 and Dominion Standard A.

Date.	Observers.	No. of comparisons.	Temperature, Fahr.	A – No. 11. micro. div.	Remarks.
1877.			°		
May 29, 10.40 a. m	Hilgard	2	63.5	+ 6.0	
					Bars interchanged.
p. m	Brunel	2	....	12.6	
	Hilgard	2	....	5.8	
	Russell	2	....	6.6	
May 30, 10.20 a. m	Hilgard	2	62.2	9.3	
a. m	....do	2	....	9.3	
11.05 a. m	....do	2	63.0	11.0	
11.16 a. m	....do	2	....	10.5	
11.25 a. m	Brunel	2	....	9.3	
11.55 a. m	....do	2	63.5	9.1	
					Bars interchanged.
3.00 p. m	Brunel	2	63.0	2.6	
3.05 p. m	Hilgard	2	63.2	7.5	
	....do	2	....	9.6	
3.30 p. m	....do	2	....	6.5	
	Wright	2	....	5.8	
	....do	2	....	7.1	
4.20	....do	2	63.5	9.3	
8.40	Hilgard	2	....	6.1	
9.00	Brunel	2	63.5	7.2	
Mean	....	....	....	7.96	

$$A = \text{No. } 11 + \overset{\text{Div.}}{7.76} = \text{No. } 11 + \overset{\text{Inch.}}{0.000162} \text{ at } 63^{\circ}.18 \text{ F.} \quad (2)$$

Abstract of comparisons between Dominion Standard A and No. 16.

Date.	Observer.	No. of comparisons.	Temperature, Fahr.	A − No. 16. micr. div.	Remarks.
1877.			°		
May 31. 10.05 a. m...	Hilgard	4	62.5	+ 3.7	
11.40 a. m...	Brunel	4		4.9	
12.00 m.....	Hilgard.......	2	63.0	4.0	
3.15 p. m...	Hilgard .... }	13	63.2	+ 3.85	Bars interchanged.
4.45 p. m...	Brunel ..... }				
Mean..........				+ 4.02	

Weighting the results, according to the number of comparisons, we obtain—

$$A = \text{No. } 16 + \overset{\text{Div.}}{4.02} = \text{No. } 16 + \overset{\text{Inch.}}{0.0000816} \quad (3)$$

Collecting the results of the direct comparisons we have—

Inch.

(1) No. 16 = No. 11 + 0.000057 from 54 comparisons on 4 days.
(2) A = No. 11 + 0.000162 from 38 comparisons on 2 days.
(3) A = No. 16 + 0.000082 from 23 comparisons on 1 day.

Inch.

From (1) we have No. 16 = No. 11 + 0.000057
From (2) and (3) we have No. 16 = No. 11 + 0.000080

The discrepancy, = 0.000023 may, in this case, be apportioned among the results in the inverse proportion of the number of comparisons from which they are deduced.

Thus we obtain, as the final result of these comparisons—

Inch.

No. 16 = No. 11 + 0.000062
A = No. 11 + 0.000155
A = No. 16 + 0.000093

According to the data accompanying the Canadian standards—

Bronze No. 16 is standard at 61°.94 F.
Bronze A is standard at 61°.91 F.,

and we should therefore have—

Standard A = Bronze 16 + 0^{in}.000010

The actual comparisons, however, give—

Standard A = Bronze 16 + 0^{in}.000093

The discrepancy = 0^{in}.000083, showing that these bars have not now the relative lengths attributed to them.

Between No. 16 and No. 11 we should have, according to the assigned standard temperatures—

No. 16 = No. 11 − 0^{in}.000051

But the foregoing comparisons give—

No. 16 = No. 11 + 0.000062, showing a relative change of 0^{in}.000113 since their comparison by the Standard Commission in 1853.

Comparisons with the Imperial Yard and other standards at the Standards Office, Westminster, London.

First series.—After having been returned to the United States No. 11 was taken to England in July, 1878, for comparison with the Imperial standard.

A first series of comparisons were made under the direction of Mr. H. J. Chaney in September, 1878, between No. 11 and No. 1 (Imperial Standard), No. 6 (Generator), and Cast-Iron Yards B No. 62 and C No. 63.

The Imperial standard is fully described in the "Weights and Measures Act, 1878," 41 and 42 Vict., chap. 49. No. 6 is the bronze yard with which all the copies of the Imperial Standard were originally compared, and, like No. 1, it has its standard length at 62° F. (Airy, Phil. Trans., vol. 75, London, 1857.)

The following extracts, given in quotation marks, are from a statement signed H. J. Chaney, and dated Board of Trade, Standard Department, September 9, 1878:

"The apparatus by which the length of these yards was now compared is the same apparatus as was used by Baily and Sheepshanks in the original comparisons of these standards. A detailed description of this apparatus is given by the Astronomer Royal in the Philosophical Transactions for 1857.

"There have been recently fitted to this apparatus, however, two better microscopes (Nos. 1 and 2), of which the value of the micrometers has been carefully ascertained by this department and particularly by Captain Heaveside, to be $0^{in}.0000319$ for each division." (8th Report, Warden of the Standards.)

"The thermometers used were made by Heicks Baudin and Negretti and Zambra, and have been pronounced by meteorological authorities to be very fine and sensitive instruments. The comparisons took place in a vault of this office known as the 'strong room.'

"The yard No. 11 has also been compared with two of the cast-iron yards B and C, the lengths of which are stated by the Standards Commission to be respectively in 1857:

Cast-iron B, No. 62, t = 62.90 F.
Cast-iron C, No. 63, t = 62.34 F.

"These two yards B and C were originally as carefully compared as the other standards verified by the Standards Committee. They have since been occasionally used, and so soon as a convenient opportunity arrives, it is desirable that they should be further compared with the cast steel A, D, C (Nos. 65, 66, 67), or the bars of copper and alloy (Nos. 51, 52, 53)."

Rates of expansion.

"In the present comparisons there have "been employed the rates of expansion given by Sheepshanks, which were accepted by the Standards Committee for the accurate reduction of standards, and in terms of which the lengths of the copies of the Imperial yard have been and are now expressed. They are as follows:

"Thermometer expansion of one yard:

36 inches for 1° F.
Baily's bronze = 0.000341 inch
Cast iron = 0.000198 inch

"The rates of expansion obtained from the independent experiments of Clarke, Fizeau, and of this department do not precisely agree with those above stated; nor is it certain that the rate of expansion of a bar, whether of an alloy or of a pure metal, remains constant. The experiments of this department would incline it to the opinion that the rate of expansion of a bar increases with age. Slight corrections may be hereafter applied to the results now obtained.

"*Results of comparisons of bronze No.* 11 (*United States*) *with bronze No.* 1 (*Imperial Yard*).

Date.	Results in micrometer divisions.	Mean temperature, Fahr.	
		No. 11.	No. 1.
		°	°
Sept. 5, 1878	No. 11 = No. 1 − 2.62	66.52	66.53
Sept. 5, 1878	No. 11 = No. 1 − 2.54	66.43	66.44
Means	2.58	66.48	66.49

"As one division equals 0.0000319 inch—

$$(a)\ \text{No. } 11 = \text{No. } 1 - 0.000082 \text{ inch}, \ t = 62^\circ \text{ F.}$$

"The present true length of No. 11 appears, therefore, to be 35.999918 inches. In 1857 the error of No. 11 was + 0.000072, its standard temperature then being 61°.79 F.

"It may be remarked that this (*a*) is the result of about 300 observations, and that the probable error of the result is ± 0.000005 inch.

"*Results of bronze No.* 11 *with bronze No.* 6 (*Generator*).

Date.	Results in micrometer divisions.	Mean temperature, Fahr.	
		No. 11.	No. 1.
		°	°
Sept. 8, 1878	No. 11 = No. 6 − 2.80	65.5	65.5

"Therefore at 62° F.—

$$(b)\ \text{No. } 11 = \text{No. } 6 - 0.000089 \text{ inch}$$

"This agrees practically with the result previously obtained, viz: − 0.000082. Only 36 observations of No. 11 − No. 6 were recorded, the probable error of the result being ± 0.00001 inch.

"*Results of comparisons of bronze No.* 11 *with cast-iron B and cast-iron C.*

Date.	Results in micrometer divisions.	Mean temperature, Fahr.	
		No. 11.	B C.
		°	°
Sept. 6, 1878	No. 11 = B + 14.76	66.2	66.1
Sept. 9, 1878	No. 11 = C + 13.30	66.4	66.4

"Therefore—

$$(c)\ \left.\begin{matrix}\text{No. } 11\\ t = 66^\circ.2\end{matrix}\right\} = \left\{\begin{matrix}\text{B}\\ t = 66.1\end{matrix}\right\} + 0.000471 \text{ inch}$$

$$(d)\ \left.\begin{matrix}\text{No. } 11\\ t = 66.4\end{matrix}\right\} = \left\{\begin{matrix}\text{C}\\ t = 66.4\end{matrix}\right\} + 0.000424 \text{ inch}$$

and at 62° F., after allowing for differences of expansion, these results will be—

$$(e)\ \text{No. } 11 = \text{B} - 0.000159 \text{ inch}$$
$$(f)\ \text{No. } 11 = \text{C} - 0.000205 \text{ inch}$$

"In 1857, at 62° F.—

	Inch.
No. 11 = No. 1	+ 0.000072
B =	− 0.000178
C =	− 0.000067

"Therefore, in 1857—

No. 11 = B	+ 0.000250
No. 11 = C	+ 0.000139

"In the comparisons of B, C, and No. 11 ninety-six observations were recorded, the probable error of the result being ±0.000008 inch.)

"CONCLUSION.

"It would thus appear that, as compared with the original Bronze Imperial Standard, the United States Bronze Yard No. 11 has, since 1857, decreased in length 0.000154 inch" (= 0.000072 + 0.000082.)

Second series.—A second series of comparisons of No. 11 with No. 1 and No. 6 was made between October 11 and 22 of the same year (1878) by Mr. Hilgard and Mr. Chaney, conjointly.

Between October 11 and 18 the observations were made on the Baily & Sheepshanks apparatus, in the "Strong room," as described and referred to in Mr. Chaney's statement above given.

During the observations the bars were so shifted as to be alternately next to the observers. They were also at times turned end for end. The microscopes were twice transposed. The temperature was derived from the indications of three thermometers, numbered as follows, 16858, 20065, and 20066. They were laid on the surface of the bars, one with its bulb near the middle of one bar, the other two with their bulbs near the extremities of the other.

The observations were made simultaneously and according to the following scheme:

Hilgard on the right, Chaney on the left; Chaney on the right, Hilgard on the left, bringing out the independent differences.

Microscope-reading, Hilgard left; microscope-reading, Hilgard right. Microscope-reading, Chaney left; microscope-reading, Chaney right.

The time occupied by each a. m. or p. m. series was about half an hour.

In the reductions the coefficient of expansion is assumed to be the same for both bars under comparison, and they are also assumed to have been at the same temperature during the comparisons.

The value of the micrometer-divisions = 0.0000319 inch.

After the comparisons in the "strong room" had been completed, No. 1 and No. 11 were removed to the "tower," and were there compared on the new comparing apparatus, a description of which will be found in the Fifth Annual Report of the Warden of the Standards, Appendix VII. The values of the micrometers of the microscopes are therein given, page 99, to be—

	Inch.
Micr. No. 1, one division =	0.00003187
Micr. No. 2, one division =	0.00003188
Mean	0.0000319

As an additional precaution against the influence of the heat radiated by the observers' bodies, the bars and thermometers were covered with cotton.

The same thermometers used in the comparisons made in the "strong room" were used in the "tower," with the addition of one, No. 12765, which, during the previous comparisons, was not available, being at Kew for comparison. They were laid on the surface of the bars. The method of conducting the observations was entirely similar to that pursued in the "strong room," and the reductions are made on the same assumptions.

In both the "strong room" and in the "tower" comparisons, the work was done by the aid of artificial illumination.

Results of comparisons between Bronze No. 11 and Bronze No. 6.

Date.	Time— A. M.	Time— P. M.	Corrected temperature. (Fahrenheit.)	Observed micrometer difference. No. 6–No. 11. Hilgard.	Observed micrometer difference. No. 6–No. 11. Chaney.
1878.			°		
Oct. 11	11.45	....	62.4	+ 2.30	+ 2.60
12	10.15	....	61.8	3.72	3.05
Means		....	62.1	3.01	2.82

Hence—

$$\text{No. } 11 = \text{No. } 6 - 0.000093 \text{ inch} \pm 0.000010$$

No. 6 and No. 11 were compared twelve times, each comparison consisting of three observations on No. 6 and three on No. 11.

Results of comparisons between Bronze No. 1 and Bronze No. 11.

Date.	Time— A. M.	Time— P. M.	Corrected temperature. (Fahrenheit.)	Observed micrometer difference. No. 1–No. 11. Hilgard.	Observed micrometer difference. No. 1–No. 11. Chaney.
STRONG ROOM.					
1878.			°		
Oct. 14	....	....	61.31	+ 4.02	+ 3.22
14	....	2.00	61.87	2.40	3.02
14	....	4.00	61.83	1.95	1.05
15	....	5.00	61.53	0.55	1.27
16	10.45	....	61.36	2.78	1.05
16	....	1.45	61.45	1.55	1.02
17	11.15	....	61.60	4.50	4.02
17	11.50	....	61.83	2.78	3.05
17	....	4.18	62.46	5.92	5.27
18	10.30	....	61.97	4.28	3.58
18	....	12.25	62.10	+ 6.10	+ 5.35
			61.75	+ 3.35	+ 2.90
OBSERVATIONS IN THE TOWER.					
Oct. 20	10.30	....	58.33	− 0.10	+ 0.30
20	....	1.55	60.60	+ 2.38	4.80
21	....	4.50	61.23	2.50	3.88
21	....	2.00	59.00	4.28	2.45
21	....	4.35	59.95	+ 2.50	+ 2.10
Means		....	59.82	+ 2.31	+ 2.71
Final mean		....	61.15	+ 2.93	

Hence—

$$\text{No. } 11 = \text{Imperial yard (No. 1)} - 0.000093 \text{ inch} \pm 0.000002 \text{ inch}$$

No. 1 and No. 11 were compared 128 times, each comparison consisting of three observations on No. 1, and three observations on No. 11.

Tabulation of results of comparisons between No. 11 and foreign standards.

Date.	Observed temperature, Fahr.	
		DOMINION STANDARDS.
1878.	°	*Inch.*
May and June....	62.93	No. 11 = No. 16 − 0.000062
May and June....	63.18	No. 11 = A − 0.000155
May and June....	62.90	A = No. 16 + 0.000093
		ENGLISH STANDARDS.
September........	66.15	No. 11 = B + 0.000464
September........	66.40	No. 11 = C + 0.000424
September........	65.50	No. 11 − { No. 6 0.000089 } 91
October...........	62.10	No. 11 − { No. 6 − 0.000093 } 91
September........	66.49	No. 11 − { No. 1 − 0.000082 } 88
October...........	61.15	No. 11 − { No. 1 − 0.000093 } 88

By reducing the results of direct and indirect comparisons to the standard temperature of 62° F., using Sheepshanks coefficients of expansion, we get the following comparative table of relative changes between the Imperial standard and the bars compared with it and No. 11.

Assigned value, 1853.	Observed and inferred value, 1878.	Change relative to No. 1.
Inch.	*Inch.*	*Inch.*
No. 1 = No. 11 − 0.000072	+ 0.000088	0.000160. No. 11 has shortened.
No. 1 = No. 6	− 0.000003	No appreciable change.
No. 1 = No. 16 − 0.000020	+ 0.000026	0.000046. No. 16 has shortened.
No. 1 = D. S. A* − 0.000031	− 0.000067	
Cast iron.		
No. 1 = B + 0.000178	0.000071	0.000249. B has lengthened.
No. 1 = C + 0.000067	− 0.000117	0.000184. C has lengthened.
Wrought iron.		
No. 1 = No. 57 + 0.000128	+ 0.00002	0.0001. No. 57 has lengthened

* Of recent construction, and compared in 1874 with No. 6.

Although the inferred relation given above between No. 1 and the iron bars cannot be accepted as of final accuracy, it is sufficiently evident that a change has taken place between the Imperia Standard and these bars, and that this change has been in one direction. We are, therefore, not justified in accepting the conclusion of the Warden of the Standards that no change has occurred in the absolute lengths of the Imperial Standard and the three Parliamentary copies. See "An account of the comparisons of the Parliamentary copies of the Imperial Standard." London, 1877.

Using Clarke and Fizeau's value of the expansion of 36 inches of Baily's metal which at 62° = 0.000351 inch for 1° F., we obtain from the equation—

$$\text{No. } 11 = \text{No. } 1 - 0.000088 \text{ inch}$$

No. 11 is standard at 62°.25 Fahr.

7. COMPARISON OF THE TROUGHTON SCALE WITH STANDARD No. 11 BRONZE.

Comparisons of the divisions of the Troughton scale among themselves, made by Mr. Hassler, and recorded in House Document No. 299, Twenty-second Congress, First Session, showed that the 36 inches included between the 27th and 63d inches of that scale corresponded to the mean of the whole scale. This distance has, therefore, been taken as the standard of reference.

In April, 1877, this length of 36 inches on the Troughton scale was compared with the British Standard No. 11, with a view to obtain a near comparison with the Imperial Standard Yard which would be available in 1878.

The comparisons were made by Mr. H. W. Blair, on the optical beam-compass comparator, subsequently used in the comparisons between Bronze No. 11 and Iron No. 57, and described in connection with those comparisons. The bars were successively brought under the microscopes, the Troughton scale by sliding transversely, the bronze yard by being lifted over the other. By means of the longitudinal motion of the beam-compass the right micrometer was made to read nearly the same on each bar, so that the difference was nearly all measured on the left micrometer. Each comparison consists of three readings, alternate, upon the Troughton scale and No. 11. The temperature was noted by three Casella thermometers, Nos. 13416, 13420, and 13135. Their combined correction, determined at the Kew Observatory is, + 0°.00 at 62°. Two of these thermometers were laid upon the Troughton scale and one upon No. 11.

It was desirable that the comparisons be made at a temperature near to that at which each bar is of standard length, in order to avoid the effect of unknown difference of expansion. On account of the marked difference in the figure of the cross-section and in the mass, stability of temperature was also of great importance.

The comparisons of April 7 were made at a temperature which had been almost constant for several days. On that afternoon the weather turned suddenly cold, and during the night the temperature of the comparing-room fell six degrees. Further comparisons were postponed until the temperature again rose above 60° and had been maintained for twenty-four hours. This was not until the 12th.

An abstract of the results of the comparison is given below.

Comparisons between Troughton scale and British bronze yard No. 11.

1877.	A. M. or P. M.	Temperature, Fahr.	Troughton scale longer than Bronze No. 11.
		°	*Inch.*
April 7	a. m.....	62.3	0.000916
7	m.......	62.4	0915
7	p. m	62.7	0950
12	m.......	61.5	0956
12	p. m	61.6	1002
17	a. m.....	63.2	0890
17	m	63.5	0923
18	a. m	65.3	0.000846
		62.8	0.000925
			± 0.000011

And we have at 62°.8 Fahr.—

$$\text{Troughton scale} - \text{Bronze No. 11} = 0^{in}.000925 \pm 0^{in}.000011$$

The comparisons of 1856 by Mr. Saxton give, at about 61° Fahr.—

$$\text{Troughton scale} - \text{Bronze No. 11} = 0^{in}.00080 \pm 0^{in}.00004.$$

The comparisons of 1877, therefore, indicate a shortening of No. 11 relative to the Troughton scale = 0in.000125, nearly agreeing with the shortening of No. 11 (0.000160), ascertained by comparison with the Imperial Standard of Great Britain.

The last-mentioned comparisons give 62°.25 Fahr. as the temperature at which No. 11 is of standard length.

No special observations have ever been made for the determination of the coefficient of expansion of the Troughton scale. For the determination of the temperature at which the Troughton yard is of standard length, its coefficient is assumed to be the same as that of No. 11, an assumption which cannot be far wrong, and the error from which must be insignificant for the small reduction required. We admit, therefore, the following statements:

		Inch.
Troughton scale, 27 to 63 inches longer than bronze standard No. 11	=	0.000925
British standard No. 11, bronze, at 62°.25 Fahr.	=	36.000000
Mean yard of United States, 84 inch scale (27 to 63), at 59°.62 Fahr.	=	36.000000

8. CONCLUDING STATEMENT.

1. The temperature at which the mean yard of the United States, 84-inch Troughton scale, is equal to the British standard yard is 59°.62 Fahr. All standards heretofore issued to the several States of the Union, on the supposition that the Troughton scale was standard at 62° Fahr., require the corresponding correction of the imputed standard temperature.

2. Bar No. 11 bronze, presented to the United States, is in all respects an original fellow of both the Imperial yard, which can be referred to only once in twenty years, and of No. 6, kept in the British Standards Office for usual comparison, and appears to have sensibly shortened in reference to them by 0.000160 inch.

3. Comparisons with No. 57 Low Moor iron, a fellow of the preceding ones, that is to say, having been constructed at the same time and undergone the same verifications, exhibits a similar shortening of No. 11, somewhat in excess of that shown by the comparison of the latter with the Imperial Standard.

4. It should now be stated that both No. 11 bronze and No. 57 Low Moor iron, for want of proper provision for their safe-keeping, have been subjected to great variations of temperature, varying fully 75° Fahr. between 1856 and 1872. They were kept in a small fire-proof building with an iron roof, safe indeed from conflagration, but subjected to the extreme variation of the American seasons.

5. From the foregoing facts, we are constrained to conclude that the bronze yard No. 11, which has been subjected to transportation and great changes of temperature, has shortened relatively to similar measures which have been preserved at a nearly constant temperature. In maintaining this proposition we must first emphasize the fact that there is not now any perceptible difference between the Imperial Standard No. 1 and the usual or accessible standard No. 6, the equality between which has not sensibly changed in twenty-four years. No. 1 has been kept at a very uniform temperature within the walls of the Houses of Parliament, while No. 6 has been subjected to but slight variations of temperature in the strong-room of the old treasury, now No. 7 Old Palace yard. We next find that a measure of the same character, but which is known to have been subjected to great variations of temperature, shows, after twenty years, a difference far beyond the possible error of comparison.

6. On the other hand we find that a wrought-iron bar (No. 57 Low Moor iron) which has been subjected to the same vicissitudes as No. 11 bronze has not only maintained its relative length to the Imperial Standard, but appears somewhat longer through the comparisons with No. 11 by an amount = 0.000108 inch, which may possibly be covered by the errors of observation. In order to obtain further evidence on this point, Iron Yard No. 57 has been sent to England for direct comparison with the British standards, and particularly with its fellow, Low Moor Iron No. 58, the only one of the original yards of the same material and construction as No. 57.

The persistence of the dimensions of material reduced to the plastic condition is strongly confirmed by the comparisons made in 1867 between one of the original iron meters long in possession of the United States Coast Survey and the platinum meter of the *Conservatoire des Arts et Metiers*, made about 1800, which exhibited no difference of so much as the thousandth part of a millimeter after so many years, involving two transportations across the ocean and extreme vicissitudes of temperature.

7. When we consider the constitution of any "bronze" metal, especially such as Baily's metal, from which, on account of its great rigidity, the British bronze standards were made, and which consists of copper, 16 parts; tin, 2½ parts; zinc, 1 part, we will observe the fact that about five-sixths of the mass is composed of copper, a very pliable and ductile metal, while the admixtures have imparted to it great hardness and rigidity. This alloy was especially selected for the latter mechanical qualities, but the suitability of the molecular structure was not considered. In the light of our recent experience we are permitted to assume that the molecules of such a casting are in a state of great tension, which will yield under changes of temperature, and, if so, perhaps in less degree, to the simple effect of continuance. Hence, while we admit that the shortening of No. 11 bronze relative to the Imperial standard, has taken place in consequence of the great variations of temperature to which it has been subjected, it is not improbable that No. 1 and No. 6 may both have shortened by the effect of time alone during the past twenty years, so as to make the excess of No. 57 (wrought iron) a reality rather than an accumulation of residual errors.

8. Finally, we may state as the result of all the comparisons of 1876–'78 between the yard of the Troughton scale, Bronze No. 11 and Iron No. 57, and the Imperial Standard of Great Britain, that

	Inch.
Bronze No. 11	= 36.000000 at 62.25 F.
Iron No. 57	= 36.000000 at 62.10 F.
Mean yard of Troughton scale	= 36.000000 at 59.62 F.

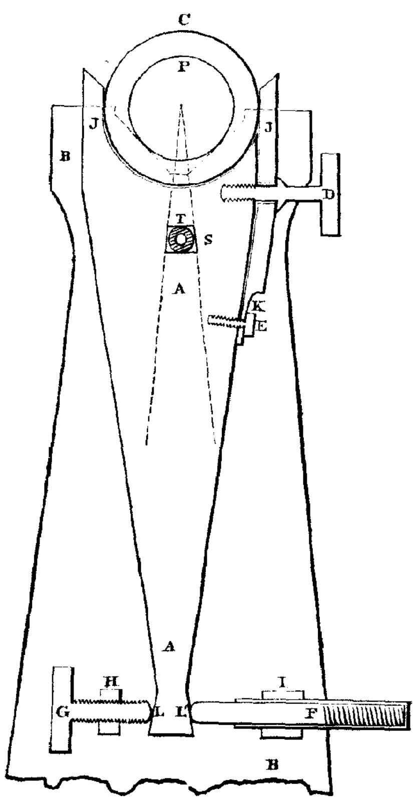
APPENDIX No. 13.

DESCRIPTION OF AN IMPROVED OPEN VERTICAL CLAMP FOR THE TELESCOPES OF THEODOLITES AND MERIDIAN INSTRUMENTS, DEVISED BY GEORGE DAVIDSON, ASSISTANT UNITED STATES COAST SURVEY.

A description of the first form of 1873 is given in Appendix No. 15 of the Superintendent's Annual Report for 1874. The main idea of both forms is the same.

This clamp has been adopted by instrument-makers outside the Coast Survey, and very favorable opinions have been expressed in regard to it.

To avoid the complication of parts, and of additional weight, the theodolites and the meridian instruments of the Coast Survey have not been furnished with reversing apparatus; necessarily, there is some inconvenience and delay experienced in reversing the telescope in the transit *axis* Y's. Moreover, it has been proven that with the ordinary vertical clamp there is a lifting action developed at the transit axis pivot if the slow-motion screw is not perfect in its movement. The resultant of this lifting action, combined with the necessary horizontal movement of the pivot, is a sliding motion of the pivot up one of the inclined planes of the transit axis Y, and a consequent change of azimuth of the optical axis of the telescope. This change is minute, but is readily detected in the larger theodolites when using a geodetic collimator, or when making the azimuth observations upon a close circumpolar near elongation.



In this newer form of clamp I have so arranged the parts that the clamp does not clasp the transit-axis collar, but holds it simply at two points, 180° apart, by the tangent-planes J J'.

The vertical plate or arm A A is held in position by the cylindrical stud T, which projects at right angles from the transit-axis pillar B B, with its extremity flush with the outer face of A A.

The slot S, in the vertical plate A A, is formed by the sweeping of the inner and outer circumference with center at the transit-axis. A screw (with washer and flat spring) fits into the stud T to keep the vertical plate from moving off the stud, and also to keep it in the same position during reversal as when unclamped for the reversal of the telescope.

The clamping-bar J' has motion about the point K, where the metal is reduced, so that a spring-like action is obtained; the shortness of this spring prevents the upward thrusting motion of J' when the clamping-screw D draws J' toward A A. The studs H and I project from the transit-axis pillar and carry the slow-motion screw G and the opposing spring F.

The noticeable angle given to the sides L L' of the lower extremity of the vertical plate A A has been adopted, in order that there shall be a tendency both of the screw G and the opposing spring F to press down the vertical plate at whatever vertical angle the plate may be. This is to counteract any lifting tendency in the point of the screw G when it is eccentric, which experience shows to be generally the case.

The recapitulation of the good qualities of the clamp may be stated thus:

I. The telescope is clamped with sufficient firmness to admit of its being moved in altitude in the vertical plane by the slow-motion screw.

II. The clamp may be made to hold the transit-axis so gently that a very delicate tap on the telescope will bring the latter to the desired elevation.

III. The top of the clamp is open, so that it permits the telescope to be lifted out for reversal and readily replaced in the Y's without carrying the clamp with it.

IV. The jaws of the open clamp remain during reversal in the same position as when unclamped before the reversal of the telescope.

V. There is no tendency to lift the vertical plate through eccentricity of the slow-motion screw, and consequently no resultant movement of the transit axis in azimuth.

APPENDIX No. 14.

OBSERVATIONS OF THE DENSITY OF THE WATERS OF CHESAPEAKE BAY AND ITS PRINCIPAL ESTUARIES. REPORT BY LIEUT. FREDERICK COLLINS, UNITED STATES NAVY, ASSISTANT COAST SURVEY.

SIR: I have the honor to submit the following report of the operations of the party under my command, lately engaged under your instructions, in a series of observations for the determination of the densities of the waters of Chesapeake Bay, from its head to the Capes; including a partial examination of its more important estuaries and tributaries.

In advance of any opportunity for study of the results obtained, the present report is necessarily confined to a concise statement of those results, with a brief description of the instruments employed, and the general method of conducting the experiments.

The general plan of operations was to make cross-sections of the bay and tributaries at certain points, occupying on each section a convenient number of stations, and securing at each of these stations serial specimens of the water, at intervals of two fathoms, from the surface to the bottom. At the same time there were to be obtained as many specimens of the bottom itself as might be necessary to give a fair idea of its characteristics in different parts.

These, together with the water specimens, were to be sent to the office for chemical analysis; the latter having first been tested for density with delicate hydrometers, as soon as possible after having been secured.

The scheme contemplated twenty-six sections, as shown in the following table:

No. of section.	Length in miles.	No. of stations.	No. of water-specimens.	No. of bottom-specimens.	Locality of section.
1	2	4	9	1	Patapsco River, Rock Point to North Point.
2	$\frac{3}{4}$	4	11	1	Susquehanna River, at Havre-de-Grace.
3	2	5	14	1	Chesapeake Bay, at Norton Point.
4	$6\frac{3}{4}$	7	19	1	Chesapeake Bay, at Bodkin Point.
5	$2\frac{3}{4}$	5	14	1	Chester River, at Love Point.
6	$\frac{3}{8}$	3	7	1	Severn River, opposite Naval Academy.
7	4	7	27	2	Chesapeake Bay, at Horseshoe Point.
8	$2\frac{1}{4}$	5	16	2	Eastern Bay, at Wade's Point.
9	3	5	16	2	Choptank River, at Cook's Point.
10	5	5	22	2	Chesapeake Bay, at Cove Point.
11	1	3	10	1	Patuxent River, at Drum Point.
12	$\frac{3}{8}$	3	14	1	Patuxent River, at Point Patience.
13	9	9	36	2	Chesapeake Bay, at Point No Point.
14	[5]	5	19	1	Potomac River, at Point Lookout.
15	[3]	5	19	2	Potomac River, at Piney Point.
16	[$2\frac{1}{2}$]	5	15	1	Potomac River, near Blackistone Island.
17	8	8	28	2	Chesapeake Bay, at Smith's Point.
18	7	8	27	2	Entrance to Tangier and Pocomoke Sounds.
19	16	11	39	6	Chesapeake Bay, at Rappahannock Spit.
20	3	5	15	1	Rappahannock River, at Windmill Point.
21	12	9	35	2	Chesapeake Bay, at New Point Comfort.
22	$2\frac{1}{2}$	4	14	4	York River, inside Tod's Point.
23	3	4	16	1	Hampton Roads, at Old Point Comfort.
24	2	5	15	3	James River, near Newport News.
25	9	6	24	1	Chesapeake Bay, entrance.
26	20	7	31	0	Outside the Capes.

NOTE.—All the stations on sections 4 and 21 were occupied twice.

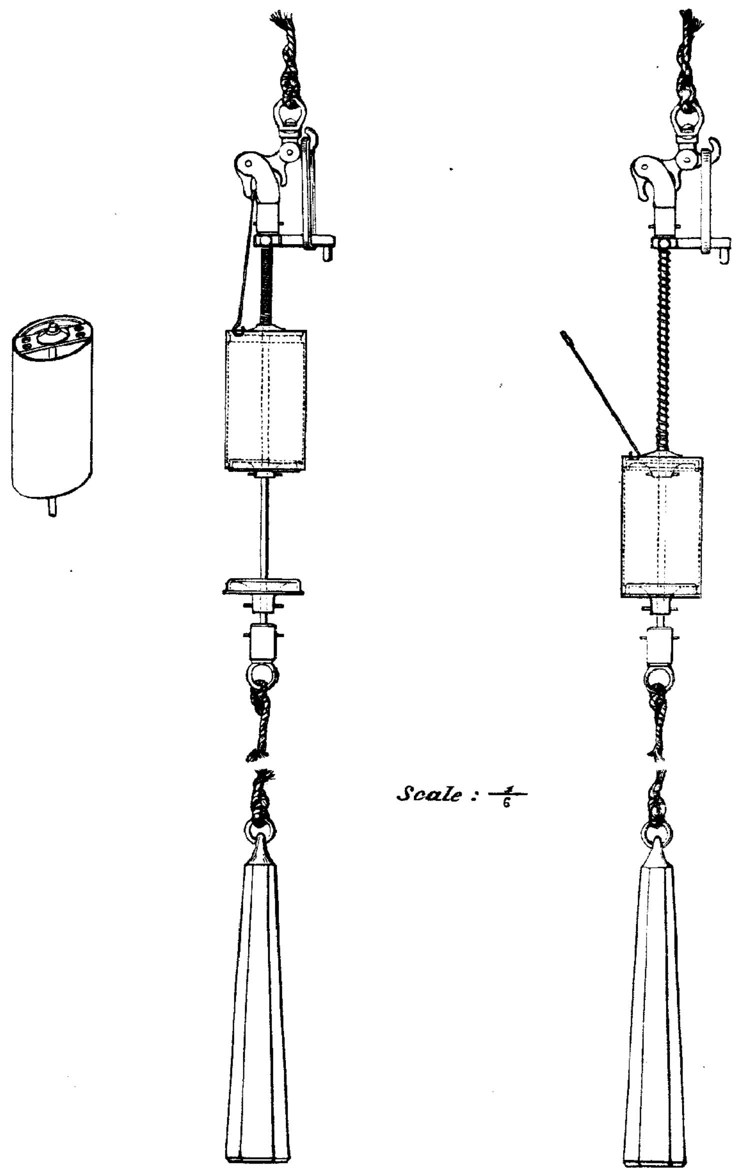
The stations exhibited in this table were occupied and specimens of the water and bottom secured as therein set forth. Appended to this report is another table,* showing in detail the position of the various stations, the depths from which the specimens were taken, the specific gravity of each specimen reduced to the standard temperature of 60° Fahr., and other information concerning the character of the bottom, stage of the tide at the time of observation, &c.

DESCRIPTION OF INSTRUMENTS EMPLOYED.

As the proposed plan was to secure water specimens at intervals of two fathoms, from the surface to the bottom, it became necessary to provide an instrument by which they could be obtained with facility, and, above all, with *absolute certainty* that each specimen should be brought from the *exact depth* required.

The Coast Survey Office was in possession of no apparatus, nor was any known to it that fulfilled completely these requirements. Cylinders with valves operating by the action of the water in ascending and descending were looked upon with distrust, especially since the experiments of Lieutenant-Commander Sigsbee, Assistant in the Coast Survey, had demonstrated their unreliability; and while the instrument devised by him appeared admirably adapted to ordinary deep-sea work, the fact that it must ascend through at least one fathom of water to close its valves, rendered it entirely useless for serial specimens at such short intervals as now proposed. Upon consideration two ways of effecting the desired result presented themselves. One was the use of a pump (used with lead pipe, by Prof. H. Mitchell, Assistant in the Coast Survey), and a sufficient length of rubber tubing for suction-hose, suggested by Commander Lull, Hydrographic Inspector; the other a new apparatus, a sketch of which accompanies this report.

The use of a cylinder closing over two fixed disks was suggested by Professor Hilgard, Assistant in charge of office. The special form adopted was devised jointly by Mr. Saegmuller, instrument-maker, and myself, subsequently modified, as practical experience showed to be advisable, to the form exhibited in the drawing.



Drop-cylinder Water-cup.

* Not here published.

The apparatus, designed to bring up one pint of water, consists of the following parts: A stem or spindle 0''.5 in diameter and 20'' in length, terminates at its lower end in a ring for the attachment of the sounding-lead, and at its upper end, in a slotted head, in which is pivoted the detaching trigger. This trigger is 3''.5 in length. It is pivoted at one end in the slotted head, and terminates at the other in a hook, curved upward, in which is placed one end of a rubber spring, as shown in the drawing. Near its middle the trigger carries a swivel for the attachment of the sounding-line; two curved lugs project from its lower side, and work, one on either side of the head of the spindle, so that when either is closed against it, by raising or depressing the free end of the trigger, the other will be open. For convenience of reference, the lug farthest from the free end of the trigger is designated the *rear* and the other the *front* lug.

Below the slotted head, at a distance of 3'' from the pivot of the trigger, the spindle carries an arm 3'' in length, projecting in the plane of the trigger, and on the same side of the spindle with it. This also ends in a hook curved downward, over which passes the lower end of the rubber spring before mentioned. This arm slides on the spindle and is furnished with a set-screw, so that its distance from the trigger may be increased at pleasure.

At a distance of 8''.4 below this arm the spindle carries a fixed disk 2''.6 in diameter, below this at a distance 4''.6, another disk 3'' in diameter. Passing freely over the former, and closing water-tight upon the latter, is a sliding cylinder 5''.4 in length. This cylinder is open at both ends, the upper end being furnished with a cross-bar and collar, working smoothly on the spindle, to guide the cylinder in sliding up and down.

Attached to this cross-bar is a wire sling, ending in a loop, and of such a length that when this loop is placed over either of the lugs of the trigger, the lower end of the cylinder will come flush with the lower surface of the upper disk, as shown in the left-hand figure.

A spiral spring, coiled around the spindle between the projecting arm and the collar of the cylinder, tends to force the latter firmly down on the lower disk.

The method of securing the specimens with this apparatus is as follows:

A lead of sufficient weight (10 to 50 pounds, depending upon the depth of water and strength of current) is bent on close to the lower ring of the spindle, and a line, marked to fathoms, to the swivel on the trigger. If, now, the bottom-specimen is desired, the instrument is prepared by sliding up the cylinder and placing the loop of the sling over the *rear* lug of the trigger. A rubber spring is then stretched over the hooks of the trigger and projecting arm, this spring being of such a strength as to yield to the weight of the lead when the apparatus is suspended by the sounding-line, thus allowing the rear lug to close against the head of the spindle, preventing the cylinder from sliding down and closing on the lower disk.

Thus prepared, the apparatus is lowered into the water. On reaching the bottom, the weight of the lead being taken off, the rubber spring draws the hooked end of the trigger downwards, thus allowing the wire sling to disengage itself from the rear lug. The cylinder, forced down by the spiral spring, closes over the disks, and thus the specimen from the stratum in which it rested is secured and drawn to the surface.

For the intermediate specimens the apparatus is prepared by placing the loop of the sling over the *front* lug of the trigger, and supplying a rubber spring of sufficient strength to hold the free end of the trigger down when the instrument is suspended by the sounding-line, thus keeping the lug closed. The line is then made fast to the rail of the boat or vessel, at such a place as will allow the mark indicating the number of fathoms from which the specimen is desired to be at the surface when the line has run out taut.

The instrument is then put overboard and allowed to descend freely. As it reaches the desired depth the line is tautened, the rubber spring yields to the shock of the arrested motion, and the cylinder closes instantly, as before.

In order to be able always to secure the proper relation between the strength of the rubber spring and the weight of the lead, a number of the springs of different strengths should be supplied with each instrument. If a slight increase only in the strength of a spring is desired, it may be giving by sliding the arm down the spindle and confining it at the necessary distance with the set-screw.

A little experience soon enables one to graduate the springs with the greatest ease, so as to secure the best results.

The pump used during the first part of the season for obtaining specimens was a small portable hand-pump furnished with twenty-five fathoms of extra four-ply rubber hose of 0″.5 interior diameter.

The capacity of the pump was so related to that of the hose that a single full stroke was sufficient to empty approximately a length of one fathom. For convenience of use the hose was divided into three lengths of eight fathoms each. In practice the lower end was bent on to a sounding-line, marked to fathoms, and at such a distance as to bring its orifice at the required depth when the lead was on the bottom and the line hauled taut. Five times the number of strokes of the pump actually necessary to empty the whole length of hose out were then given before taking the specimen. This number, it was thought, was sufficient to insure getting the water unmixed from the place where the orifice of the hose rested.

To test this important matter several experiments were made, water from the same spot being taken simultaneously with both hose and cylinder side by side. The specimens were then tested with the hydrometer. The results gave conclusive proof of the reliability of the pump and hose thus used, as is shown by the following record of one of the tests:

Instrument.	Depth.	Hydrometer-reading.	Temperature, Fahr.
			°
Cylinder	2 fathoms	1.0104	68
Pump	do	1.0104	68
Cylinder	5 fathoms	1.0103	68
Pump	do	1.0103	68

Although thus satisfied of the reliability of the pump and hose, they were so much less convenient of manipulation—especially in a strong tideway when the resistance of the hose caused much trouble—that we soon discarded them entirely for the cylinders, which appeared to fulfill all the required conditions, for moderate depths, perfectly.

The specimens, having been brought to the surface, were usually corked in Congress water bottles, to each of which was attached a tag bearing the following data necessary for its complete identification:

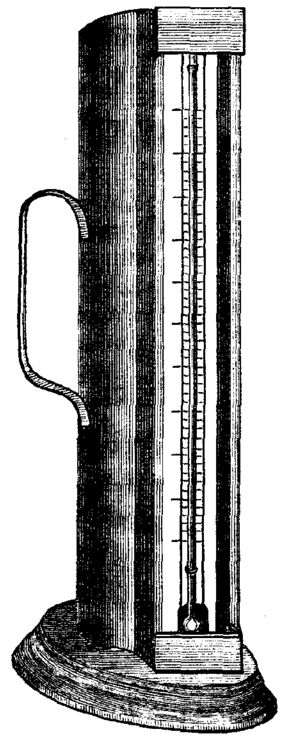
Number of the section.
Letter of the station.
Depth.
Stage of the tide, and on the lowest specimens the character of the bottom at the station.

All specimens were then immediately entered in a journal in which were recorded the foregoing data, with the bearings or angles necessary to fix the position of each station.

The bottles were then packed away in racks provided for the purpose to await a favorable opportunity for the

DETERMINATION OF THE SPECIFIC GRAVITY

of their contents. The instruments used for this purpose were the salinometers devised by Prof. J. E. Hilgard, Assistant in charge, figured and fully described in Appendix No. 16 to the Report of the Superintendent of the Coast Survey for the year 1874. The sketch is republished here. They comprised a series of three floats, each about 9″ in length. The scale of the first extended from 1.0000 to 1.0110; that of the second from 1.0100 to 1.0210, and that of the third from 1.0200 to 1.0310. Each unit in the third decimal place, or thousandths of the density of fresh water, is represented on the scale by a length of three-tenths of an inch, which is subdivided into five parts, admitting of an accurate reading of a unit in the fourth place of decimals by estimation.



The floats were accompanied by a copper can of a capacity of one pint, with a thermometer inserted within the cavity, which is glazed in front. The improved form of this can, with which we were furnished, terminates at the top in a short cylinder of glass which allows the reading of the salinometer-scale either above or below the capillary meniscus.

Accompanying the instruments were tables for the reduction of the observed readings to the standard temperature of 60° Fahr.

Since with instruments of such delicacy, the motion of the vessel, even though slight, would interfere with the accuracy of the observations, the experiments for density were always made when lying at anchor on favorable days, every precaution being taken to secure the utmost attainable accuracy.

METHOD OF CARRYING ON THE WORK.

In making sections of five miles or less in length, the exact location of the section having been determined upon and the stations marked on the chart, our usual course was to anchor the vessel as nearly as possible on the middle station, and then fix her position accurately by the three-point problem when proper objects were available for the purpose, otherwise as well as possible by cross-bearings. Two boats were then sent out to occupy the stations on either side, they fixing their positions by ranges, bearings, and mast-head angles as found practicable.

By these means, and the assistance of the soundings, it was found possible to occupy the predetermined stations very approximately.

In sections of greater length than five miles the vessel was moved and re-anchored a sufficient number of times to afford mast-head angles large enough to insure a satisfactory determination of the positions of the boats.

Working in this way, it was found possible, under favorable circumstances, to complete a section of five stations in about three hours.

In the lower part of the bay, where the sections were long and the shores destitute of prominent objects, all the stations were occupied by the vessel, ranges being secured when practicable and the positions determined by cross-bearings of such objects as were available for the purpose. This afforded a less close approximation than the former method, but it was the best that could be done without building signals.

The rapidity with which this work could be executed depended, of course, very much upon the wind. With the improved form of cylinder, and a sufficient number of them already arranged for bringing up the number of specimens desired at each station, it was only necessary to heave the vessel to when on the proper bearings, secure the specimens, and fill away again; the whole operation, in depths of ten to twelve fathoms with four cylinders working, not occupying more than two minutes.

On sections 17 and 19 (the former across the bay from *Smith's Point* and the latter across from *Windmill Point*) there was absolutely nothing available for cross-bearings. These sections, therefore, were run by compass course and time, the log being hove immediately after filling away at each station.

From such a method no very close approximation could be anticipated, but the circumstances in each of these cases being favorable the results were better than I had supposed possible, and I am confident that the desired stations were occupied with sufficient nearness for the attainment of the object in view.

Working in this way, but little more time is necessary than is required to sail over the course. Section 19 is sixteen miles in length, with eleven stations. It was completed, thirty-nine specimens being secured within four hours, and nearly half of this time was spent in getting the specimens from the first and last stations, which, being in one fathom of water only, were necessarily occupied by the boats.

The result of our experience is, that, with the apparatus in its present form, but little experience is required to enable a properly equipped party to secure serial specimens from moderate depths with the utmost facility, and, under favorable circumstances, with great rapidity.

This is evident from the fact that my party, wholly new to the work and suffering considerable detentions from incompleteness of outfit at the outset, within the space of two months, in a sailing vessel, completed twenty-eight sections, aggregating one hundred and thirty-five miles in length, occupying one hundred and sixty-four stations, and securing five hundred and seventy-one specimens.

EXPLANATION OF THE TABLES ACCOMPANYING THE FULL REPORT DEPOSITED IN THE ARCHIVES OF THE COAST SURVEY.

The first column contains the letters of the stations occupied; the second shows the depths from which the specimens were taken; the third gives the observed readings of the salinometer; the fourth, the temperature of the specimen at the time of reading the salinometer; the fifth, the salinometer-readings reduced to the standard temperature of 60° Fahr.; the sixth, the stage of the tide at the time of securing the specimens; the seventh, the character of the bottom at the stations; the eighth, the bearings and distances of prominent objects from each station.

The last specimen recorded under each station was invariably taken from the *bottom*.

The salinometer-readings are given to the fourth place of decimals, as the instruments used could readily be read to each unit in that place (see page 12). It does not follow, however, that the densities are reliable to that degree of precision.

An extended series of experiments is about to be undertaken by the Assistant in charge, to determine the probable limits of error. Until that is concluded but little can be said on the subject. From my experience in the matter, however, I conclude that the results given are not to be depended upon within two units of the fourth-decimal place on an average, while occasional discrepancies considerably larger may be expected.

The salinometers used in determining the densities given in the tables had the following corrections, which have been applied in reducing the results:

No. 1 indicating from 1.0000 to 1.0100 − .0001
No. 2 indicating from 1.0010 to 1.0200 + .0001
No. 3 indicating from 1.0020 to 1.0300 + .0002

All readings given in the tables have been made *above the capillary meniscus;* to reduce them to readings *below* it, a correction of + .0002 must be applied.

Respectfully submitted.

FREDERICK COLLINS,
Lieut. U. S. N., Asst. U. S. Coast Survey, Comd'g Schr. Palinurus.

To C. P. PATTERSON,
Supt. U. S. Coast Survey, Washington, D. C.

APPENDIX No 15.

A QUINCUNCIAL PROJECTION OF THE SPHERE.

BY C. S. PEIRCE, ASSISTANT.

For meteorological, magnetological, and other purposes, it is convenient to have a projection of the sphere which shall show the connection of all parts of the surface. This is done by the one shown in the plate. It is an orthomorphic or conform projection formed by transforming the stereographic projection, with a pole at infinity, by means of an elliptic function. For that purpose, l being the latitude, and θ the longitude, we put—

$$\cos^2 \varphi = \frac{\sqrt{1 - \cos^2 l \cos^2 \theta} - \sin l}{1 + \sqrt{1 - \cos^2 l \cos^2 \theta}},$$

and then $\frac{1}{2} F\varphi$ is the value of one of the rectangular co-ordinates of the point on the new projection. This is the same as taking—

$$\cos am\,(x + y\sqrt{-1})\ (\text{angle of mod.} = 45°) = \tan \frac{p}{2}\,(\cos \theta + \sin \theta\ \sqrt{-1}),$$

where x and y are the co-ordinates on the new projection, p is the north polar distance. A table of these co-ordinates is subjoined.

Upon an orthomorphic projection the parallels represent equipotential or level lines for the logarithmic potential, while the meridians are the lines of force. Consequently we may draw these lines by the method used by Maxwell in his Electricity and Magnetism for drawing the corresponding lines for the Newtonian potential. That is to say, let two such projections be drawn upon the same sheet, so that upon both are shown the same meridians at equal angular distances, and the same parallels at such distances that the ratio of successive values of $\tan \frac{p}{2}$ is constant. Then number the meridians and also the parallels. Then draw curves through the intersections of meridians with meridians, the sums of numbers of the intersecting meridians being constant on any one curve. Also do the same thing for the parallels. Then these curves will represent the meridians and parallels of a new projection having north poles and south poles wherever the component projections had such poles.

Functions may, of course, be classified according to the pattern of the projection produced by such a transformation of the stereographic projection with a pole at the tangent points. Thus we shall have—

1. Functions with a finite number of zeroes and infinites (algebraic functions).
2. Striped functions (trigonometric functions). In these the stripes may be equal, or may vary progressively or periodically. The stripes may be simple, or themselves compounded of stripes. Thus, sin (a sin z) will be composed of stripes each consisting of a bundle of parallel stripes (infinite in number) folded over onto itself.
3. Chequered functions (elliptic functions).
4. Functions whose patterns are central or spiral.

I. *Table of rectangular co-ordinates for construction of the "quincuncial projection."*

x (for longitudes in upper line). *y* (for longitudes in lower line).

Lat.	0° 90	5° 85	10° 80	15° 75	20° 70	25° 65	30° 60	35° 55	40° 50	45° 45	50° 40	55° 35	60° 30	65° 25	70° 20	75° 15	80° 10	85° 5	Lat.
°																			°
85	.033	.033	.033	.032	.031	.030	.029	.027	.025	.024	.021	.019	.017	.014	.011	.009	.006	.003	85
80	.067	.066	.066	.064	.063	.061	.058	.055	.051	.047	.043	.038	.033	.028	.023	.017	.012	.006	80
75	.100	.100	.099	.097	.094	.091	.087	.082	.077	.071	.065	.058	.050	.042	.034	.026	.017	.009	75
70	.135	.134	.133	.130	.127	.122	.117	.110	.103	.095	.087	.077	.067	.057	.046	.035	.023	.012	70
65	.169	.169	.167	.163	.159	.154	.147	.139	.130	.120	.109	.097	.085	.072	.058	.044	.029	.015	65
60	.205	.204	.201	.198	.192	.185	.177	.168	.157	.145	.131	.117	.102	.086	.070	.053	.036	.018	60
55	.241	.240	.237	.232	.226	.218	.208	.197	.184	.170	.154	.138	.120	.102	.082	.062	.042	.021	55
50	.278	.277	.274	.269	.261	.251	.240	.227	.212	.196	.178	.159	.139	.117	.095	.072	.048	.024	50
45	.317	.316	.312	.306	.297	.286	.273	.258	.241	.223	.202	.181	.158	.134	.109	.083	.055	.028	45
40	.357	.356	.351	.344	.334	.321	.307	.290	.270	.250	.228	.204	.179	.151	.123	.094	.063	.032	40
35	.400	.398	.393	.384	.373	.358	.341	.322	.301	.279	.254	.228	.200	.170	.139	.106	.071	.036	35
30	.446	.443	.437	.427	.413	.396	.377	.356	.332	.308	.281	.258	.222	.190	.155	.119	.081	.041	30
25	.495	.492	.484	.471	.455	.435	.414	.391	.365	.338	.309	.279	.246	.211	.174	.134	.091	.046	25
20	.548	.545	.534	.518	.498	.476	.452	.426	.398	.369	.339	.307	.272	.235	.195	.151	.104	.053	20
15	.609	.604	.589	.568	.544	.517	.490	.461	.432	.401	.369	.336	.300	.262	.219	.173	.121	.062	15
10	.681	.672	.649	.620	.590	.559	.528	.497	.466	.434	.401	.367	.330	.291	.248	.200	.143	.076	10
5	.775	.752	.713	.673	.635	.600	.566	.532	.500	.467	.433	.399	.363	.324	.282	.234	.177	.102	5
0	1.000	.841	.774	.723	.679	.639	.602	.567	.533	.500	.467	.433	.398	.361	.321	.277	.226	.159	0

II. *Preceding table enlarged for the spaces surrounding infinite points.*

x (for longitudes in upper line). *y* (for longitudes in lower line).

Lat.	0° 90	1° 89	2° 88	3° 87	4° 86	5° 85	6° 84	8° 82	10° 80	12½° 77½	15° 75	75° 15	77½° 12½	80° 10	82° 8	84° 6	85° 5	86° 4	87° 3	88° 2	89° 1	Lat.
°																						°
15	.609	.609	.608	.607	.606	.604	.602	.596	.589	.579	.568	.173	.147	.121	.098	.074	.062	.050	.038	.025	.013	15
12½	.643	.643	.642	.641	.639	.636	.634	.627	.618	.606	.594	.185	.159	.131	.107	.082	.069	.055	.042	.028	.014	12½
10	.681	.681	.680	.678	.675	.672	.668	.659	.649	.635	.620	.200	.173	.143	.118	.091	.076	.062	.047	.031	.016	10
8	.715	.714	.713	.710	.706	.702	.697	.686	.674	.658	.641	.213	.185	.155	.129	.100	.085	.069	.052	.035	.018	8
6	.753	.752	.750	.746	.741	.735	.728	.714	.700	.681	.662	.227	.199	.169	.142	.112	.095	.078	.060	.040	.020	6
5	.775	.774	.770	.765	.759	.752	.745	.729	.713	.692	.673	.234	.207	.177	.150	.119	.102	.084	.065	.044	.022	5
4	.798	.797	.793	.786	.779	.770	.761	.743	.725	.704	.683	.242	.215	.185	.158	.128	.110	.092	.071	.049	.025	4
3	.825	.823	.817	.808	.798	.788	.778	.757	.738	.715	.693	.250	.224	.194	.168	.137	.120	.101	.079	.055	.029	3
2	.857	.853	.843	.831	.819	.806	.794	.772	.750	.726	.703	.259	.233	.204	.178	.148	.131	.112	.090	.065	.035	2
1	.899	.889	.872	.854	.839	.824	.810	.785	.763	.737	.713	.268	.243	.215	.190	.161	.144	.126	.105	.079	.046	1
0	1.000	.929	.899	.877	.857	.841	.825	.798	.774	.747	.723	.277	.253	.226	.202	.175	.159	.143	.123	.101	.071	0

LIST OF SKETCHES.

PROGRESS SKETCHES.

ILLUSTRATION.