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E. LESTER JONES, Director

GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1912, TO DECEMBER 31, 1921

(Report to the Section of Geodesy of the International Geodetic and Geophysical Union, International Research Council)

BY

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GEODETIC OPERATIONS IN THE UNITED STATES, JANUARY 1, 1912, TO DECEMBER 31, 1921.

By WILLIAM BOWIE, *Chief, Division of Geodesy, U. S. Coast and Geodetic Survey.*

INTRODUCTION.

The greater portion of the geodetic work in this country is done by the U. S. Coast and Geodetic Survey. This bureau began the work shortly after it was established in 1816, primarily, to control the hydrographic charts made along our coasts. After the coast triangulation had progressed to a considerable extent it was found necessary to establish arcs of precise triangulation parallel with the coasts, but somewhat back in the interior, with spurs running to the coast triangulation on which the topographic and hydrographic surveys were based. Later an arc of precise triangulation was extended from the Atlantic to the Pacific coasts in order to place the charts of our eastern and western waters on the same geodetic datum.

The precise triangulation done by the U. S. Coast and Geodetic Survey for the purpose of correlating the coast charts was found to be so useful for other purposes that our Congress decided to authorize the extension of arcs of triangulation within our entire area.

The U. S. Lake Survey was organized a number of years ago for the purpose of making charts of the five great lakes on or near the boundary between the United States and Canada. This organization was actively engaged for a number of years in carrying on geodetic work for the horizontal control of its surveys and charts. Its geodetic work was completed before January 1, 1912, and therefore no work of this character has been done by the Lake Survey during the past 10 years.

The U. S. Geological Survey is the agency charged with the topographic mapping of the interior of our country. In order that it might have the proper horizontal and vertical control for its detailed mapping, this organization has done many miles of triangulation, traverse, and leveling of the third class, which has the requisite accuracy for the topographic work. This organization has been actively engaged in topographic mapping and the necessary third-order control surveys during the past 10 years. Only brief mention of this work will be made in this report, for it is believed that the results will not be of scientific geodetic value until the work has been adjusted into the precise network of triangulation and of leveling after these networks have been much further extended over the country.

While in the past several organizations ran lines of precise leveling, the U. S. Coast and Geodetic Survey is the only one which has done this kind of geodetic work since January 1, 1912. The first precise leveling done in the United States was by the Corps of Engineers of the U. S. Army in connection with river improvements and flood control. This class of work was also done to a certain extent by the U. S. Lake Survey and the U. S. Geological Survey in order to provide vertical control for charts and maps. Three of our railroads have done a limited amount of leveling for their immediate needs, and have made their results available to anyone needing them. These railroads are the Pennsylvania, the Baltimore & Ohio, and the Buffalo, Rochester & Pittsburgh.

About two-thirds of the precise leveling of this country has been done by the U. S. Coast and Geodetic Survey. At first this precise leveling was run to provide elevations for use in reducing base lines to sea level and also for controlling the trigonometric leveling carried on coincidently with precise triangulation, but for many years the work has been done to furnish fundamental elevations for all surveying, mapping, and other engineering work of the country.

Other geodetic work done in the United States during the period covered by this report includes the determination of astronomic latitudes, longitudes, and azimuths; the determination of the intensity of gravity; the measurement of earth tides; observations for the variation of latitude; isostatic investigations; investigations in methods for map projections; certain geophysical studies; and the design and improvement of geodetic instruments. The several classes of geodetic activities mentioned above are considered in more or less detail in the pages which follow.

GEODETIC WORK ACCOMPLISHED.

GEODETIC ASTRONOMY.

All the astronomic work of a geodetic character in the United States completed during the past 10 years has been done by the U. S. Coast and Geodetic Survey.

AZIMUTHS.

Azimuth observations on Polaris are made at the time the triangulation stations are occupied for the measurement of horizontal directions. When an astronomic azimuth and an astronomic longitude are observed at a triangulation station, we can obtain a meridian free from the effect of station error or the deflection of the vertical. A triangulation station at which the astronomic azimuth and longitude are determined is called a Laplace station. As is well known, the triangulation azimuths are subject to systematic errors, and it is only by means of the combination of the longitude and azimuth observations at a triangulation station that we are able to obtain a true north and south line which can be used in the adjustment of an arc or a network of triangulation.

In general, an azimuth depends upon observations made at from 12 to 16 positions of the horizontal circle, making from 24 to 32 pointings on the star and on the mark. At a Laplace station we have a minimum of 40 pointings on the star and on the mark made in 16 positions of the circle and the observations are distributed over at least two nights. The azimuth observations made at triangulation stations other than the Laplace stations are for the purpose of furnishing deflections in the prime vertical for use in investigations of the figure of the earth.

Azimuths of the first and also of the second order of accuracy have been observed along the lines of traverse in order to control the directions in this class of work. It is evident that an azimuth observed for controlling directions in a traverse does not furnish any means of obtaining the deflections of the vertical, and therefore the azimuth stations established for the control of lines of traverse are not included in the number of azimuth stations reported on in this paper.

The azimuths established at triangulation stations during the 10-year period are 102 in number. These azimuths are located along the arcs of triangulation which have been established since January 1, 1912. The number observed before that date is 285.

The azimuths observed in connection with the Laplace stations have a probable error seldom greater than $\pm 0.30''$. At the other azimuth stations the probable error is seldom greater than $\pm 0.50''$. The precise azimuth stations in the United States are shown on figure 1. Those established since January 1, 1912, are in red, while the older stations are in black. None of the azimuth stations connected with the traverse are shown. Each azimuth station shown is coincident with a triangulation station.

LONGITUDES.

The astronomic longitude determinations in the United States during the past 10 years have been mostly for immediate use in determining the deflections of the vertical at stations of new arcs of triangulation and lines of precise traverse in connection with the computation of Laplace or true geodetic azimuths. A longitude station was established at Rochester, N. Y., for the use of the Bausch & Lomb Optical Co. in connection with the testing of their instruments.

In the summer of 1914 the difference in longitude between the Naval Observatory at Washington and the observatory at Cambridge, Mass., was redetermined, and the differences in longitude between the first of those stations and Far Rockaway on Long Island, N. Y., and between Far Rockaway and the observatory at Cambridge were determined. This work was done with extreme accuracy, as it was to be a part of a connection in longitude between the United States and Germany. The determination of the longitude of Far Rockaway by means of time signals sent over the cables was undertaken by the Prussian Geodetic Institute. The outbreak of the European War prevented the completion of the part of the work which was to have been done by Germany.

The longitude work done to obtain the difference between Germany and the United States has been published in a report by this Bureau as Special Publication No. 35, entitled "Determination of difference in longitude between each two of the stations Washington, Cambridge, and Far Rockaway, by Fremont Morse and O. B. French." The reports listed on another page, giving the data for arcs of precise triangulation, contain the results of any differences of longitude which may have been determined along these arcs.

In all there was established during the 10-year period covered by this report 59 longitude stations of the first order. Before January 1, 1912, 211 such stations had been established. Of the total of 270 stations, 195 are connected with the triangulation system.

The longitude stations established in the United States are shown in figure 2. Those stations established since January 1, 1912, are shown in red, while the older stations are shown in black. On this sketch are shown the connections between the longitude stations used in the adjustment of the net made in 1897. The work done since that date has been fitted into the adjusted net, for it has been found that the adjusted differences agree very closely with the work done since the adjustment. It has been the desire to hold fixed the values of longitudes assigned by the adjustment rather than to change them every time that a few more differences are added to the net.

In Alaska there are 7 astronomic longitude stations of the first class. These stations are connected with the longitude net of the United States. They were established prior to January 1, 1912. In the Philippines there are 37 astronomic longitude stations of the first class, all established before January 1, 1912.

Beginning with 1914, all observations, except at the Rochester station, for the determination of differences in longitude have been made with the Bamberg broken-telescope transit. It was found that the results obtained with this type of instrument were superior to those with the straight-telescope transits which had been used prior to 1914. The desired accuracy could be secured with observations on a smaller number of stars. The probable error of a difference in longitude is seldom greater than ± 0.02 second of time.

LATITUDES.

A latitude party established a number of stations in 1913 along the one hundred and fourth meridian arc of precise triangulation, and in 1914 another party determined latitude stations along the Texas-California arc of precise triangulation, along the arc of triangulation of the third order which runs between Nevada and California, and at several triangulation stations of the third order in Arizona which had been established by the U. S. Geological Survey. A latitude was determined at Rochester, N. Y., at the office of the Bausch & Lomb Optical Co., and two others on the boundary line between the States of Kentucky and Tennessee for the sole purpose of locating a small section of this boundary. The observations at the other latitude stations established since January 1, 1912, were made by several longitude parties and one gravity party and were incidental to the other work. After 1914 observations for latitude with few exceptions have been made with the Bamberg broken-telescope transit; all latitudes are observed by the Talcott method and depend upon observations made on 12 or more pairs of stars. The probable error of the result is seldom greater than $\pm 0.10''$.

The latitude stations established in the United States are shown in figure 5. Those stations which were established after January 1, 1912, are shown in red, while the older stations are in black. No precise latitude determinations were made during the 10-year period in the Philippine Islands or in any other outlying territory belonging to the United States, except in Alaska, where one was observed.

In all, there were 125 precise astronomic latitude stations established during the 10-year period from January 1, 1912. Before that date 559 stations of the first class had been established in the United States, 60 stations in Alaska, and 38 stations in the Philippine Islands. Of the 684 astronomic stations in the United States 580 are connected with the triangulation system.

AZIMUTH

U.S. Coast and Geodetic Survey

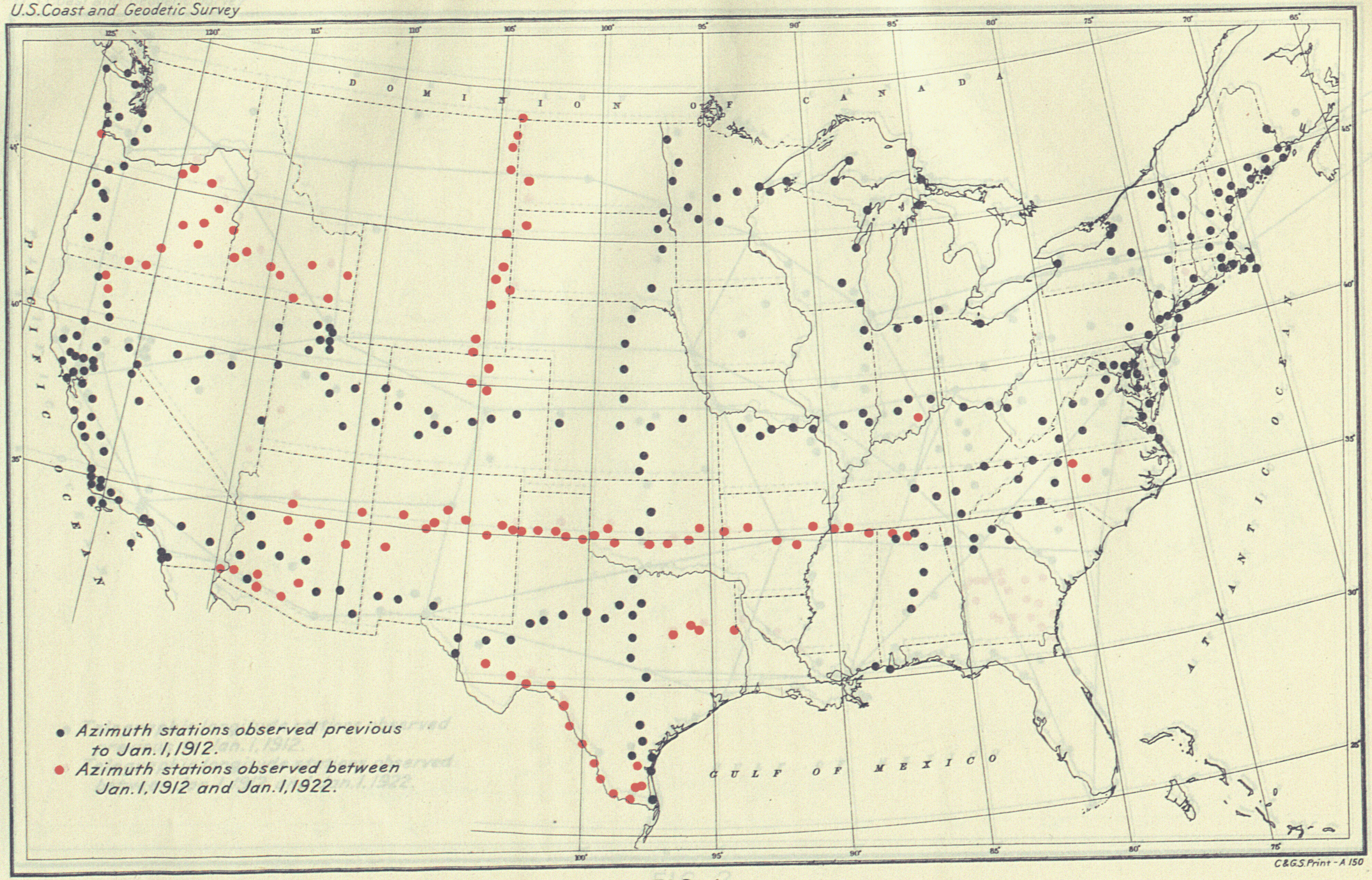

FIG. I

TELEGRAPHIC LONGITUDE AND NET

U.S. Coast and Geodetic Survey

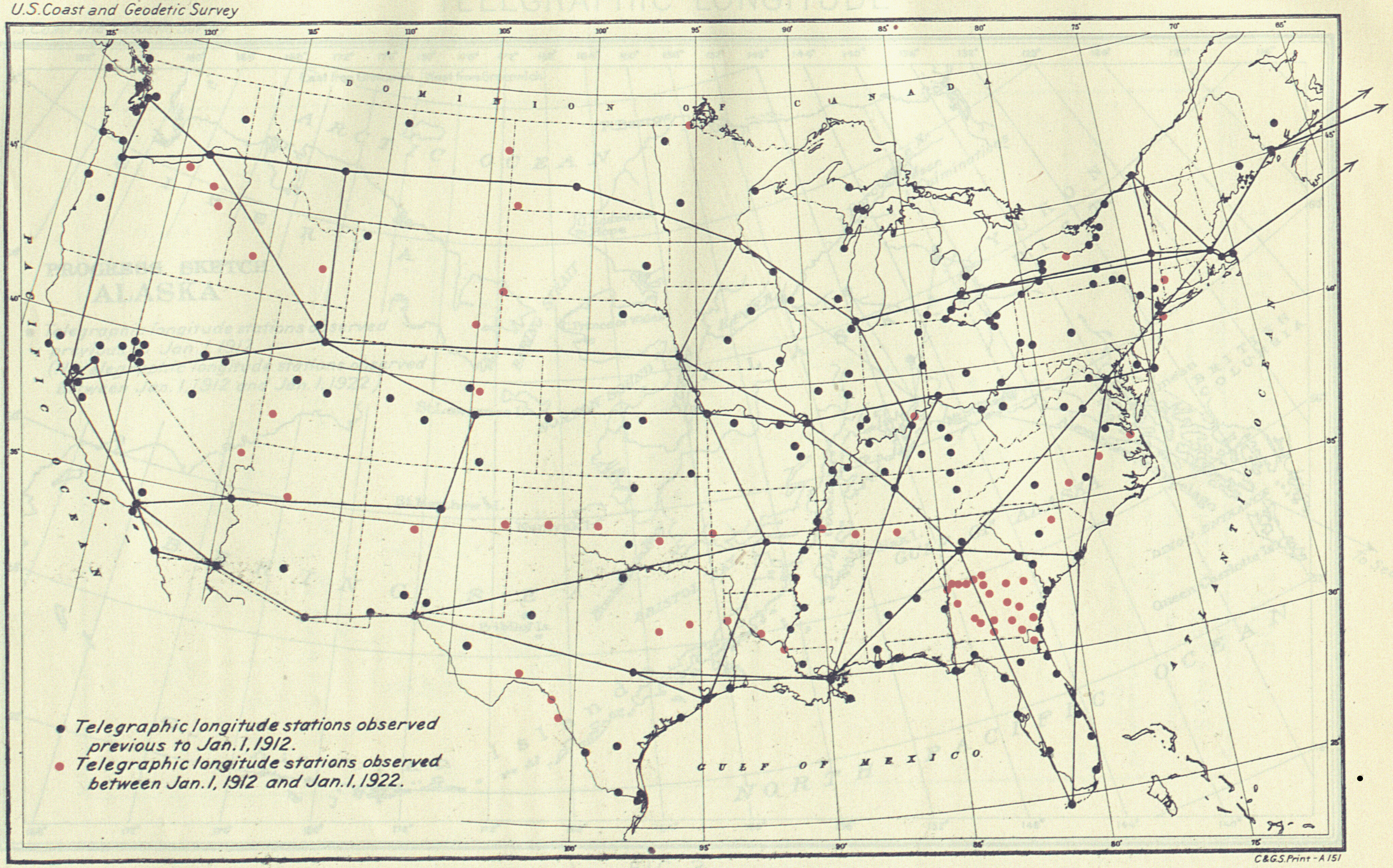

FIG. 2

TELEGRAPHIC LONGITUDE

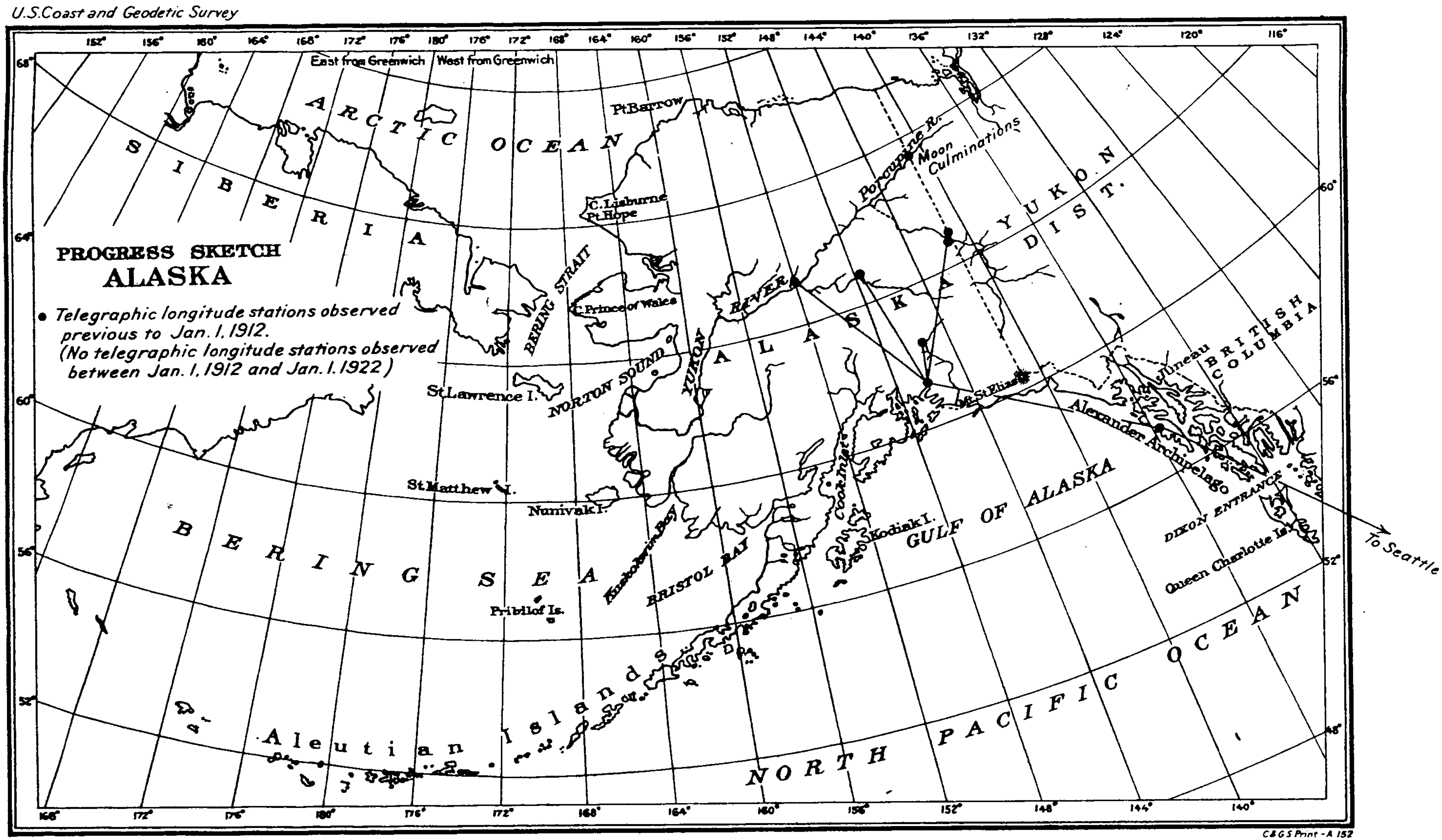

FIG. 3

TELEGRAPHIC LONGITUDE

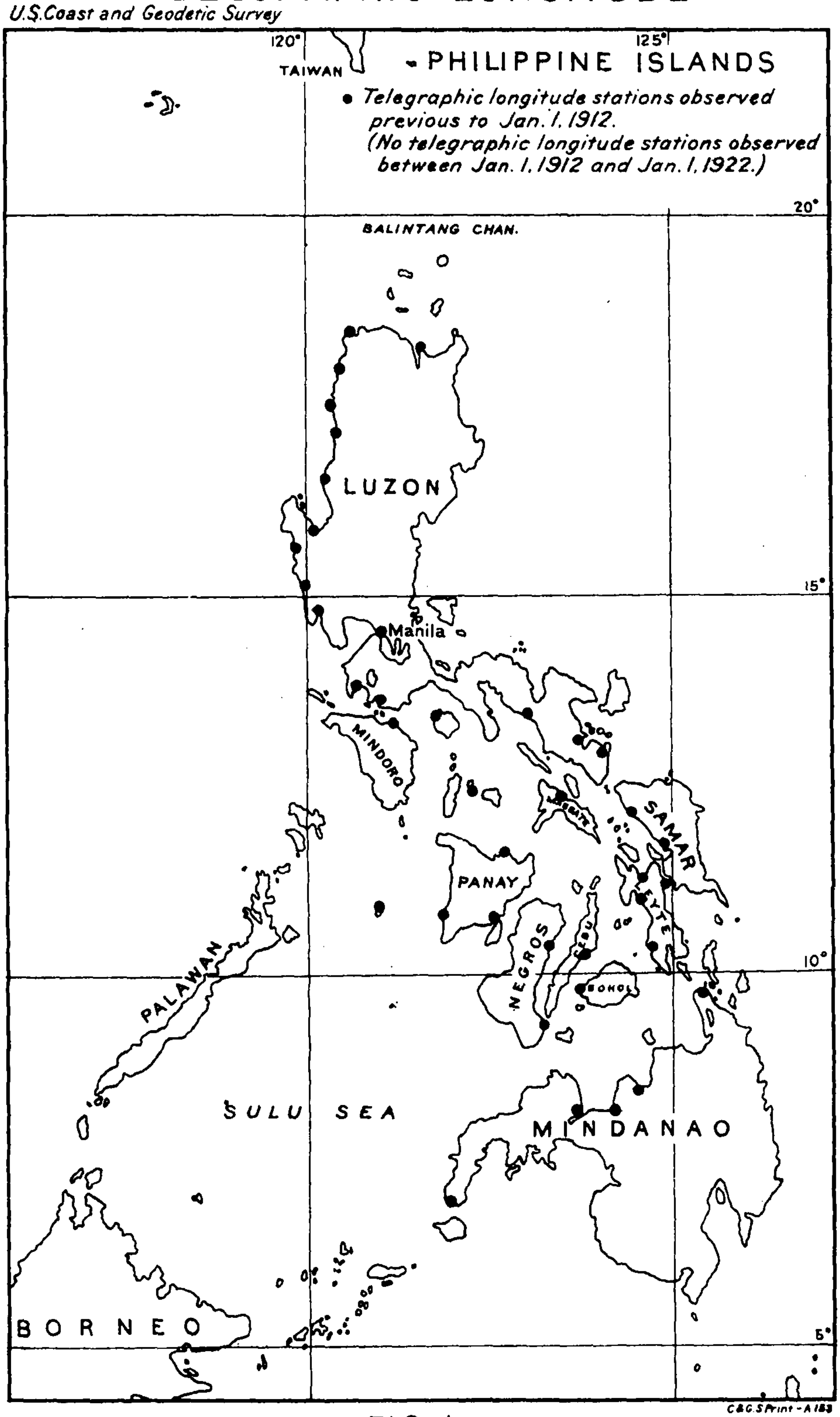

FIG. 4

LATITUDE

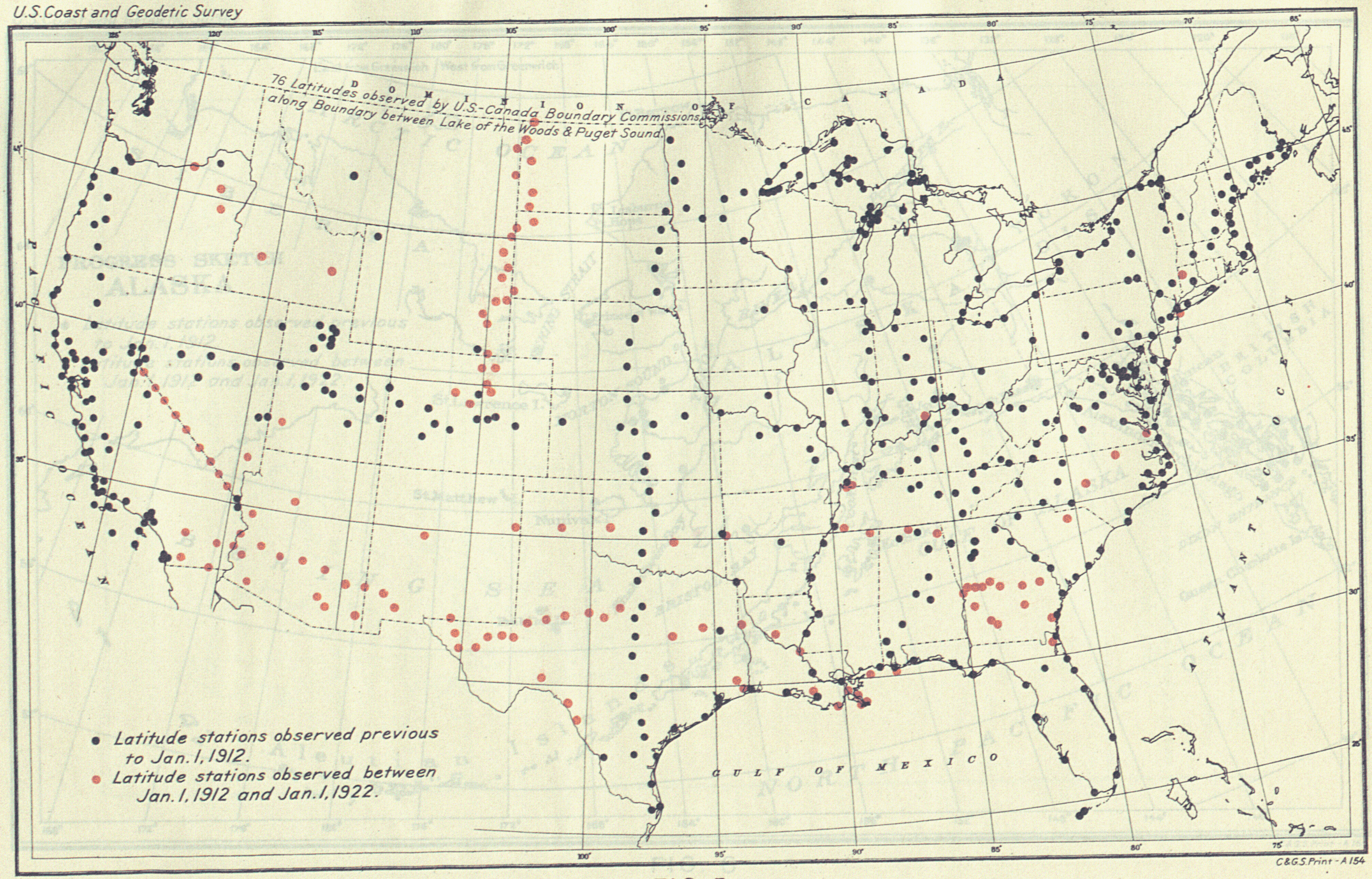

FIG. 5

LATITUDE

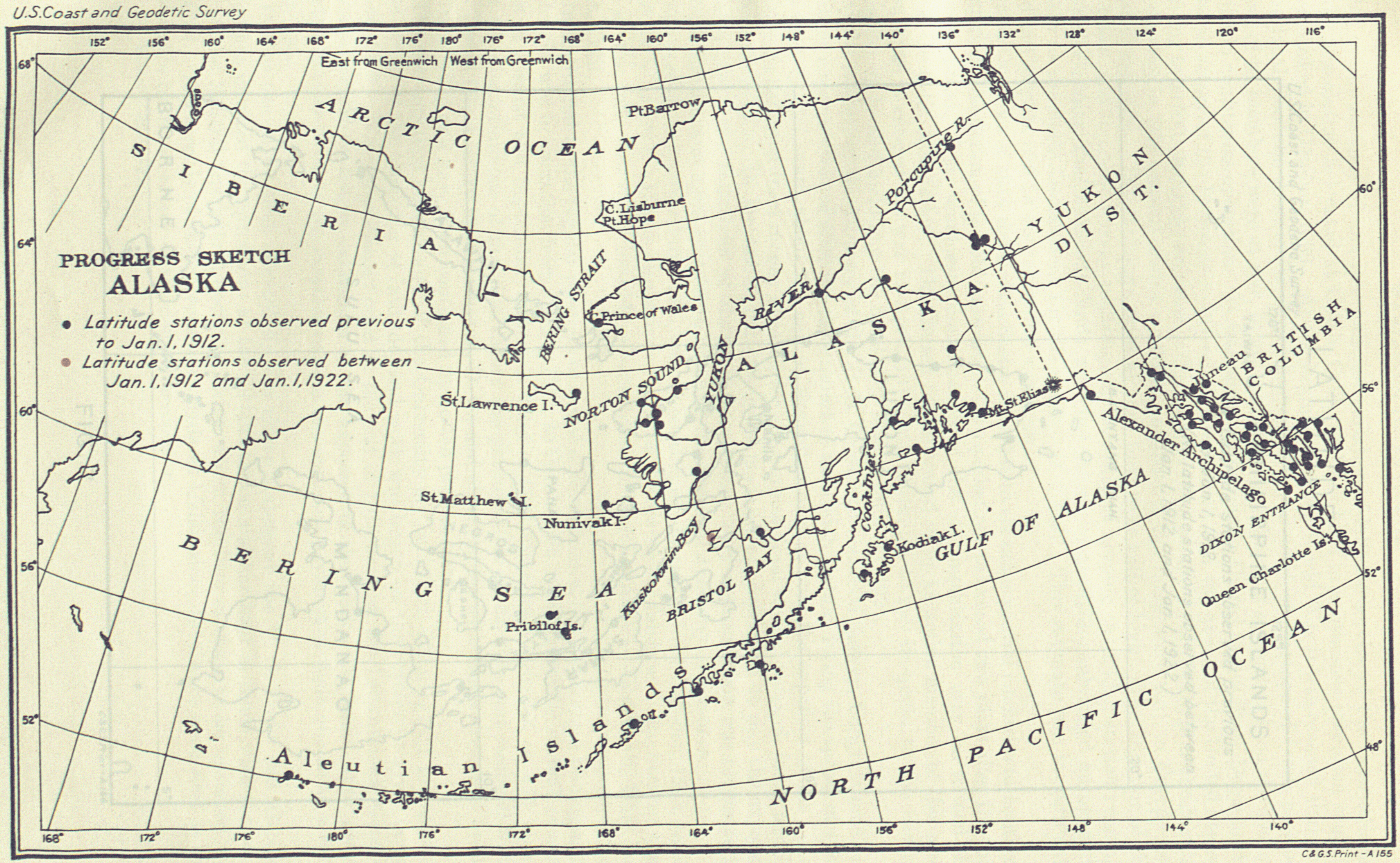

FIG. 6

LATITUDE

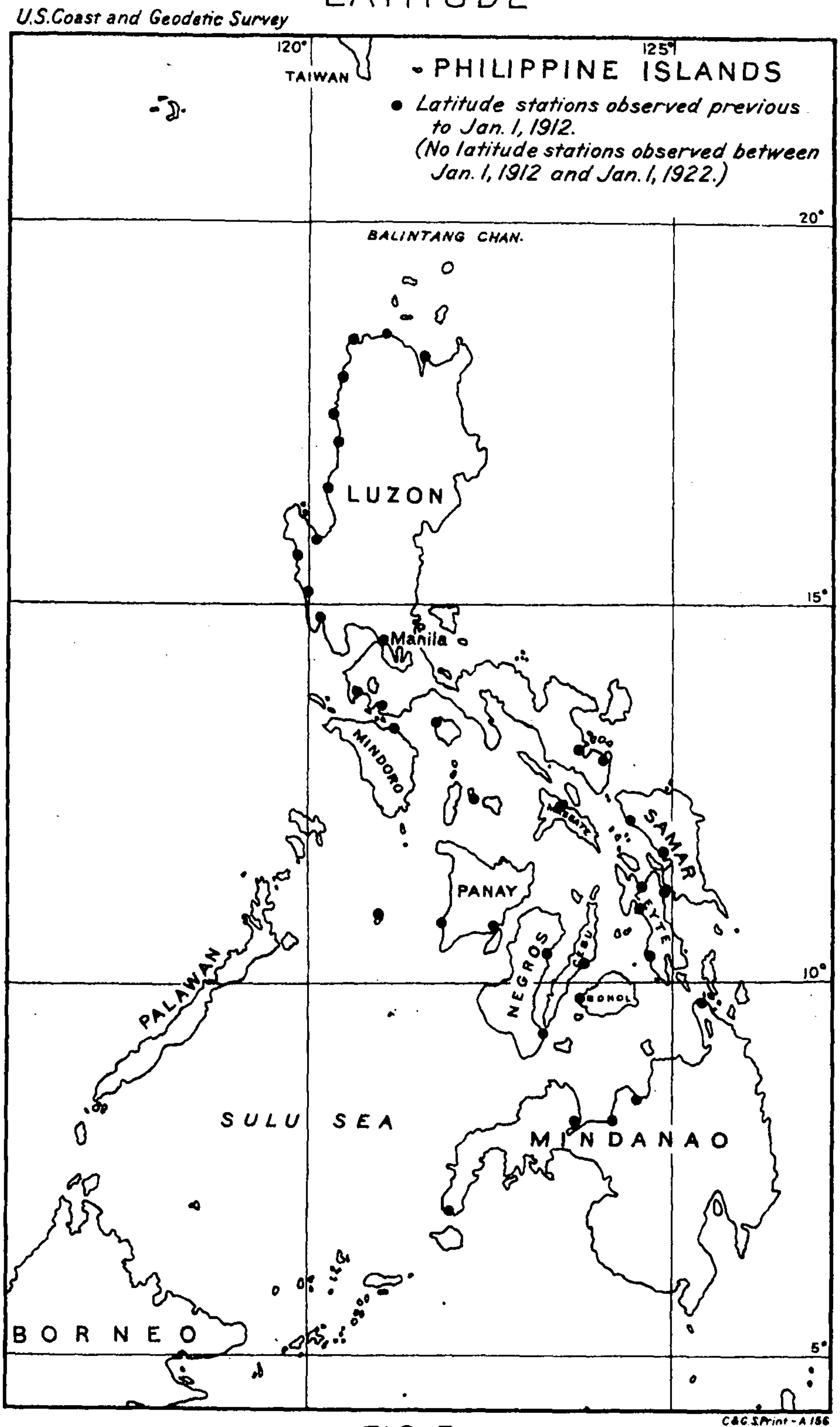

FIG. 7

VARIATION OF LATITUDE.

One of the stations of the international variation-of-latitude service of the International Geodetic Association is located at Ukiah, Calif., and has been in continuous operation since it was established in October, 1899. At the beginning of the World War it was realized that the International Geodetic Association would be unable, on account of shortage of funds because so many of its members were at war, to give the necessary financial support to keep the station at Ukiah in continuous operation. It was agreed between the United States State Department and the secretary of the International Geodetic Association that the quota of the United States, amounting to $1500, should be retained in this country for the support of Ukiah, thus eliminating the reduction in this amount which would be incurred if the funds were sent to Europe and then returned here. The exchange rates at that time were rather high. The Director of the U. S. Coast and Geodetic Survey realizing the necessity of keeping the Ukiah station running, and understanding that sufficient funds were not otherwise available, submitted an estimate of $2500 to the State Department for the support of Ukiah. This estimate was in turn submitted to Congress and an appropriation was made.

In the autumn of 1916 the United States agreed with six other neutral countries to continue the expiring convention of the old association for a period not to exceed two years after the conclusion of peace. This temporary continuation of the old organization may be termed the Neutral Geodetic Association. The United States ceased to be an active member of this association when it entered the war in April, 1917, but continued to pay its quota to the neutral association up to and including the fiscal year ending June 30, 1921.

At the request of the Director of the U. S. Coast and Geodetic Survey, Congress made an additional appropriation of $500 for the support of the Ukiah station during the spring of 1921. From July 1, 1921, until about the end of November of that year the expenses of the Ukiah station were defrayed from money allotted for the purpose from several research funds and by several individuals. In December, 1921, Congress made an appropriation to pay the expenses of Ukiah during the remainder of the fiscal year 1922. This appropriation was requested by the State Department upon recommendation of the National Academy of Sciences.

The station at Gaithersburg, Md., was in continuous operation from October, 1899, to the end of the year 1914. It was discontinued because of shortage of funds and also because there were at the time two other latitude observatories in North America—Cincinnati, Ohio, and Ukiah, Calif.

In additional to the regular program of visual observations at Gaithersburg, a photographic zenith tube was in operation from June 9, 1911, to October 23, 1914, except for a break of seven weeks in August and September, 1911. A total of 6944 stars were observed on 450 nights. After the discontinuance of the observatory the photographic zenith tube was removed to the U. S. Naval Observatory at Washington, D. C., and observations with it were resumed toward the end of 1915 and have been continued up to the present time.

The astronomical observatory of the University of Cincinnati, Ohio, agreed to cooperate in the study of the variation of latitude, and work was begun on the regular program in September, 1899. Work was discontinued at the end of 1915 because the International Geodetic Association could no longer contribute to the expenses of the work. Its funds were greatly depleted because most of the member nations discontinued payment of their quotas as a result of the war.

During the entire time covered by the above statement the U. S. Coast and Geodetic Survey has directed the operations at the Ukiah station and has kept in touch with the secretary of the Neutral Geodetic Association, from whom the lists of stars to be observed were obtained. The records of the observations made at Ukiah since 1916 have been sent as soon as available to the secretary of the neutral association.

91616°—22——2

PRECISE BASE LINES.

During the 10 years since January 1, 1912, 20 base lines were measured in the United States by the U. S. Coast and Geodetic Survey for the control of lengths in the precise triangulation. The location of these base lines, their lengths, and probable errors are shown in the table below.

The measurements of the base lines were made in all cases, except one, by the party carrying on the triangulation. The methods employed were the same as those described at the meeting of the International Geodetic Association at Hamburg in 1912. (See Appendix 4, Report for 1910, and Special Publication No. 19 of the U. S. Coast and Geodetic Survey.) The 50 m. invar tapes were used, each base depending on three tapes. The tapes were standardized by comparison with the 5 m. iced-bar at the Bureau of Standards before and after each field season. The base lines were placed along the arcs of triangulation at certain distances apart, depending on the strength of the distance angles in the best chain of triangles through the arcs. The method of determining when a base line is needed is described in detail in U. S. Coast and Geodetic Survey Special Publications Nos. 19 and 23.

Precise bases measured in the United States since January 1, 1912.

Name of base and State.	Geographic position, center of base.		Length in meters.	Probable error.	
	°	′		Millimeters.	Proportional part.
Ambrose, N. Dak.	48 103	58 33	10479.1774	± 3.5	1/3 000 000
Provo, S. Dak.	43 103	11 49	14559.2511	± 4.6	1/3 200 000
El Paso, Colo.	38 104	58 31	11288.0852	± 3.1	1/3 600 000
Cheyenne, Wyo.	41 105	17 00	6650.4367	± 2.8	1/2 400 000
Samfordyce, Tex.	26 98	20 34	7627.5753	± 22.1	1/340 000
Dryden, Tex.	30 102	03 08	6675.3886	± 5.5	1/1 200 000
Paloma, Tex.	28 100	56 32	8044.2860	± 9.0	1/900 000
Zapata, Tex.	27 99	00 17	7495.3672	± 3.2	1/2 340 000
Carrizo, Tex.	28 100	21 01	10126.2145	±13.7	1/740 000
Stanfield, Oreg.	45 119	46 23	16596.6680	± 7.6	1/2 200 000
Paisley, Oreg.	42 120	45 34	14527.5683	±11.9	1/1 200 000
Alki, Wash.	47 122	30 25	3190.9638	± 3.3	1/990 000
Admiralty Bay, Wash.	48 122	10 38	3798.5044	± 4.2	1/960 000
Jacksonville, Tex.	31 95	56 15	8948.7279	±10.8	1/830 000
Little Rock, Ark.	34 92	43 11	7490.8828	± 7.6	1/990 000
Capleville, Miss. and Tenn.	34 89	59 49	6022.0937	± 4.8	1/1 250 000
Prescott, Ariz.	34 112	46 26	10012.9271	± 8.2	1/1 050 000
Vega, Tex.	35 102	07 36	12645.9101	± 7.3	1/1 730 000
Belen, N. Mex.	34 106	26 39	18288.9711	±12.0	1/1 520 000
Savanna, Okla.	34 95	49 51	7543.8032	± 8.4	1/900 000

FIRST AND SECOND CLASS TRIANGULATION AND TRAVERSE.

From year to year the use of data furnished by triangulation in the United States is becoming greater. This fact has made it necessary for our Government to increase the appropriations necessary for this class of work. During the 10-year period beginning January 1, 1912, there were established in the United States 4659 miles (7498 km.) of arcs of first-class triangulation and 350 miles (563 km.) of arcs of second-class triangulation.

First-class triangulation has an accuracy represented by an average closing error of a triangle of about one second of arc, second-class triangulation by an average closing error between two and three seconds of arc, and third-class triangulation by an average closing error between four and five seconds of arc. All of the first and second class triangulation executed in the United States during the last 10 years has been done by the U. S. Coast and Geodetic Survey, and this organization is working toward a definite plan by which we shall eventually have a triangulation station of the first order within about 50 miles (80 km.) of each point in the United States. Except where it has been necessary to concentrate efforts in rather small areas to furnish geographic positions for topographic engineers who wish the results immediately, the U. S. Coast and Geodetic Survey has endeavored to divide the great areas of our country which previously had no horizontal control.

As a supplement to the triangulation of the first order there has been run in the United States 3060 miles (4925 km.) of precise traverse which also furnishes fundamental geographic positions. This traverse was run in comparatively short lines between arcs of triangulation and was designed to furnish standard geographic positions in areas which were low in elevation and rather heavily wooded. This work should be placed in the same category as the precise triangulation, as in no case will triangulation be made over the same area where traverse has been run.

The most important arcs of precise triangulation established during the period covered by this report are: First, the one hundred and fourth meridian arc, which extends from central Colorado northward to the Canadian boundary; second, the Utah-Washington arc; third, the Rio Grande arc, which extends parallel with the river from the southern end of the ninety-eighth meridian, where it touches the Rio Grande, to approximately longitude 105°; fourth, the arc running from El Reno, Okla., to the vicinity of Needles, Calif.; fifth, the arc which extends from the vicinity of Huntsville, Ala., westward through Memphis, Tenn., and Little Rock, Ark., to the ninety-eighth meridian near El Reno, Okla.; sixth, the California-Oregon arc, extending from near Mount Shasta, Calif., northeastward to the vicinity of Ontario, Oreg., where it connects with the Utah-Washington arc; and, seventh, the arc extending from the ninety-eighth meridian triangulation near Waco, Tex., to Naples, La.

Data concerning the several pieces of precise triangulation done during the interval from January 1, 1912, to December 31, 1921, are given in the table below. The approximate latitude and longitude of each end of each arc are given, as well as the length in miles through the middle of the scheme. There is also given in a following table similar information for the second-class triangulation that was done during the 10-year period covered by this report. The third table which follows furnishes data for the precise traverse lines which have been run since January 1, 1912. The total amount of first and second grade triangulation and precise traverse done between January 1, 1912, and December 31, 1921, is 8069 miles (12 986 km.).

The observations for horizontal angles or directions in this triangulation and traverse were made by direction theodolites, and in the triangulation the observations over the main scheme directions were made on lamps. Beginning in 1918 most of the observations were made on electrical signal lamps which proved to be far more efficient than the calcium-carbide lamps which had been used for some years previously.

In addition to the triangulation of the first and second class done in the United States, 235 miles (378 km.) of arcs of first-class triangulation were extended among the islands in southeastern Alaska. It is the purpose of the U. S. Coast and Geodetic Survey and of the Geodetic

Survey of Canada to extend, in cooperation, an arc of precise triangulation from the vicinity of Puget Sound, at the northwest corner of the United States, northward into northwest Canada and Alaska. Good progress has been made on this project.

Attention should be called to the fact that the triangulation nets of Mexico and the United States have been joined at the point where the ninety-eighth meridian crosses the Rio Grande and at the international boundary between California and Lower California.

Precise triangulation between January 1, 1912, and December 31, 1921.

Name of arc.	Geographic position.		Length.	
	Beginning.	End.	Miles.	Kilometers.
	° ′ ″	° ′ ″		
One hundred and fourth meridian, 1912	38 50 26 105 02 37	48 59 57 103 44 00	720	1159
Louisville connection, October-November, 1914	38 51 18 83 54 42	38 22 38 85 48 49	33	53
South end of 98th meridian (with Mexican connection), 1913	27 43 41 97 56 24	25 59 19 98 00 14	175	282
Utah-Washington, 1915-16	41 12 01 111 52 53	45 56 07 121 49 12	640	1030
Rio Grande, 1917-18	26 09 41 98 02 45	30 48 10 104 42 35	586	943
Memphis, Tenn.-Huntsville, Ala., 1914-15	34 37 05 86 46 40	35 05 33 90 05 20	190	306
Griffin-Atlanta, Ga. (connects traverse to oblique arc), 1918	33 41 05 84 16 50	33 03 05 84 02 30	55	89
Sanford-Madison, N. C., 1919	35 24 06 79 15 05	36 35 50 80 22 49	120	193
Mexican connection in California, 1920	32 53 35 116 55 45	32 30 40 116 46 00	40	64
Ninety-eighth meridian, vicinity of Waco, Tex., to Mansfield, La., 1919-20	31 32 35 97 53 37	32 00 30 93 43 05	245	394
California-Oregon, 1920	44 10 09 117 39 41	41 15 36 122 46 47	550	885
Puget Sound, Tacoma to forty-ninth parallel (connects with Canadian triangulation), 1921	47 17 50 122 29 00	48 25 20 123 03 20	105	169
Little Rock, Ark.-ninety-eighth meridian, 1917-20	34 43 47 92 09 15	34 50 30 97 28 15	300	483
El Reno, Okla.-Needles, Calif., 1919-21	35 10 15 97 48 30	34 17 25 113 36 00	900	1448
Total			4659	7498

Second-class triangulation between January 1, 1912, and December 31, 1921.

Name of arc.	Geographic position.		Length.	
	Beginning.	End.	Miles.	Kilometers.
	° ′ ″	° ′ ″		
Nogales-Yuma, Ariz. (United States-Mexico boundary), 1919-20	32 04 10 110 49 05	32 40 15 114 45 55	225	362
Utah Forest areas, 1919-20	39 49 10 111 34 50	38 25 05 111 50 43	125	201
Total			350	563

TRIANGULATION

U.S.Coast and Geodetic Survey

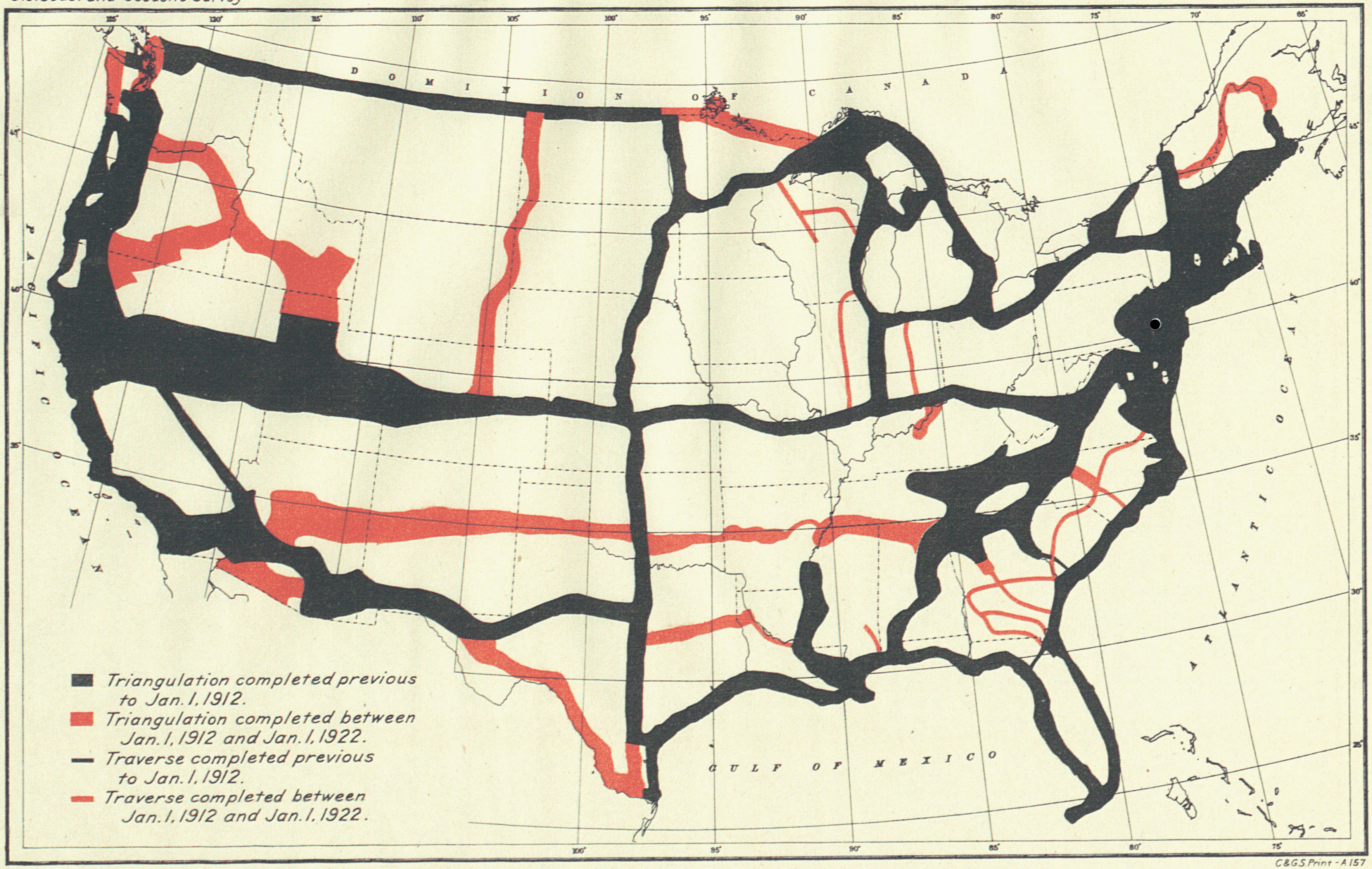

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FIG. 8

TRIANGULATION

U.S. Coast and Geodetic Survey

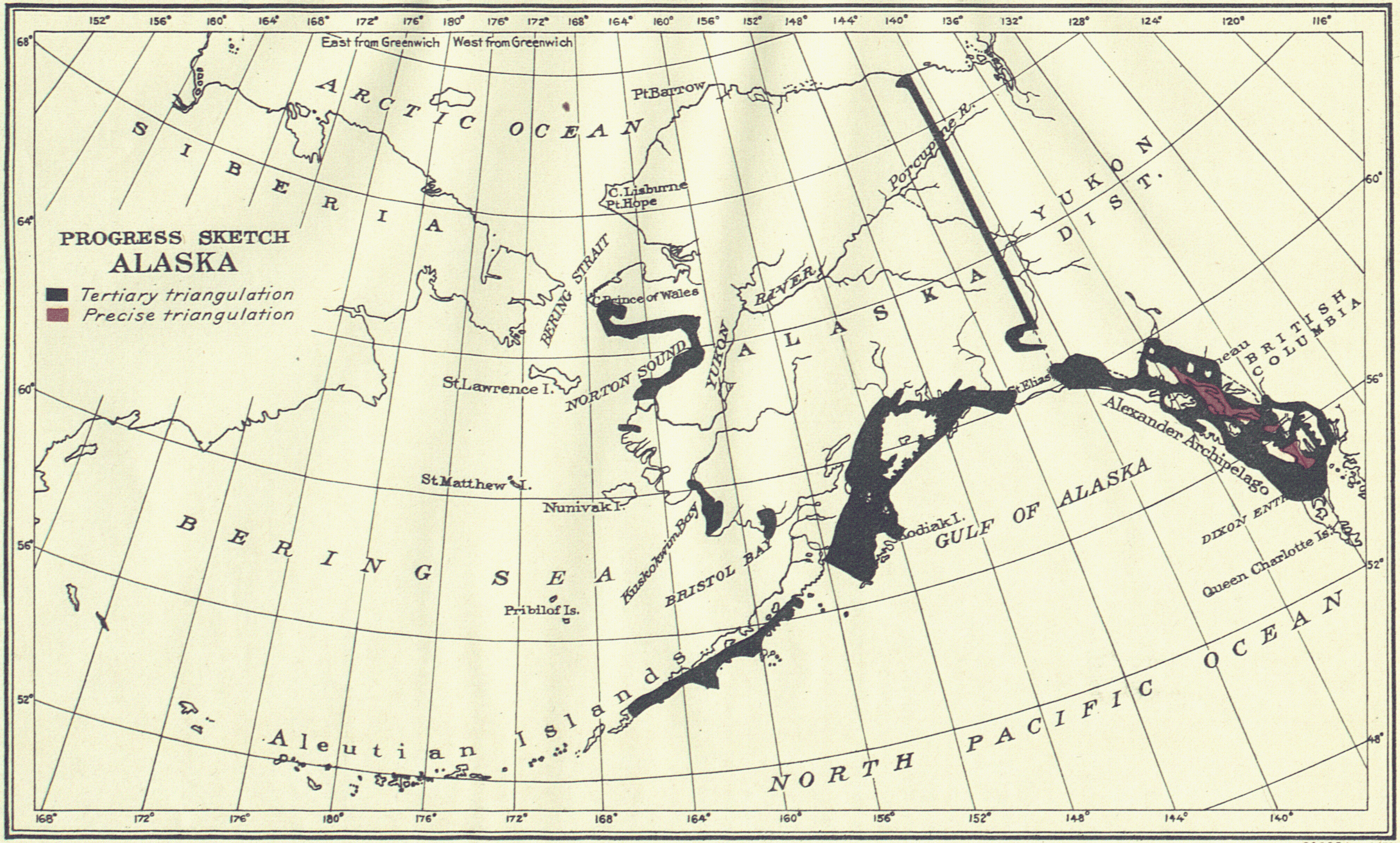

FIG. 9

TRIANGULATION

U.S.Coast and Geodetic Survey

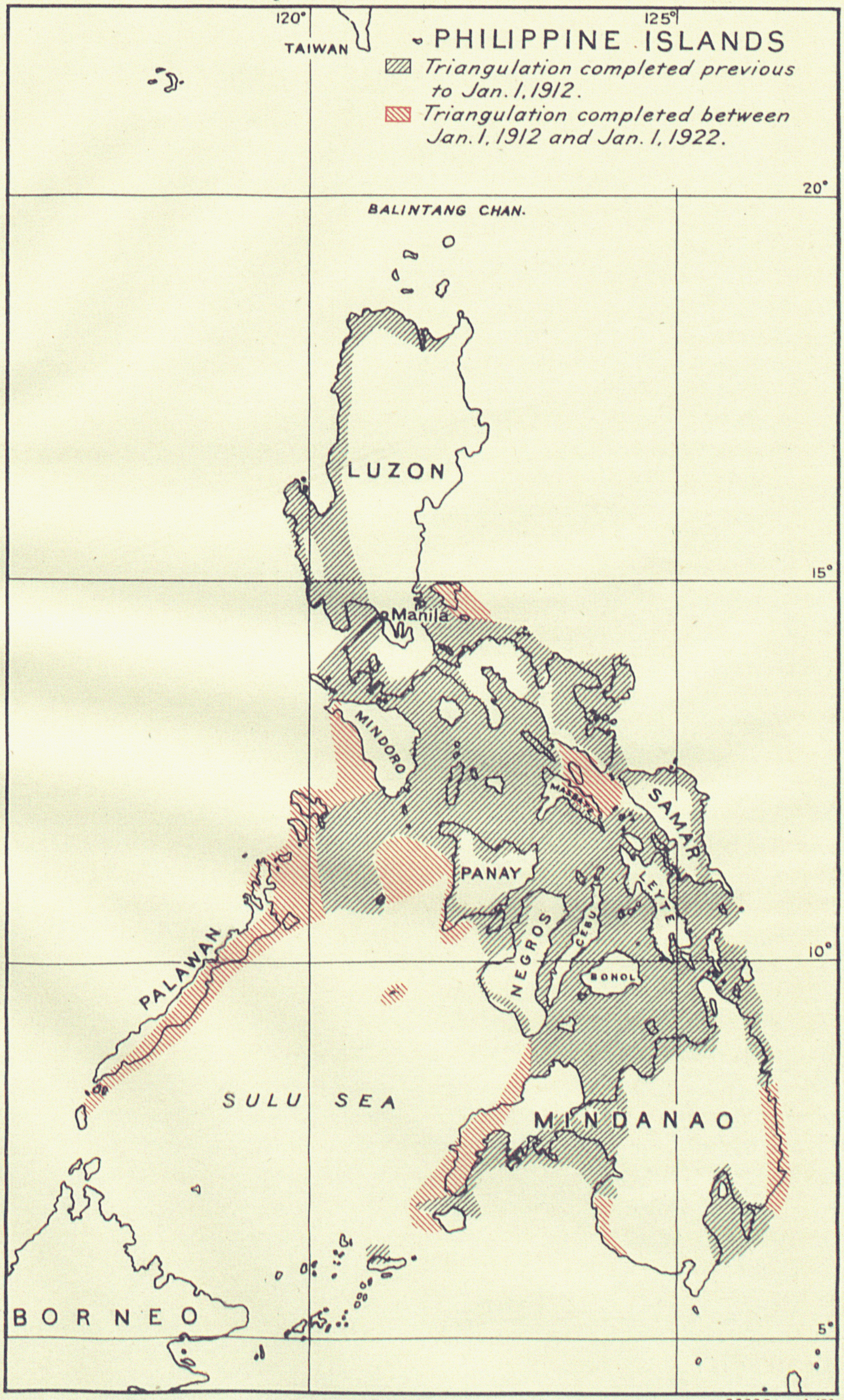

FIG. 10

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Precise traverse lines between January 1, 1912, and December 31, 1921.

Name of line.	Geographic position.		Length.	
	Beginning.	End.	Miles.	Kilometers.
	° ′ ″	° ′ ″		
Jacksonville, Fla.-Columbus, Ga., 1917	30 18 54 81 39 39	32 29 02 84 49 36	275	443
Brunswick-Columbus, Ga., 1917	31 10 12 81 30 12	32 29 02 84 49 36	300	483
Callahan, Fla.-Albany, Ga., 1917-18	30 33 38 81 50 11	31 33 48 84 06 43	185	298
Macon-Forsyth, Ga., 1917	82 50 03 83 8 24	88 02 15 83 56 24	30	48
Barnesville-Griffin, Ga., 1917	33 04 57 84 11 44	33 14 18 84 13 58	20	32
Macon-Savannah, Ga., 1918	32 50 03 83 38 24	32 04 52 81 08 51	185	298
Savannah-Everett City, Ga., 1918	32 04 52 81 08 51	31 23 36 81 38 30	60	97
Savannah, Ga.-Norfolk, Va., 1918	32 04 52 81 08 51	36 48 11 76 17 58	525	845
Sanford-Wilmington, N. C., 1918	35 27 33 79 08 53	34 14 28 77 56 57	115	185
Memphis, Tenn.-Little Rock, Ark., 1916	35 09 12 90 04 12	34 43 47 92 09 15	130	209
Mansfield-Naples, La., 1919	31 59 31 93 43 36	30 55 53 91 39 31	160	257
Pascagoula-Ovett, Miss., 1921	30 20 32 88 43 15	31 28 44 89 01 59	100	161
North Vernon-South Bend, Ind., 1920	38 59 58 85 38 38	41 38 53 86 12 26	215	346
Beloit, Wis.-Vandalia, Ill., 1920	42 29 47 89 02 17	38 56 57 89 06 03	255	410
Beloit-Racine, Wis., 1920	42 29 47 89 02 17	42 40 25 88 05 03	55	89
Green Bay-Superior, Wis., 1921	44 33 33 88 03 23	46 45 30 92 10 06	350	563
Ladysmith-Wisconsin Rapids, Wis., 1921	45 27 45 91 06 16	44 24 15 89 50 01	100	161
Total			3000	4925

THIRD-CLASS TRIANGULATION AND TRAVERSE.

Triangulation of the third class, amounting to 679 miles (1093 km.), has been done during the 10-year period since January 1, 1912, by the U. S. Coast and Geodetic Survey at several places along the coasts of the United States to revise the coast triangulation previously established. In the State of Washington new third-class triangulation was extended from Grays Harbor to the Straits of Fuca, a distance of 110 miles (177 km.). Third-class triangulation and traverse have been done by the U. S. Geological Survey in many local areas of the country for the immediate use of engineers carrying on topographic surveys. A small amount of third-class horizontal control was done by the Forest Service in the areas under its jurisdiction.

Along the very broken coasts of Alaska a total of 1065 miles (1714 km.) of arcs of new third-class triangulation was done by the U. S. Coast and Geodetic Survey during the 10-year period. All of the Alaska triangulation is now on independent datums. As noted in another part of this report, the North American datum is being carried into Alaska and northwestern Canada by cooperation between the United States and Canada. When this work has been completed, it will be possible to compute the Alaska triangulation on the North American datum.

NORTH AMERICAN DATUM.

In 1901 the U. S. Coast and Geodetic Survey adopted for the triangulation system of the United States what was called the United States Standard Datum, consisting of the Clarke spheroid of reference of 1866 as expressed in meters, an adopted latitude and longitude of triangulation station Meades Ranch, Kans., and an azimuth for the line Meades Ranch-Waldo. All of the connected triangulation that has been done in the United States has been computed on this standard datum.

In 1913 the United States Standard Datum for geographic positions was adopted by Canada and Mexico for the triangulation of those countries. Because of the international character of what had been the United States Standard Datum its name was changed to the North American Datum. This adoption of a single datum for the triangulation of a continent is a most noteworthy event in the history of geodesy. By the use of a single datum the maps at the boundary of any two contiguous countries will be free from the overlaps, gaps, and offsets which have caused so much trouble in the past for the geographers of various nations. Furthermore, the combined system will be of greater value in figure of the earth investigations.

PRECISE LEVELING.

Of the 15 975 miles (25 709 km.) of precise leveling in the United States completed during the past 10 years all has been done by the U. S. Coast and Geodetic survey except 500 miles (800 km.) by the Buffalo, Rochester & Pittsburgh Railroad in the western portions of the States of New York and Pennsylvania. To a certain extent this work by the U. S. Coast and Geodetic Survey has been done for the purpose of referring the lengths of base lines and the observed horizontal directions to sea level, but the primary purpose has been to furnish accurate elevations as the framework from which leveling of lower degrees will be extended over the country to control surveying, mapping, and various other engineering activities. It is planned that such an amount of precise leveling will be done in this country that no place will be more than about 50 miles from a precise leveling bench mark. Due to the fact that practically all of the leveling is done along railroads, it is reasonably certain that within a very few years a line of precise levels will run through nearly every one of our large cities and towns. Undoubtedly the most of these cities and towns will then adopt mean sea level as the datum for elevations for their surveying and other engineering work.

Owing to the fact that we have 48 separate States and also that our lines of precise levels frequently have to extend across the borders of the States, it has been found most economical for the whole country to have the precise leveling, as well as the precise triangulation and traverse, run by an agency of the General Government.

Most of the leveling during the past 10 years has been extended through very large areas with a view to gradually diminishing the sizes of the loops forming our precise level net. By working in this way it becomes gradually easier to furnish accurate elevations within any specified area where precise elevations are urgently needed. All of the leveling has been done with the instrument which is described in Appendix 3, U. S. Coast and Geodetic Survey Report for 1903. This instrument has been found to be very satisfactory, because of the fact that it is made of an alloy of low-temperature coefficient and also on account of the peculiar design of the instrument. This instrument has been somewhat modified during the past year, and it is believed to be even better than the original design. The modified instrument is described in another part of this report.

It would add too much to this report to describe in detail each line of the precise levels run during the past 10 years. It may be said that the leveling is of the accuracy of leveling of high precision as defined by the International Geodetic Association at its meeting at Hamburg in 1912. The probable accidental error is approximately ± 0.9 mm. per kilometer and the correction for the closing error of the circuits in the leveling done since 1912 is about 0.12 mm. per kilometer. No precise leveling was done in the Territory of Alaska nor in the Philippine Islands during the 10-year period.

The level nets of the United States and Canada have been connected at 12 places along the boundary between the two countries. No adjustment of the elevations of the bench marks common to the two level nets has been made, but this will be done as soon as additional leveling in the vicinity of the boundary is completed.

The following statement furnishes information in regard to the several lines of precise leveling done in the United States from January 1, 1912, to December 31, 1921, by the U. S. Coast and Geodetic Survey. The total length of this leveling is 15 475 miles (24 904 km.).

PRECISE LEVELING

U.S. Coast and Geodetic Survey

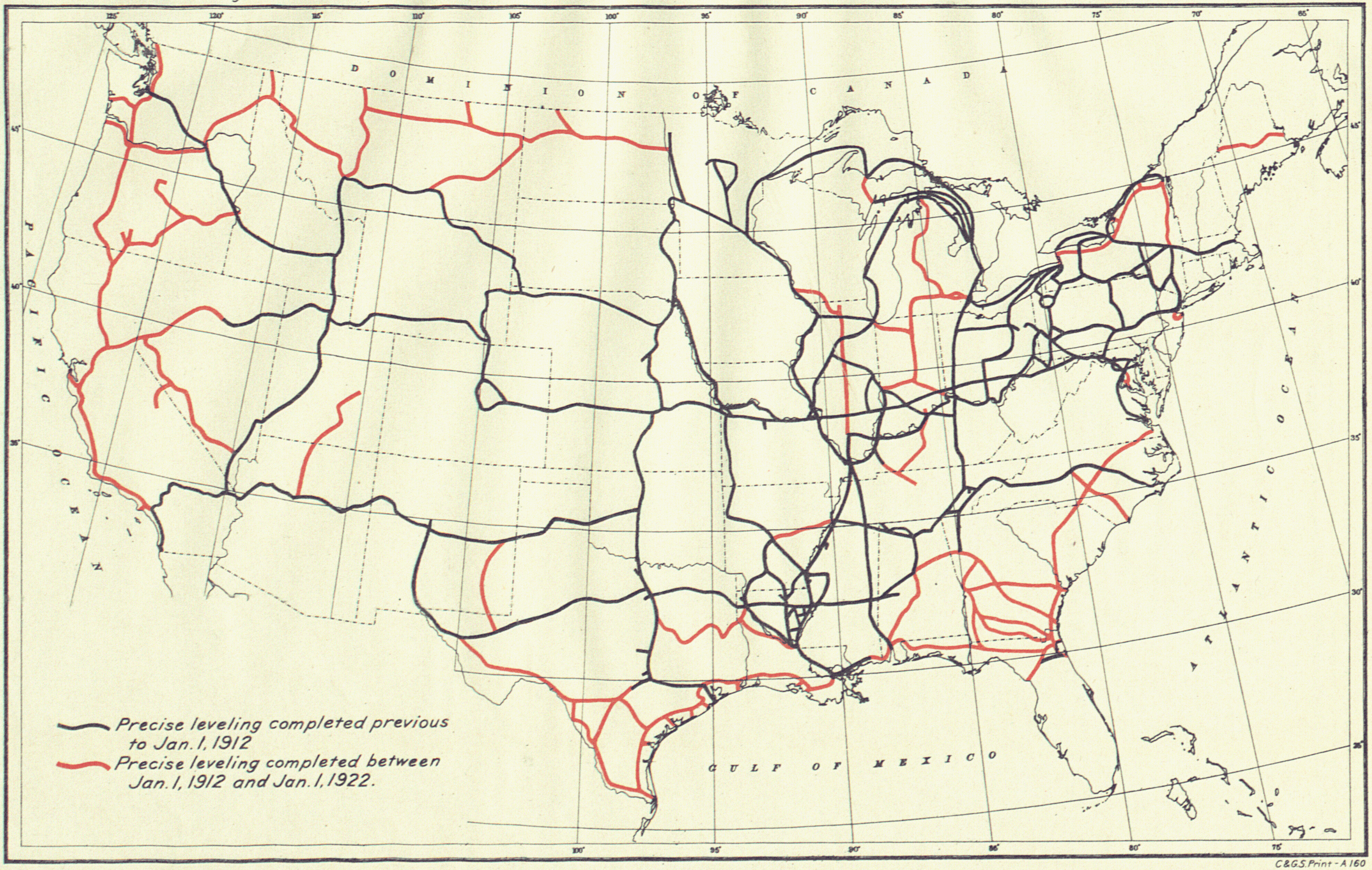

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FIG. II

The amount of leveling done before 1912 by the U. S. Coast and Geodetic Survey and other organizations is 30 000 miles (48 280 km.).

1. San Francisco, Calif. (37° 46′, 122° 24′), to Beowawe, Nev. (40° 35′, 116° 30′), through San Jose and Roseville, Calif., and Reno, Nev., 589 miles (948 km.).

2. Crookston, Minn. (47° 47′, 96° 36′), to Berthold, N. Dak. (48° 19′, 101° 45′), through Devils Lake and Minot, N. Dak., including spur line from Minot to Portal, N. Dak., 344 miles (554 km.).

3. Butte, Mont. (46° 01′, 112° 31′), to Devon, Mont. (48° 28′, 111° 29′), through Helena, Great Falls, and Shelby, Mont., including spur line from Shelby to Sweetgrass, Mont., 336 miles (541 km.).

4. Butte, Mont. (46° 01′, 112° 31′), to Pasco, Wash. (46° 14′, 119° 06′), through Superior, Mont., Sandpoint, Idaho, and Ritzville, Wash., including spur line from Sandpoint to Porthill, Idaho, 617 miles (993 km.).

5. Berthold, N. Dak. (48° 19′, 101° 45′), to Devon, Mont. (48° 28′, 111° 29′), through Snowden and Hinsdale, Mont., 509 miles (819 km.).

6. Perth Amboy, N. J. (40° 31′, 74° 16′) to Sandy Hook, N. J. (40° 28′, 74° 00′), through South Amboy, N. J., 29 miles (47 km.).

7. Louisville, Ky. (38° 15′, 85° 46′), to Charlestown, Ind. (38° 26′, 85° 40′), 14 miles (22 km.).

8. Blaine, Wash. (49° 00′, 122° 45′), to Seattle, Wash. (47° 37′, 122° 20′), through Mount Vernon, Wash., 128 miles (206 km.).

9. Reno, Nev. (39° 32′, 119° 49′), to Las Vegas, Nev. (36° 12′, 115° 08′), through Tonopah Junction, and Rosewell, Nev., including spur line from Tonopah Junction, Nev., to Laws, Calif., 547 miles (880 km.).

10. Huntley, Mont. (45° 54′, 108° 17′), to Snowden, Mont. (48° 02′, 104° 06′), through Miles City, Mont., 296 miles (477 km.).

11. Cedar Keys, Fla. (29° 09′, 83° 02′), to Fernandino, Fla. (30° 41′, 81° 27′), through Gainesville, Baldwin, Jacksonville, and Yulee, Fla., including spur line from Jacksonville to St. Augustine, Fla., 203 miles (326 km.).

12. Lawrenceburg, Ind. (39° 06′, 84° 49′), to Terre Haute, Ind. (39° 28′, 87° 24′), through Indianapolis, Ind., 170 miles (274 km.).

13. Indianapolis, Ind. (39° 46′, 86° 10′), to Chicago, Ill. (41° 53′, 87° 38′), through Anderson and Warsaw, Ind., 232 miles (373 km.).

14. Baldwin, Fla. (30° 18′, 81° 58′), to River Junction, Fla. (30° 42′, 84° 50′), through Madison and Tallahassee, Fla., 193 miles (311 km.).

15. Tallahassee, Fla. (30° 27′, 84° 17′), to Atlanta, Ga. (33° 46′, 84° 23′), through Kimbrough, Columbus, and McDonough, Ga., 305 miles (491 km.).

16. Warsaw, Ind. (41° 14′, 85° 56′), to Detroit, Mich. (42° 20′, 83° 03′), through Kalamazoo and Jackson, Mich., 240 miles (386 km.).

17. Mackinaw, Mich. (45° 47′, 84° 44′), to Jackson, Mich. (42° 15′, 84° 25′), through Grayling, Walton, Big Rapids, and Ionia, Mich., 337 miles (542 km.).

18. Memphis, Tenn. (35° 09′, 90° 04′), to Little Rock, Ark. (34° 44′, 92° 09′), through Devalls Bluff, Ark., 139 miles (224 km.).

19. Boundary, Me. (45° 31′, 70° 43′), to Vanceboro, Me. (45° 34′, 67° 26′), through Moosehead, Lake View, and Bancroft, Me., 211 miles (340 km.).

20. Whitehall, N. Y. (43° 33′, 73° 25′), to Rouses Point, N. Y. (45° 00′, 73° 23′), through Westport, N. Y., 115 miles (185 km.).

21. Clovis, N. Mex. (34° 25′, 103° 12′), to Pecos, Tex. (31° 24′, 103° 25′), through Roswell, N. Mex., 277 miles (445 km.).

22. Atlanta, Ga. (33° 46′, 84° 23′), to Mobile, Ala. (30° 40′, 88° 03′), through Rockmart, Ga., and Birmingham and Selma, Ala., 438 miles (705 km.).

23. Washington, D. C. (38° 54′, 77° 01′), to Popes Creek, Md. (38° 24′, 76° 59′), through Upper Marlboro and White Plains, Md., including spur line from White Plains to Indian Head, Md., 70 miles (112 km.).

24. Jacksonville, Fla. (30° 19′, 81° 40′), to Kimbrough, Ga. (32° 00′, 84° 41′), through Callahan, Fla., and Waycross and Albany, Ga., 234 miles (376 km.).

25. Sierra Blanca, Tex. (31° 10′, 105° 22′), to San Antonio, Tex. (29° 26′, 98° 28′), through Marfa, Sanderson, and Spofford, Tex., including spur line from Spofford to Eagle Pass, Tex., 570 miles (917 km.).

26. Brunswick, Ga. (31° 10′, 81° 30′), to Columbus, Ga. (32° 29′, 84° 50′), through Everett, McRae, Macon, and Fort Valley, Ga., 314 miles (505 km.).

27. Marquette, Mich. (46° 33′, 87° 24′), to Escanaba, Mich. (45° 45′, 87° 04′), through Negaunee and Lathrop, Mich., 80 miles (129 km.).

28. Algonac, Mich. (42° 37′, 82° 32′), to St. Clair Flats, Mich. (42° 33′, 82° 37′), 14 miles (23 km.).

29. Albany, Ga. (31° 34′, 84° 07′), to Callahan, Fla. (30° 34′, 81° 50′), through Valdosta, Ga., 178 miles (287 km.).

30. Macon, Ga. (32° 50′, 83° 38′), to McDonough, Ga. (33° 27′, 84° 09′), 66 miles (107 km.).

31. New Braunfels, Tex. (29° 44′, 98° 06′), to Point Isabel, Tex. (26° 04′, 97° 12′), through San Antonio, Sinton, Harlingen, and Brownsville, Tex., including spur line from Robstown to Corpus Christi, Tex., 365 miles (588 km.).

32. Macdona, Tex. (29° 20′, 98° 42′), to Laredo, Tex. (27° 30′, 99° 29′), through Kirk, Gardendale, and Webb, Tex., 143 miles (230 km.).

33. Savannah, Ga. (32° 05′, 81° 09′), to Yulee, Fla. (30° 39′, 81° 36′), through Everett, Ga., 116 miles (186 km.).

34. Sinton, Tex. (28° 02′, 97° 28′), to New Orleans, La. (29° 58′, 90° 04′), through Bay City and Houston, Tex., and Lafayette and Morgan City, La., including spur lines to Port Lavaca, Matagorda, Velasco, and Sabine Pass, Tex., and Weeks Island and South Bend, La., 706 miles (1136 km.).

35. Biloxi, Miss. (30° 24′, 88° 54′), to River Junction, Fla. (30° 42′, 84° 50′), through Mobile and Atmore, Ala., and Pensacola and De Funiak Springs, Fla., 359 miles (577 km.).

36. Savannah, Ga. (32° 05′, 81° 09′), to Norfolk, Va. (36° 48′, 76° 18′), through Columbia, S. C., and Sanford, Raleigh, and Norlina, N. C., 544 miles (876 km.).

37. Macon, Ga. (32° 50′, 83° 38′), to Savannah, Ga. (32° 05′, 81° 09′), through Dublin and Statesboro, Ga., 190 miles (306 km.).

38. Wilmington, N. C. (34° 14′, 77° 57′), to Greensboro, N. C. (36° 04′, 79° 47′), through Fayetteville and Sanford, N. C., 181 miles (292 km.).

39. Harlingen, Tex. (26° 12′, 97° 42′), to Eagle Pass, Tex. (28° 44′, 100° 28′), through Roma, Laredo, Webb, and Carrizo Springs, Tex., 320 miles (515 km.).

40. Hillsboro, Tex. (32° 02′, 97° 07′), to Gallatin, Tex. (31° 56′, 95° 12′), through Jewett, Tex., 190 miles (306 km.).

41. Tenaha, Tex. (31° 58′, 94° 15′), to Shreveport, La. (32° 30′, 93° 45′), through Logansport and Keithville, La., 60 miles (97 km.).

42. Keithville, La. (32° 19′, 93° 50′), to Naples, La. (30° 56′, 91° 40′), through Mansfield and Alexandria, La., 193 miles (311 km.).

43. Troy, N. Y. (42° 44′, 73° 41′), to Whitehall, N. Y. (43° 33′, 73° 25′), through Saratoga Springs, N. Y., 78 miles (126 km.).

44. Kirk, Oreg. (42° 44′, 121° 49′), to Roseville, Calif. (38° 45′, 121° 16′), through Klamath Falls, Oreg., and Weed and Red Bluff, Calif., 373 miles (601 km.).

45. Rouses Point, N. Y. (45° 00′, 73° 23′), to Buffalo, N. Y. (42° 53′, 78° 52′), through Moira, Watertown, Oswego, and Charlotte, N. Y., including spur line from Watertown to Cape Vincent, N. Y., 463 miles (745 km.).

46. San Jose, Calif. (37° 19′, 121° 54′), to Santa Ana, Calif. (33° 45′, 117° 52′), through Castroville, San Miguel, Port Arguello, and Los Angeles, Calif., including spur lines to Monterey and San Pedro, Calif., 490 miles (788 km.).

47. Weed, Calif. (41° 26′, 122° 24′), to Auburn, Wash. (47° 18′, 122° 13′), through Glendale, Eugene, and Portland, Oreg., and Centralia, Wash., including spur lines from Portland to Astoria, Oreg., and from Centralia to Grays Harbor, Wash., 785 miles (1,264 km.).

48. Klamath Falls, Oreg. (42° 13′, 121° 47′), to Ontario, Oreg. (44° 02′, 116° 57′), through Lakeview, Gap Ranch, and Crane, Oreg., including spur line from Gap Ranch to Bend, Oreg., 547 miles (880 km.).

49. Tenaha, Tex. (31° 58′, 94° 15′), to Gallatin, Tex. (31° 56′, 95° 12′), through Nacogdoches, Tex., 78 miles (126 km.).

50. Moira, N. Y. (44° 50′, 74° 34′), to Cornwall, Canada (45° 01′, 74° 45′), 20 miles (32 km.).

51. Rockford, Ill. (42° 16′, 89° 05′), to Prairie du Chien, Wis. (43° 03′, 91° 09′), through Freeport, Ill., and Dodgeville, Wis., 166 miles (267 km.).

52. Rockton, Ill. (42° 26′, 89° 03′), to Centralia, Ill. (38° 32′, 89° 08′), through Rockford, Davis Junction, La Salle, and Bloomington, Ill., 303 miles (487 km.).

53. Louisville, Ky. (38° 15′, 85° 46′), to Cerulean, Ky. (36° 58′, 87° 43′), through West Point, Elizabethtown and Bowling Green, Ky., and Clarksville, Tenn., including spur line from Clarksville to Nashville, Tenn., 294 miles (473 km.).

54. Hinsdale, Mont. (48° 24′, 107° 06′), to Boundary Line, Mont. (49° 00′, 107° 10′), 50 miles (80 km.).

55. Green River, Utah (39° 00′, 110° 11′), to Flagstaff, Ariz. (35° 13′, 111° 38′), through Halls Crossing, Utah, and Lees Ferry, Ariz., 416 miles (669 km.).

56. Portland, Oreg. (45° 31′, 122° 42′), to Wallula, Wash. (46° 04′, 118° 55′), through Hood River, Biggs, and Castle Rock, Oreg., 211 miles (340 km.).

57. Bend, Oreg. (44° 03′, 121° 18′), to Prineville, Oreg. (44° 18′, 120° 52′), through Prineville Junction, Oreg., 38 miles (61 km.).

DETERMINATIONS OF INTENSITY OF GRAVITY.

The U. S. Coast and Geodetic Survey is charged with the duty of extending gravimetric surveys over our area, and this organization is the only one that has done such work in the United States. There are now 286 gravity stations in this country, of which 162 were established between January 1, 1912, and December 31, 1921. Before 1921 all of the observations were made with the half-second bronze pendulums which are described in detail in U. S. Coast and Geodetic Survey Special Publication No. 69. In 1921 ten stations were established near the mouth of the Mississippi River, at which observations were made with both the new invar pendulums and the bronze pendulums. The invar pendulums are identical in pattern with the bronze pendulums.

It is now known that the invar pendulums are entirely satisfactory, and by exercising certain precautions they can be made so nearly free from any disturbing effect of magnetiza-

GRAVITY

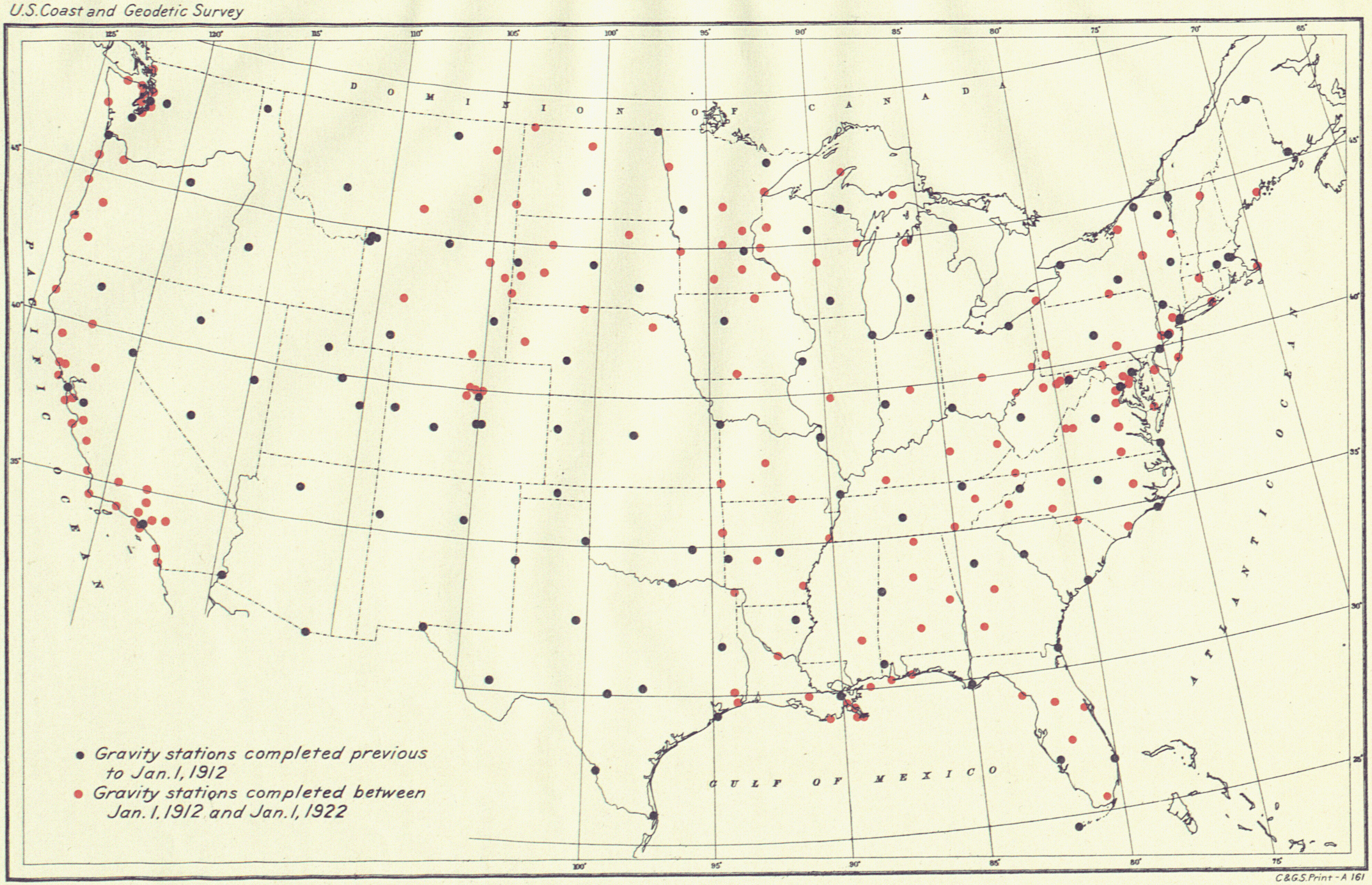

FIG. 12

tion that the results given by them will be thoroughly reliable. The observations with these pendulums have the great advantage of being free from serious effects resulting from inadequate temperature control, and therefore constant temperature rooms are not necessary for them at field stations. Where a building with a suitable floor is not available, the invar pendulums can be swung in a tent and mounted on a portable stand, as was done at several stations during the 1921 season. A more detailed discussion of the invar pendulums will be found in another part of this report under the heading "New instruments."

A few of the gravity stations of the United States have been established at physical laboratories, but most of them have been established especially for the purpose of furnishing information to be used in deriving a gravity formula, for determination of the shape of the earth, and in investigations of the variations from normal of the density of the materials of the earth's crust. This matter of densities in the earth's crust is considered below under the heading "Isostatic investigations." There are three primary gravity stations and seven secondary stations in Alaska which were established before January 1, 1912. None has been established since that date. There is only one station in the Philippine Islands. It was established in 1921.

During the 1921 field season, when 10 gravity stations were established, two bronze and three invar pendulums were swung at the first and next to the last stations, in places where the temperature control was excellent and good concrete floors were available on which to set up the case. At two of the other stations, where conditions were similar to those above, one bronze and two invars were swung, and at the other six stations, where temperature control was poor and where a tent had to be used for shelter, only the three invar pendulums were swung. At all stations the values of gravity as determined by the individual pendulums checked each other closely, proving that the amount of magnetism in the invar pendulums, which was kept fairly constant throughout the season, caused no variation in the period due to effects of the earth's magnetic intensity, and also that no change in lengths of the invar pendulums had occurred from molecular processes.

The standardizations of the invar pendulums at Washington before and after the 1921 field season, magnetization being approximately the same, gave values from the preliminary computations as follows:

Period before.	Period after.
B_7 0.5008866 second.	B_7 0.5008864 second.
B_8 0.5008194 second.	B_8 0.5008190 second.
B_9 0.5007903 second.	B_9 0.5007902 second.

As the probable error of a single observation is usually about five in the seventh place, the above results, which vary much less than the probable error, are clear evidence that no change of length occurred in the pendulums during the field season.

ISOSTATIC INVESTIGATIONS.

For a number of years the U. S. Coast and Geodetic Survey has carried on investigations looking toward the correction of deflections of the vertical and the observed values of the intensity of gravity for the effect of topography and isostatic compensation. This work was done under the direction of Dr. J. F. Hayford, who was in charge of the geodetic work of the Bureau, from 1898 to 1909, and for the past 12 years under the direction of the author of this report.

A number of reports on these investigations have been published as well as many articles in the scientific press. The two publications on the figure of the earth [1] give in detail the methods employed in applying the theory of isostasy to deflections of the vertical, while Special Publications Nos. 10, 12, and 40 give details in regard to the application of this theory to the reduction of gravity determinations. It would seem to be reasonable to conclude from the accumulated data and the result of the investigations by the U. S. Coast and Geodetic Survey and by organizations and individuals in other countries that the theory of isostasy is substantially

[1] Figure of the earth and isostasy from measurements in the United States, and Supplementary investigation in 1909 of the figure of the earth and isostasy, by J. F. Hayford.

true. It is reasonably certain that blocks of the earth's crust of the order of magnitude of 100 miles square are independently in equilibrium—that is, that any block contains very nearly the same mass as any other block—the blocks having the same area at their lower surfaces which are at what is called the depth of compensation. It is not known, of course, nor can it be definitely determined, what is the depth within which the compensation is located, but it appears from the investigations made at the U. S. Coast and Geodetic Survey that the order of magnitude of the depth is about 60 miles (96 km.).

The dimensions of the earth as derived from data corrected for the effect of topography and isostatic compensation are far more reliable than the values obtained from the same data uncorrected for these effects. Likewise a gravity formula will be more accurate if the theory of isostasy is taken into account in its derivation. As the theory of isostasy has been proved to be substantially true, it is certain that this fact will have to be considered in investigations in geology and other geophysical sciences, especially in connection with structural and dynamic geology.

It is possible that the determination of the intensity of gravity and the application of the theory of isostasy may have a practical value. There are stations in the United States in localities which are underlaid by crystalline rocks, and in such cases the anomaly or difference between the observed and the computed value of gravity tends to be positive, showing the observed value to be greater than normal. It is believed that these positive anomalies are largely due to material which is denser than normal close to the gravity stations. It is possible that the fact that the pendulum shows a positive anomaly for gravity when over crystalline rocks at or close to the surface will enable us to predict from a gravity anomaly map the character of the material close to the earth's surface. Several articles have been prepared in the United States on the relation of isostasy to certain geological phenomena and theories. (See list in another part of this report.)

EARTH TIDE OBSERVATIONS.

A new type of apparatus for the determination of the yielding of the earth under the tide-producing forces of the sun and moon was designed by Prof. A. A. Michelson, of Chicago University, and in 1913 was installed at Williams Bay, Wis., on the ground of the Yerkes Observatory. The apparatus is described in some detail in another part of this report. The observations consist of determining the tidal movement of water in two horizontal pipes—one in the meridian and the other in the prime vertical. From the relation of the amount of the actual observed tide in these pipes to the corresponding theoretical tides the yielding of the earth can be computed.

The definitive series of observations was begun on November 20, 1916, and continued for a year. The results obtained with Michelson's apparatus are of the same nature as those obtained with horizontal pendulums, but in manageableness and in accuracy they appear to be much superior to those obtained with the older form of apparatus.

The ratio of the observed water tide in the pipe to the theoretical water tide in such a pipe on a rigid earth or, what is the same thing, the ratio of the observed deflection of the vertical to the theoretical deflection for a rigid earth was found to be practically the same for both the east and west and the north and south directions. This ratio came out about 0.69. This is the result from the short period earth tides uncorrected for the secondary effects of the oceanic tides of like periods. On account of the distance of Williams Bay from the sea this correction is probably smaller than at most of the places where observations have been made with horizontal pendulums. An apparatus similar to the one used at Williams Bay was installed at Pasadena, Calif., in 1921. It was found practicable to shorten the length of pipe used, the shortening being compensated by increased accuracy in reading the water levels. No report has yet been made on the results obtained at Pasadena with this apparatus.

A list of papers dealing with earth tides is given in another part of this report.

ACTIVITIES AT THE OFFICE OF THE U. S. COAST AND GEODETIC SURVEY.

The reduction and adjustment of observations made in the field are carried on by the mathematicians attached to the office of the U. S. Coast and Geodetic Survey at Washington. The classes of work treated are principally base measurements, triangulation, precise leveling, gravity determinations, and astronomic work. As rapidly as possible the field observations are worked over and the data secured from them are prepared for the printer. It is evident that the results will be of more value if they are available to the public in printed form rather than in manuscript.

In addition to the work connected with the reduction of field observations research has been done in a number of lines including the theory of isostasy, projections for maps, variation of latitude, and other geophysical matters.

The publications of the U. S. Coast and Geodetic Survey listed under another heading show the extent of the activities of the office.

The following statement indicates the magnitude of the activities of the geodetic work done at the Washington office of the U. S. Coast and Geodetic Survey during the 10-year period covered by this report. It does not include the geodetic work done at the office of the U. S. Coast and Geodetic Survey at Manila, P. I.

Triangulation and traverse of first class: 2058 geographic positions computed and adjusted.
Triangulation of third class: 12 667 geographic positions computed and adjusted.
Precise base lines: 20 computed and adjusted.
Precise leveling: 15 975 miles (25 709 km.) computed and adjusted.
Astronomic work: 178 azimuths, 80 latitudes, and 74 differences of longitude computed and adjusted.
Gravity observations: Values at 162 stations computed and adjusted.
Isostatic work: Effect of topography and isostatic compensation computed for 162 gravity stations.
Preparation of manuscript for printing: Manuscript for 4140 printed pages prepared.
Proof reading: 5164 printed pages compared with manuscript.

Another important line of geodetic work carried on at the Washington office is the designing and construction of new geodetic instruments and the improvement of old types. (See pp. 21–25.)

GEODETIC PUBLICATIONS IN THE UNITED STATES.

A large number of publications giving the results of geodetic work and investigations have appeared since January 1, 1912. As far as practicable the results of precise triangulation in the interior of the country are placed in print as soon as possible after the work is done in order that they may be available to scientists and to engineers engaged in surveying, mapping, and other activities.

As rapidly as the circumstances will permit the triangulation along the coast, much of which was done many years ago, is printed for the use of the engineers and any others needing the data. These reports, in general, are confined to individual States in order that they may not be too bulky and also to make it possible to print the report as soon as the manuscript for any particular State is completed.

The results of any piece of triangulation are not published until the computations of the geographic positions have been made on the North American datum. There is given below a list of the publications of the U. S. Coast and Geodetic Survey which contain the results of triangulation done by that Bureau which have appeared since January 1, 1912, or which are now in the hands of the printer. The publications issued contain the geographic positions on the North American datum of 10 150 stations, and the manuscript of the reports now in the hands of the printer contains the geographic positions on the North American datum of 3203 stations. There are geographic positions on the North American datum for 6126 triangulation stations (not duplicated in later reports) in publications of the U. S. Coast and Geodetic Survey which appeared before January 1, 1912.

The total number of geographic positions on the North American datum, in print or in the hands of the printer, is therefore 19 479.

TRIANGULATION PUBLICATIONS BY THE U. S. COAST AND GEODETIC SURVEY.

Special Publication No. 11. The Texas–California arc of primary triangulation. 1912. William Bowie.

Special Publication No. 13. The California–Washington arc of primary triangulation. 1913. A. L. Baldwin.

Special Publication No. 16. Triangulation along the west coast of Florida. 1913. C. H. Swick.

Special Publication No. 17. Triangulation on the coast of Texas, from Sabine Pass to Corpus Christi Bay. 1913. Charles A. Mourhess.

Special Publication No. 19. Primary triangulation on the one hundred and fourth meridian and on the thirty-ninth parallel in Colorado, Utah, and Nevada. 1914. William Bowie.

Special Publication No. 24. Triangulation in Alabama and Mississippi. 1915. Walter F. Reynolds.

Special Publication No. 30. Triangulation in West Virginia, Ohio, Kentucky, Indiana, Illinois, and Missouri. 1915. A. L. Baldwin.

Special Publication No. 31. Triangulation along the Columbia River and the coasts of Oregon and northern California. 1915. Charles A. Mourhess.

Special Publication No. 43. Triangulation in Georgia. 1917. C. H. Swick.

Special Publication No. 45. Descriptions of triangulation stations in Georgia. 1917. C. H. Swick.

Special Publication No. 46. Triangulation in Maine. 1918. Walter F. Reynolds.

Special Publication No. 54. Report on the connection of the arcs of primary triangulation along the ninety-eighth meridian in the United States and in Mexico and on the triangulation in southern Texas. 1919. William Bowie.

Special Publication No. 62. Triangulation in Rhode Island. 1920. Earl Church.

Special Publication No. 74. Utah–Washington arc of precise triangulation. 1921. C. V. Hodgson.

Special Publication No. 76. Triangulation in Massachusetts. 1922. O. P. Sutherland.

Special Publication No. 78. Precise triangulation in Texas, Rio Grande arc. 1922. Clem L. Garner.

Special Publication No. 79. Precise traverse and triangulation in Indiana, 1922. Charles A. Mourhess and J. S. Bilby.

Publications of the U. S. Coast and Geodetic Survey containing triangulation results on the North American datum which were printed before January 1, 1912, are shown in the following reports:

Appendix 8 of the report for 1888, positions in Connecticut. Charles A. Schott.

Appendix 8 of the report for 1893, positions in Pennsylvania, Delaware, and Maryland. W. C. Hodgkins.

Appendix 6 of the report for 1901, positions and descriptions in Kansas and Nebraska. John F. Hayford.

Appendix 4 of the report for 1903, positions and descriptions in Kansas, Oklahoma, and Texas. John F. Hayford.

Appendix 9 of the report for 1904, positions and descriptions in California. A. L. Baldwin.

Appendix 5 of the report for 1905, positions and descriptions in Texas. John F. Hayford.

Appendix 3 of the report for 1907, positions and descriptions in California. John F. Hayford and A. L. Baldwin.

Appendix 5 of the report for 1910, positions and descriptions in California. C. R. Duvall and A. L. Baldwin.

Appendix 4 of the report for 1911, positions and descriptions in Nebraska, Minnesota, North Dakota, and South Dakota. William Bowie.

Appendix 5 of the report for 1911, positions and descriptions in Texas. A. L. Baldwin.

Appendix 6 of the report for 1911, positions and descriptions in Florida. Hugh C. Mitchell.

TRIANGULATION PUBLICATIONS BY ORGANIZATIONS OTHER THAN THE U. S. COAST AND GEODETIC SURVEY.

The following publications contain the results of triangulation computed on the North American datum. Some of these were published before January 1, 1912, but they have been included to make the list complete.

Appendix EEE, pages 2905–3031, Annual Report of the Chief of Engineers, United States Army, 1902, positions of points on and near the Great Lakes.

Professional Paper No. 24, Corps of Engineers, United States Army, 1882, descriptions of points on and near the Great Lakes.

Publications of the Massachusetts Harbor and Land Commission.

Report on the Triangulation of Greater New York, 1908.

Report on a plan of Sewerage for the City of Cincinnati, 1912.

Report of the International Boundary Commission upon the reestablishment of the boundary between the United States and Canada from the forty-ninth parallel to the Pacific Ocean, 1921.

These reports contain the geographic positions of 1934 triangulation stations.

During the interval 1912–1921 Bulletins Nos. 496, 551, 552, 644, and 709 have been published by the U. S. Geological Survey. These contain the geographic positions and descriptions of triangulation and traverse stations in the United States established by that organization and also the results of triangulation by others where the work of the latter is close to the work of the former. The triangulation and traverse covered by the U. S. Geological Survey bulletins are largely of the third class in character, and therefore will be subject to some revision when the precise network of triangulation is further extended. This triangulation will be of much value in investigations of the figure of the earth and of isostasy when it has been adjusted to the precise net and after the astronomic latitude and longitude have been observed at many of the stations.

LEVELING PUBLICATIONS BY THE U. S. COAST AND GEODETIC SURVEY.

The results of the precise leveling in the United States are given in the following publications of the U. S. Coast and Geodetic Survey:

Appendix 8, report for 1899, Precise leveling in the United States. John F. Hayford.

Appendix 3, report for 1903, Precise leveling in the United States, 1900–03. John F. Hayford.

(Not numbered) Precise leveling in the United States, 1903–07. John F. Hayford and L. Pike, 1909.

Special Publication No. 18, Fourth general adjustment of the precise level net in the United States and the resulting standard elevations. W. Bowie and H. G. Avers, 1914.

Special Publication No. 22, Precise leveling from Brigham, Utah, to San Francisco, Calif. W. Bowie, 1914.

Special Publication No. 39, Precise leveling from Reno to Las Vegas, Nev., and from Tonopah Junction, Nev., to Laws, Calif. H. G. Avers and G. D. Cowie, 1916.

Special Publication No. 77, Precise leveling in Texas. H. G. Avers, 1922.

These reports contain data for 32 672 miles (52 581 km.) of precise leveling and the elevations for 13 667 bench marks.

When Special Publication No. 18 was prepared, it was possible, on account of the small space required, to include the elevations of all adjusted precise leveling bench marks. It was considered impracticable, however, to assemble in the same volume the descriptions of the bench marks which had been printed in previous reports. The index of Special Publication No. 18 refers to Appendix 8, report for 1899, Appendix 3, report for 1903, and precise leveling in the United States, 1903-1907, which contain the descriptions of the bench marks established in the earlier leveling.

The methods employed in the field and the office in precise leveling are discussed in detail in Special Publications Nos. 18 and 22. There are in the United States about 12 000 miles (19 300 km.) of precise leveling, the results of which have not yet been printed. This is because of the necessity of adding more leveling to the net before the final adjustment is made. This is especially the case with the precise leveling in our Northwestern States. Before the final adjustment of the lines in that section it is desired to make additional connections between the precise level nets of the United States and Canada and to adjust the nets of both countries together.

LEVELING PUBLICATIONS BY THE U. S. GEOLOGICAL SURVEY.

The United States Geological Survey has a number of bulletins covering the results of spirit leveling which it has done in various States of the country. Most of the leveling published in these bulletins was done for the immediate control of the topographic mapping and is of the third class, although the bulletins also contain the results of any precise leveling that may have been done in the region covered by the report. The elevations of the third-class leveling will, in many cases, be changed when the precise leveling net is expanded.

There are 46 of these reports all together, of which 42 have appeared since January 1, 1912. Some of them supersede previous reports, as it is the practice to publish a new bulletin for a State as soon as sufficient new material has accumulated. It is not believed necessary to indicate the individual numbers of the bulletins in this report.

PUBLICATIONS BY THE U. S. COAST AND GEODETIC SURVEY DEALING WITH GRAVITY AND THE THEORY OF ISOSTASY.

The field and office methods employed in the determination of the intensity of gravity are given in detail in Special Publication No. 69 of the U. S. Coast and Geodetic Survey, which is used as a guide and manual in this work. Three publications of the U. S. Coast and Geodetic Survey on the subject of gravity and isostasy have appeared since January 1, 1912. They are as follows:

Effect of topography and isostatic compensation on the intensity of gravity, Special Publication No. 10, by John F. Hayford and William Bowie, 1912.

Effect of topography and isostatic compensation on the intensity of gravity, second paper, Special Publication No. 12, by William Bowie, 1912.

Investigations of gravity and isostasy, Special Publication No. 40, by William Bowie, 1917.

Each of these publications contains the results of an investigation to show whether what are called gravity anomalies are lessened by the application of the theory of isostasy in the reduction of the gravity values. The work supplements that done by Prof. J. F. Hayford on the figure of the earth and isostasy, two reports on which appeared prior to January 1, 1912. These reports were entitled:

Figure of the earth and isostasy from measurements in the United States, 1909.

Supplementary investigation in 1909 of the figure of the earth and isostasy, 1910.

The above reports cover in detail the methods employed in computing the effect of topography and the isostatic compensation on the vertical and on the value of gravity.

It would take too much space in this report to go into details as to the findings of the investigations in isostasy or to abstract the papers listed above. It suffices to say that the subject is becoming one of great importance in many branches of the geophysical sciences, and it is hoped that isostatic investigations will be made by all other countries which have geodetic organizations. Many of them have material available in the form of deflections of the vertical and values of the intensity of gravity which could be used in investigations of the figure of the earth and of the theory of isostasy. Even though the stations may be confined within a limited area, if they were reduced by some method that is approved by the Section of Geodesy, the results would be of much value to anyone who wished to extend investigations already made.

ARTICLES BEARING ON ISOSTASY NOT PUBLISHED BY THE U. S. COAST AND GEODETIC SURVEY.

A number of papers not printed by the U. S. Coast and Geodetic Survey have appeared in the United States during recent years on the question of isostasy or its application to some geological or other geophysical question. These papers are listed below. There are other scientific articles which have appeared in the United States during the past 10 years which touch on isostasy incidentally, but are not strictly isostatic publications.

Isostasy, a rejoinder to the article by Harmon Lewis, Journal of Geology, Vol. XX, No. 6. 1912. John F. Hayford.

Condition of the earth's crust, Science, December 20, 1912. G. R. Putnam.

Some relations between gravity anomalies and the geologic formation in the United States, American Journal of Science, March, 1912. William Bowie.

Some results of the Hayford method of gravity reduction, Journal of Washington Academy of Sciences, December 19, 1912. William Bowie.

The strength of the earth's crust, Journal of Geology, Vol. XXII, Nos. 1-8; Vol. XXIII, Nos. 1, 5, and 6, 1914 and 1915. Joseph Barrell.

Isostasy and the size and shape of the earth, Science, May 15, 1914. William Bowie.

Interpretation of anomalies of gravity, U. S. Geological Survey Prof. Paper 85, 1913. G. K. Gilbert.

Isostasy and radio-activity, Geological Society of America, Bull. March 31, 1915; Science, January 29, 1915. G. F. Becker.

Assumptions involved in the doctrine of isostatic compensation, with a note on Hecker's determination of gravity at sea, Journal of Geology, October-November, 1916. W. H. Hobbs.

Isostasy in the light of the planetesimal theory, American Journal of Science, October, 1916. T. C. Chamberlin.

On the hypothesis of isostasy, Journal of Geology, February-March, 1917. W. D. McMillan.

The gravimetric survey of the United States, Proc. Nat. Academy of Sciences, March, 1917. William Bowie.

Our present knowledge of isostasy from geodetic evidence, Journal of Geology, July-August, 1917. William Bowie.

Local versus regional distribution of isostatic compensation, Am. Journal of Science, June, 1917. William Bowie.

Possibility of using gravity anomalies in the search for salt dome oil and gas pools, Science, December 7, 1917. E. W. Shaw.

Gravity and isostasy, Science, April 13, 1917. John F. Hayford.

The earth from a geophysical standpoint, Smith. Inst., Ann. Rept., 1916. John F. Hayford.

The status of the theory of isostasy, American Journal of Science, October, 1919. Joseph Barrell.

The nature and bearings of isostasy, American Journal of Science, October 19, 1919. Joseph Barrell.

The mathematics of isostasy, American Journal of Science, May, 1920. T. C. Chamberlin.

Isostatic measure of the Rocky Mountains, Geological Magazine, June, 1920. Charles Keyes.

The mathematics of isostasy, American Journal of Science, May, 1920. W. D. McMillan.

Some geologic conclusions from geodetic data, Proceedings of the National Academy of Sciences, January, 1921. William Bowie.

The relation of isostasy to uplift and subsidence, American Journal of Science, July, 1921. William Bowie.

ARTICLES ON GRAVITY AT SEA.

The following articles on the measurement of the intensity of gravity at sea have appeared during the 10 years covered by this report:

A new method of measuring gravity at sea with some trans-Pacific observations. L. J. Briggs. (Abstract.) Physical Review, vol. 5 (1915), p. 184.

A new method of measuring acceleration of gravity at sea. L. J. Briggs. Proceedings of the National Academy of Sciences, vol. 2 (1916), p. 399.

Measurement of gravity at sea—A review. L. J. Briggs. Bulletin of the National Research Council, vol. 3, p. 2 (January, 1922), No. 17.

ARTICLES ON THE VARIATION OF LATITUDE.

There have been several papers issued during the 10-year period covered by this report on the variation of latitude. The most important of these are:

Latitude observations with the photographic zenith tube at Gaithersburg, Md. Frank E. Ross, Special Publication No. 27 of the U. S. Coast and Geodetic Survey, 1915.

Variations of latitude: Their bearing upon our knowledge of the interior of the earth. Frank Schlesinger. Proceedings of the American Philosophical Society, vol. 5 (1915), p. 351.

Variations of latitude observations at U. S. Naval Observatory, 1915.9–1920. F. B. Littell. Astronomical Journal, vol. 33 (1921), p. 123.

Variations of latitude observations at the U. S. Naval Observatory. F. B. Littell. Astronomical Journal, vol. 33 (1921), p. 173.

The mobility of the coast ranges of California: An exploitation of the elastic rebound theory. Andrew C. Lawson. University of California Publications, Bulletin of the Department of Geology, vol. 12 (1921), No. 7. This article bases certain geological conclusions on the Ukiah observations of the International Latitude Service and on latitude observations at Lick Observatory, Mount Hamilton, Calif.

An investigation of the latitude of Ukiah, Calif., and of the motion of the pole. W. D. Lambert. Special Publication No. 80 of the U. S. Coast and Geodetic Survey. (In the hands of the printer.) A partial summary of this publication is given in the Journal of the Washington Academy of Sciences, vol. 12 (1922), p. 28.

PUBLICATIONS ON MAP PROJECTIONS BY THE U. S. COAST AND GEODETIC SURVEY.

A number of publications by the U. S. Coast and Geodetic Survey dealing with projections have appeared during the last 10 years. When the United States entered the war, it was found that there was very little published in the English language dealing with the projections in actual use in the war area in Europe. The U. S. Coast and Geodetic Survey immediately prepared publications on projections to meet the needs of our Army. Since the war several publications have been issued which deal with various other projections useful in map production. The publications on projections referred to above are given in the following list:

The Lambert conformal conic projection with two standard parallels. Special Publication No. 47, 1918 Charles H. Deetz.

The Lambert projection tables with conversion tables. Special Publication No. 49, 1918. Charles H. Deetz.

The Lambert projection tables for the United States. Special Publication No. 52, 1918. Oscar S. Adams.

General theory of the Lambert conformal conic projection. Special Publication No. 53, 1918. Oscar S. Adams.

General theory of polyconic projections. Special Publication No. 57, 1919. Oscar S. Adams.

Grid system for progressive maps in the United States. Special Publication No. 59, 1919. William Bowie and Oscar S. Adams.

A study of map projection in general. Special Publication No. 60, 1919. Oscar S. Adams.

Latitude developments connected with geodesy and cartography, with tables, including a table for Lambert equal area meridional projection. Special Publication No. 67, 1921. Oscar S. Adams.

Elements of map projection with applications to map and chart construction. Special Publication No. 68, 1921. Charles H. Deetz and Oscar S. Adams.

Radio compass bearings. Special Publication No. 75, 1921. Oscar S. Adams.

ARTICLES DEALING WITH EARTH TIDES.

Since January 1, 1912, a number of articles have appeared in the scientific journals of the United States dealing with earth tide investigations. The most important of these are listed below:

Preliminary results of the measurement of the rigidity of the earth. A. A. Michelson. Journal of Geology, vol. 22 (1914), p. 97, or Astrophysical Journal, vol. 39 (1914), p. 105. (An oversight in the calculation of these preliminary results which made it appear that the ratio of observed tide to theoretical tide was essentially different according as the pipe was in the meridian or the prime vertical was corrected in an article in Science, vol. 50 (1919), p. 327.)

The Rigidity of the Earth. A. A. Michelson and Henry G. Gale. Astrophysical Journal, vol. 50 (1919), p. 330, or Journal of Geology, vol. 27 (1919), p. 585.

The theory of tides in pipes on a rigid earth. F. R. Moulton. Astrophysical Journal, vol. 50 (1919), p. 346.

The problem of the earth tides. W. D. Lambert. Bulletin of the National Research Council, No. 17 (January, 1922).

NEW GEODETIC INSTRUMENTS.

ELECTRIC SIGNAL LAMPS.

The great cost of even unskilled labor and therefore of a field party carrying on triangulation makes imperative the greatest possible effectiveness of the signal lights used, as the failure of a lamp at a distant station when needed frequently causes the loss of a day for the whole party.

Careful consideration of this point resulted in the design by E. G. Fischer, chief of the instrument section of the U. S. Coast and Geodetic Survey, of a new type of electric signal lamp, which was first used in the field early in the year 1916. It consists of an automobile headlight with a 23 cm. parabolic reflector mounted on a baseboard so as to be adjustable in elevation and azimuth. A sighting tube secured to the reflector serves to direct the beam of light in the proper direction. A small rheostat, switch, and ammeter are provided for current regulation. The apparatus and its packing case weighs 11.4 kg.

When taking up the design of this new lamp, it was found that electric bulbs suitable to produce a beam of light of very small angle, the primary requisite for long-distance illumination, were not on the market and were not made by the lamp-bulb manufacturers. The latter were therefore induced to make such bulbs specially for this purpose according to specifications furnished by the office of the U. S. Coast and Geodetic Survey. The resulting lamp bulb has a highly concentrated filament and requires for maximum intensity a current of about 9.5 volts and 2.4 amperes, which in field practice is obtained from dry cells of the standard size connected in series of six and seven multiples of three cells each. The test of the lamp so prepared showed an apparent beam candlepower of 250 000 at a distance of 100 feet (30 m.). Its penetrating power is so great that even in unfavorable conditions of the atmosphere the observations can be carried on, thus saving many days in each season for the party. The lamp has frequently been seen with the unaided eye at a distance of over 100 miles (160 km.). At one station it was seen at a distance of 152 miles (241 km.) and appeared like a star of the magnitude of Polaris.

THE SMALL ELECTRIC SIGNAL LAMP.

In schemes of triangulation in which the length of the lines rarely exceeds 60 miles (96 km.) it would manifestly be uneconomical to use signal lamps much more powerful than needed. Another and smaller lamp was therefore designed and constructed and put into the field in November, 1920. It is made up of an automobile headlight with a parabolic reflector 17 cm. in diameter pivoted for adjustment in elevation in a wooden box frame 28 by 26 by 17 cm., which is mounted on the triangulation point by means of a center screw, permitting of adjustment in azimuth. A small rheostat, switch, and sighting tube are provided as for the larger lamp. The lamp bulb is likewise specially made from specifications furnished by the Survey. The filament, being designed for a current of only 3 to 4 volts and 0.6 ampere, is concentrated into a space of only about a cubic millimeter and when adjusted into the focus of the reflector produces a beam very nearly parallel. The test showed an apparent beam candlepower at a distance of 100 feet (30 m.) of 74 000, with a current of 0.64 ampere furnished by three dry cells connected in series. The lamp has been seen with the unaided eye at a distance of 80 miles (128 km.).

Both the large and small signal lamps are arranged so as to permit the use of either the 2.4-ampere or the 0.6-ampere lamp bulb. This facilitates adaptation to special conditions at any station and has resulted in a large saving in expenditures for dry cells.

Preparations are now in progress for providing clocks to be connected with the electric circuit of the signal lamps in such a manner that the lamps will light up and go out each night automatically. The triangulation station, after being put in proper working order, can then be left without an attendant until the lamp is to be directed to another station. The clock needs winding only once in a week. More than one station can thus be operated by one man and the operating cost reduced very materially.

TRACK LEVEL.

Until recently the inclination of the base tape in traverse measurements along railroad tracks has been determined with the Y level. It was thought that time and expense could be saved by measuring the inclination of the track for each tape length with a simple instrument manipulated by a single member of the party during the progress of the tape measurements.

Such an instrument, called the "Track level," was designed by E. G. Fischer, chief of the instrument section of the U. S. Coast and Geodetic Survey, and constructed in July, 1920. It consists of a light wooden footpiece 1.83 m. long, 12 cm. high in the middle, and 9 cm. at each end, with a vertical extension 72 cm. high, 13 cm. wide below, widening to 28 cm. at the top. At the ends of the footpiece are vertical extensions which carry hardened steel pins for resisting wear where it rests on the track. (See *A*, fig. 14.) At the front is mounted a wooden arm 12.5 by 48 cm. pivoted near the bottom (*P*, fig. 14), with a metal vernier (*V*) on its upper face. This arm is held against the vertical extension by a metal arc secured to the latter. This arc, which has a radius of 77.5 cm., is graduated into 10-minute spaces, the vernier reading to single minutes for ranges of 5° on either side of the normal. The graduations are bold and can be read easily with the unaided eye. About 6 cm. below the arc there is secured to the vernier arm a level (*B*) readily adjustable, with a value of about 20″ per division of 2 mm.

At the rear of the vertical extension is a handle for carrying the apparatus from place to place and also a prop which can be thrown out for setting the instrument on the ground in an upright position when not in use. At each side of each foot is a metal side guard which can be turned up and out of use. The two on either side desired can be turned down to serve as guides to assure that the two feet rest near the middle of the rail. The distance between the feet is 1.78 m. The weight of the whole apparatus is 4 kg.

For each tape length the track level is placed on the rail near the center of the tape. The accuracy attainable was found to be ample to provide reliable corrections for reducing inclined tape lengths to the horizontal.

INVAR PRECISE LEVEL.

The general features of the instrument described here are embodied in the precise level described and illustrated in detail in Appendix 6 of the U. S. Coast and Geodetic Survey Report for 1900. As the features held in particular view in the design of that instrument have proven so effective, the several improvements, made and successfully tried out in the field in 1921, are thought to be of sufficient interest to be mentioned in this report.

The experiences gathered in many years' use of precise levels prior to the adoption of the one in question impressed the designer, E. G. Fischer, chief of the instrument section of the U. S. Coast and Geodetic Survey, with the necessity for the greatest possible rigidity, a strict constancy of the relation between the line of collimation and level, and the utmost facility and certainty in reading the rod and level without disturbing the instrument in the slightest degree.

In filling the first of these requirements the designer disregarded the previously accepted forms, which had become conventionalized. In place of the customary small base of support, generally about 5.5 cm., the distance of the foot screws from the center was made 9 cm. The distance of the collimation line above the plane of support, from 16 to 18 cm. in most precise levels, was reduced to 11 cm. in this one, though its vertical axis is one-third longer and the aperture and focal length of the telescope are very much larger than those of the usual instruments. This instrument, mounted on a tripod also designed particularly with the view to rigidity, is used successfully in any winds against which the rodman is able to hold the rod upright and steady.

The careful study of the level records of many years had proven beyond doubt that certain large systematic errors were directly related to differences of temperature of different parts of the instrument when making the backsights and the foresights. In other words, these errors indicated that the instrument was either exposed to or shielded from heat radiation differently

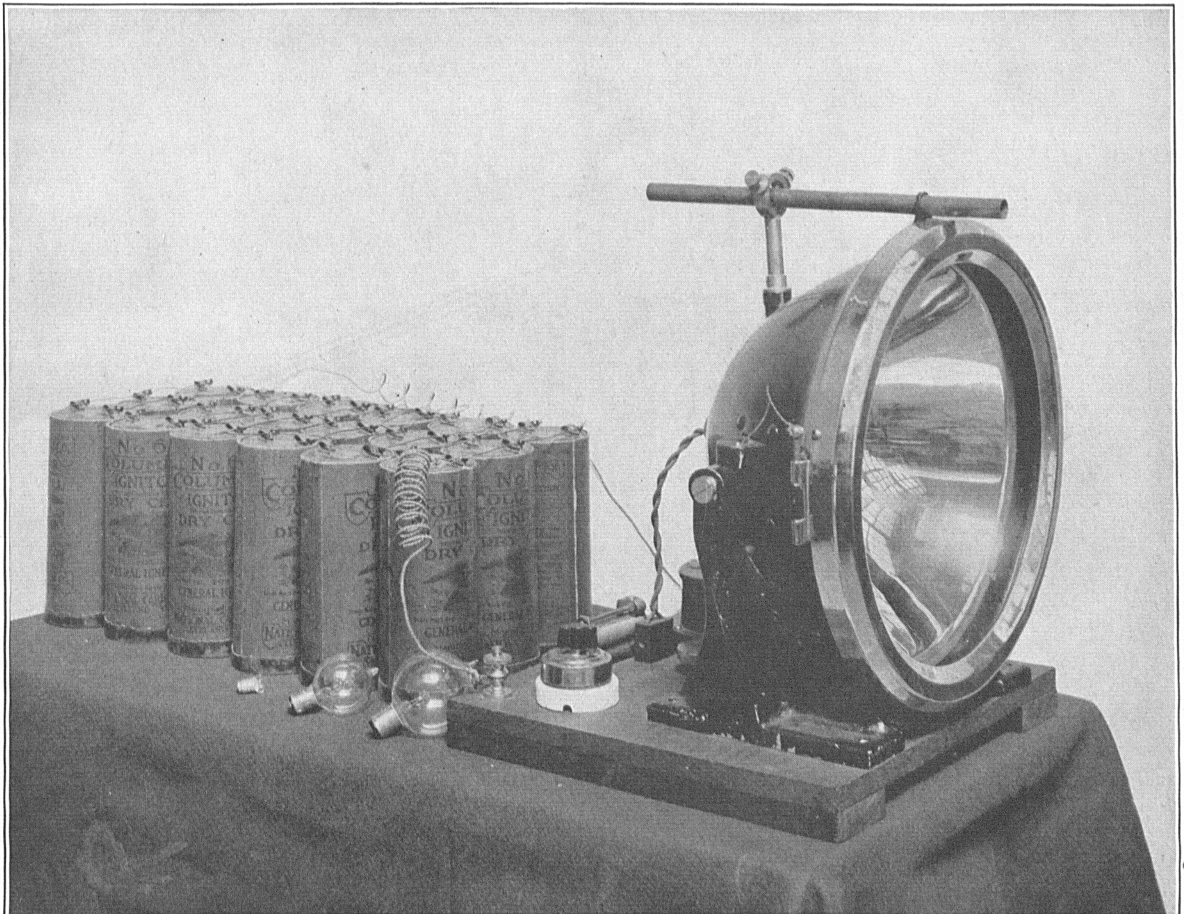

FIG. 13.—LARGE ELECTRIC SIGNAL LAMP.

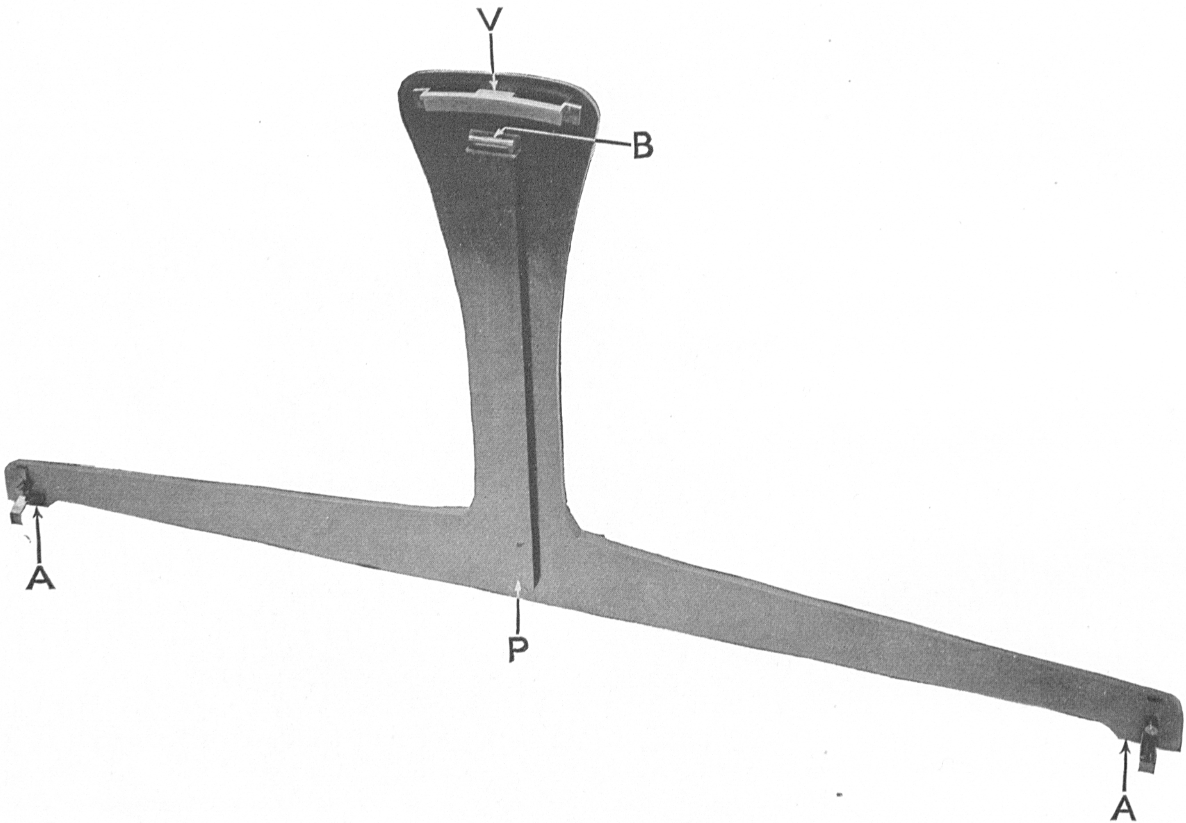

FIG. 14.—TRACK LEVEL.

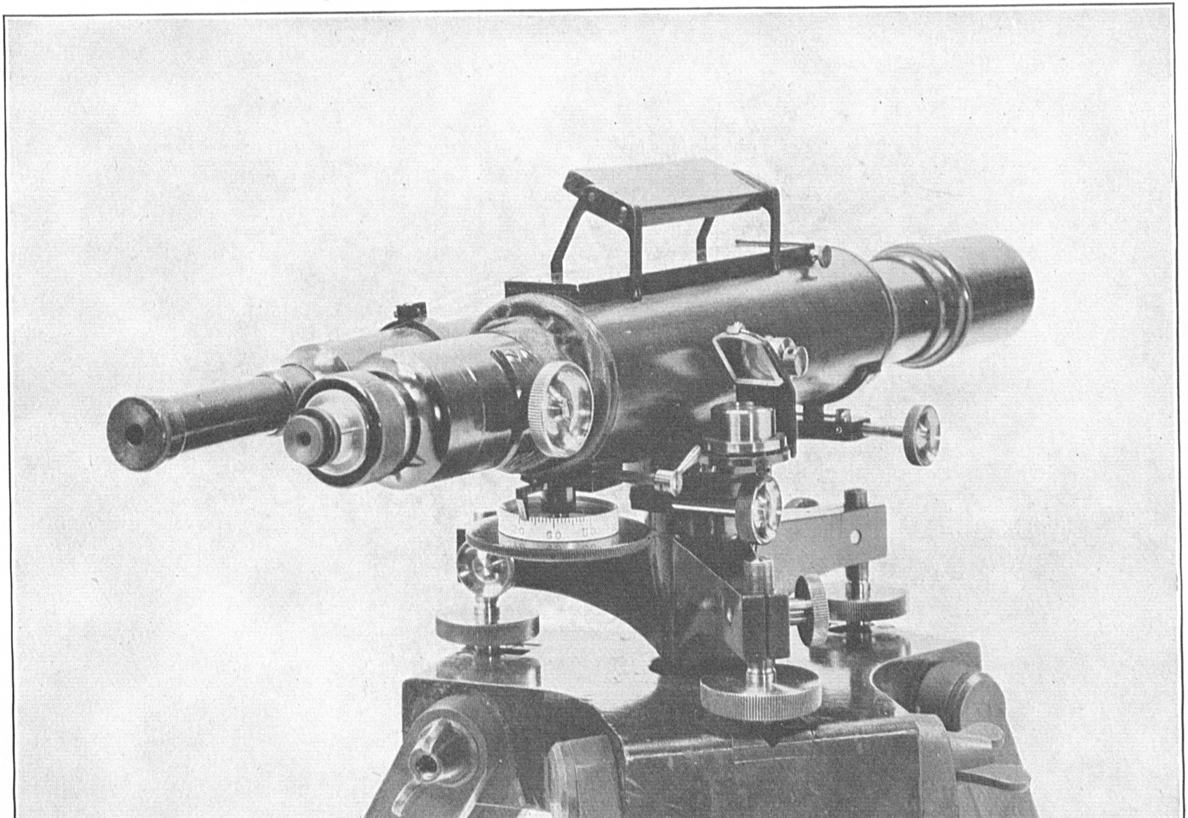

FIG. 15.—NEW PRECISE LEVEL.

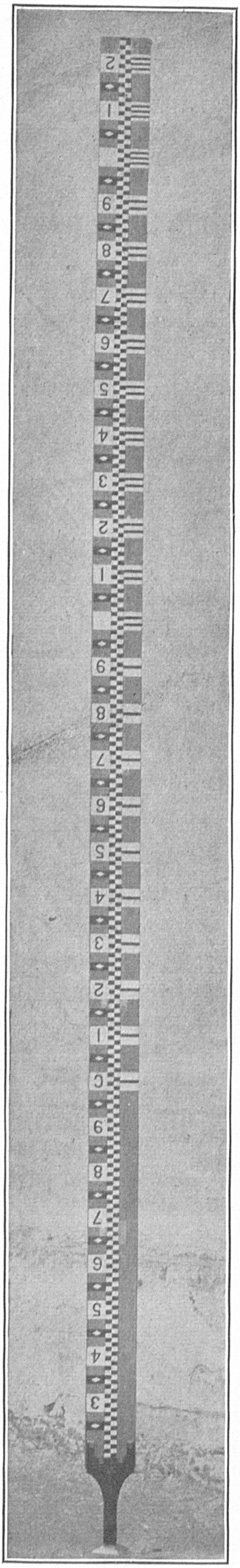

FIG. 16.—INVAR LEVELING ROD.

during the fore and back sights, and that the consequent thermal expansions caused systematic changes in the relation between the level and the line of collimation. To reduce this unavoidable effect to a minimum, the designer selected a material with a very low temperature coefficient and reduced to a minimum the vertical distance of the parts connecting the level and the line of collimation.

The older type of instrument is made of an alloy of one part grain nickel and two parts cast iron, with a coefficient of 0.000004 per degree centigrade. The level vial is sunk into and fastened directly to the telescope as closely as the cone of the image producing rays will permit. These arrangements yield a constancy of the relation between the level and the line of collimation, which requires readjustment but rarely. On numerous occasions an instrument after having been adjusted has been sent hundreds of miles and been used for weeks in the field without readjustment being necessary.

When it became possible to obtain nickel-steel or invar in the form of tubing and when forms could be molded in sand and cast in invar, with coefficients not exceeding 0.000001 per degree centigrade in either case, a new precise level was constructed. All of its parts now being of a ductile and therefore stronger material it could be made somewhat lighter than the former type, which being of a softer and more brittle material, had to be made quite massive. In this latest precise level the telescope is pivoted at a point on the vertical axis. This avoids the danger of slight systematic differences in the height of the instrument between the back and fore sights should the observer habitually adjust the vertical axis out of the normal in one particular direction. This fault exists in the former type of level as the telescope is pivoted 9.7 cm. forward of the axis.

The results obtained with the instrument used in the geodetic leveling of the United States may be expressed in a few words, as follows: The average length of sights is about 85 m., the maximum reaching 150 m.; the average time for each set-up is somewhat less than three minutes; the average distance of leveling per month is 135 km., or about 270 km. of single line; the average amount of line failing to check within 4 mm. $\sqrt{k}$ and required to be run a second time is about 10 per cent; the probable error of the resulting elevations is about 0.9 mm. per kilometer. In this connection it should be noted that the engineer is held to the maxim that any increase in accuracy beyond that established by the International Geodetic Association, if attained by increase of cost in either time or money, is undesirable.

INVAR ROD FOR PRECISE LEVELING.

In September, 1916, an important improvement was made in the type of rod used in geodetic leveling by the U. S. Coast and Geodetic Survey. Up to that time reliance as to the constancy of the rod had been placed on pine wood thoroughly permeated with paraffine. The new rod consists essentially of a strip of invar 26 mm. wide and 0.9 mm. thick, with a thermal coefficient not exceeding 0.000001 per degree centigrade, rigidly fastened to a metal foot with a hardened steel sole. This foot is shaped so as to permit of the use of the spikes securing the rail to the wooden crossties for turning points. The invar strip carries the alternating black and white centimeter graduation of the usual form, extending to 3.25 m., and the wooden rod 28 by 83 mm. serves only to hold the strip straight and to carry the marks and numbers indicating the decimeters and meters. A thermometer is mounted with its bulb just back of the strip, and a circular level enables the rodman to hold the rod vertically. The weight of the rod is 5.7 kg.

Hardened bronze pins with spherical crowns are driven into the ground to serve as turning points when the spikes of a railroad track are not available. They are also used when leveling on railroad tracks for transferring the line temporarily to the ground before the passage of a train in order to avoid possible disturbance of the turning point.

NEW INVAR PENDULUMS AND IMPROVEMENTS IN THE GRAVITY APPARATUS.

During the early part of 1920 two new sets of gravity pendulums made of invar metal were completed by the instrument section of the U. S. Coast and Geodetic Survey. These new pendulums are similar in design to the bronze pendulums which have been used during the past 30 years for all determinations of the intensity of gravity in the United States. They are somewhat heavier, and the bobs are about 4 mm. thicker, but their outstanding characteristic is the low coefficient of expansion, which is only one-fifteenth that of the bronze pendulums. The temperature and pressure coefficients of these new pendulums have been determined and the results, together with correction tables, are shown in U. S. Coast and Geodetic Survey Special Publication No. 69.

Much experimental work was done at the Washington base station to determine how and to what extent the pendulums are affected by magnetism. It was found that, when the pendulums were magnetized with the north seeking pole down, the periods were appreciably shorter than for the same pendulums when demagnetized. In order to obtain quantitative measures of the magnetization of the pendulums a compass declinometer was equipped with long arms extending out on either side from which a pendulum could be suspended at a distance of 13 or 15 centimeters from the needle and at right angles to its normal position. With the pendulum suspended first east and then west of the needle and at equal distances from its center a measure of the magnetization is obtained from the amounts of deflection.

An apparatus consisting of a solenoid about 4 inches in diameter connected with two dry cells, a reversing switch, and a variable resistance was used for changing the amount of magnetism in the pendulums or for practically demagnetizing them when desired.

It was necessary to supplement this experimental work at Washington by similar work in the field at a considerable distance away in order to ascertain the effect of variations in the strength of the earth's magnetic field. Ten stations, located on or near the Mississippi Delta, were occupied during the latter part of 1921, and where constant temperature rooms were available both the invar and bronze pendulums were used. The final computations for these stations have not been completed, but the preliminary results indicate a very close agreement between the invar and bronze pendulums.

It was found, contrary to expectations, that the magnetization of the invar pendulums was not materially affected by shipment. The solenoid was used only at the first field station to demagnetize one pendulum which had been highly magnetized for experimental purposes at Washington. Tests with the compass declinometer before and after swinging each pendulum indicated only slight changes in their amounts of magnetism throughout the entire field season. It may be found desirable in the final computations to apply small corrections to the results on account of these slight changes in the residual magnetism. The results of the field work show such a slight difference between the determinations of gravity with the bronze and invar pendulums that the effect of the variation of the intensity of the earth's magnetic field can not be deduced from the results.

There have been two recent improvements in the gravity apparatus in addition to the change in the material of the pendulums. One is a case made of wool felt about 3 inches thick covered with leather which is placed around the receiver to control the temperature when the bronze pendulums are used. There are openings in this case opposite the windows and levers in the receiver to permit lowering and starting the pendulum and making the readings, but these openings are kept closed except while the observations are being made. The foot screws of the receiver are placed on three small stone blocks to allow a section of this felt and leather case to be placed on the bottom of the receiver. (See fig. 17.)

The other improvement is a prism to fit on the object end of the observing telescope. This makes it possible to mount the receiver on a concrete floor without constructing a pier and still permit the observer to make his coincidence readings in a comfortable position by using the telescope vertically as shown in figure 17.

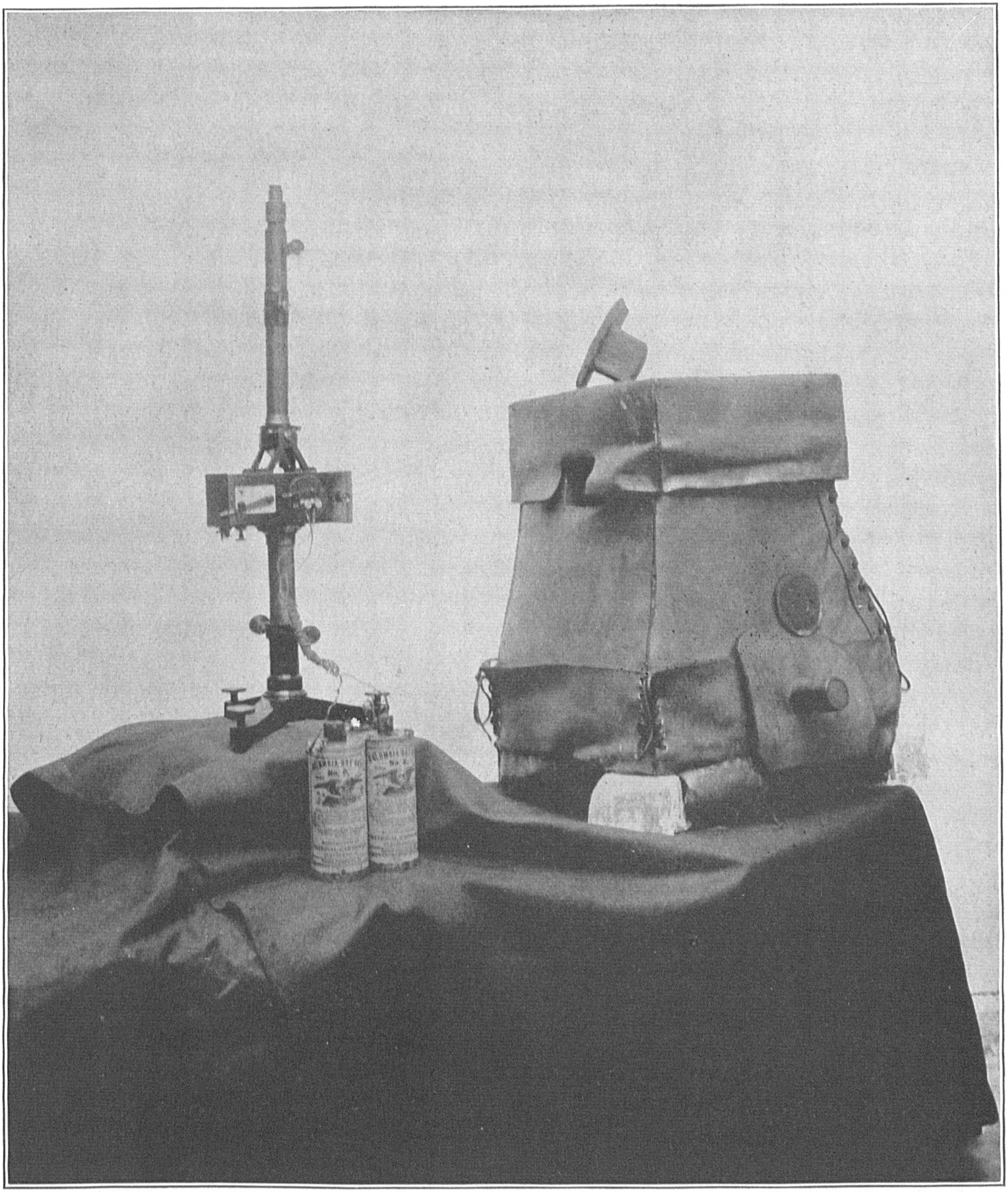

FIG. 17.—VERTICAL TELESCOPE AND TEMPERATURE-CONTROL CASE FOR GRAVITY APPARATUS.

EARTH-TIDE APPARATUS.

In 1913 an apparatus for the determination of tides in the earth was installed by Prof. A. A. Michelson at Williams Bay, Wis., on the grounds of the Yerkes Observatory. The deflections of the vertical caused by the tide-producing forces produce corresponding changes in the level of the free surface of a liquid. The free surface may be considered as tipping about its center of gravity, so as to remain always perpendicular to the instantaneous direction of the vertical at the central point. The difficulty is to keep the surface calm and to record accurately the rise and fall of its edges. This difficulty was surmounted by using as the liquid surface that of water in a horizontal pipe 6 inches in diameter and about 500 feet long and only partly filled with water. The water in the pipe was deep enough, so that the time taken for an impulse to travel from end to end was very small in comparison with the periods of the tidal forces.

The pipe was buried to a depth of 6 feet to diminish surface vibrations and temperature effects. Readings on the surface of the water were taken in pits at the ends of the pipe. There were, in fact, two such pipes, one in the meridian and one in the prime vertical. Preliminary observations were started in September and continued for two months. The readings on the level of the water were taken with miscroscopes. The results were so promising that a more accurate method of reading the level was installed, namely, by means of interferometers.

APPARATUS FOR RECORDING RADIO TIME SIGNALS.

At the request of the U. S. Coast and Geodetic Survey the U. S. Bureau of Standards has perfected an apparatus for receiving radio signals graphically. The apparatus records the signals on a chronograph by actuating the same pen that records the beats of the local timepiece, and thus a direct comparison of the time received by wireless and the local chronometer time may be made easily and accurately. This apparatus will be used for receiving the Naval Observatory time signals transmitted by radio telegraphy and will thus fill a very important need in connection with the determination of longitude and the intensity of gravity.

At the time this report is written the apparatus has been perfected but has not undergone field tests. No difficulty is anticipated in receiving by means of this apparatus time signals sent from the Annapolis station, anywhere in the United States or probably in a great part of Alaska. If this apparatus meets the expectation of the officials of the Coast and Geodetic Survey and of the Bureau of Standards, its use in the field will expedite certain classes of geodetic work and will decrease the cost.

There has been only one article published on this apparatus, namely, in the Journal of the Washington Academy of Sciences, Vol. II, 1921, pages 308-311, by E. A. Eckhardt and J. C. Karcher. This article includes several illustrations showing essential features of the apparatus

MISCELLANEOUS ACTIVITIES.

AMERICAN GEOPHYSICAL UNION.

After the scientific conference at Brussels, held in July, 1919, to create the International Research Council and its branches, the American Geophysical Union was organized as the national committee on geophysics for the United States. This union has sections which correspond to the sections of the International Geodetic and Geophysical Union, and in addition has a section of geophysical chemistry which has no counterpart in the international union. Besides performing the functions of the national committee on geophysics the American Geophysical Union and its sections have taken an active part in coordinating the activities of the several branches of geophysics and have furthered the interests of geophysical sciences in the United States.

BOARD OF SURVEYS AND MAPS.

In December, 1919, the President of the United States by Executive order created a Board of Surveys and Maps for the purpose of preventing duplication of effort by the several organizations of the Government making surveys and maps and to provide means of coordinating the efforts of these organizations.

The board was organized in January of 1920 and has been in existence continuously since that date. It has more than justified its creation by the results obtained through its efforts in bringing the representatives of a number of Government agencies together on the board. There have also been very beneficial results obtained by having in the board a means of contact between Government agencies doing surveying and mapping work and the map-using public.

The board has done much in promoting the adoption of standards of accuracy and in outlining methods which should be followed in the various branches of surveying and map making. One of the reports of the board outlined a definite plan for the extension of the network of fundamental triangulation and leveling over the country to meet the needs of engineers engaged on surveying, mapping, and other work. This report gave the designation *precise*, *primary*, and *secondary* to the triangulation and leveling of the first three classes. Previously the first three classes of triangulation had been called *primary*, *secondary*, and *tertiary* by the U. S. Coast and Geodetic Survey. A variety of terms have been applied in the past by other organizations to the several classes of triangulation and leveling.

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