Serial No. 270

DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

E. LESTER JONES, Director

GEODETIC OPERATIONS IN THE UNITED STATES AND OUTLYING POSSESSIONS JANUARY 1, 1922, TO DECEMBER 31, 1923

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

By

WILLIAM BOWIE

CHIEF, DIVISION OF GEODESY, U. S. COAST AND GEODETIC SURVEY

Special Publication No. 104

WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

National Oceanic and Atmospheric Administration

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document, please contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or www.reference@nodc.noaa.gov.

LASON
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 1, 2006

CONTENTS

ILLUSTRATIONS

GEODETIC OPERATIONS IN THE UNITED STATES AND OUTLYING POSSESSIONS, JANUARY 1, 1922, TO DECEMBER 31, 1923

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

INTRODUCTION

During the period covered by this report all of the precise and primary triangulation and precise leveling in the United States proper were done by the U. S. Coast and Geodetic Survey. This is true also of the precise or primary determinations of astronomic latitude, longitude, and azimuth, the measurements of precise or primary base lines, and the determinations of the intensity of gravity. In fact, all of the precise and primary geodetic work in this country is now done by the U. S. Coast and Geodetic Survey, which makes every effort to supply these high grades of geodetic data to other agencies which may need them. It is evident that when an organization is well equipped to carry on a given class of work it is more efficient that this organization should do all such work for a country than that two or more agencies should be engaged in exactly the same class of work.

The only exception to the above statement is the case of high-grade geodetic work for the small areas of cities in the United States. For these areas the work is to be used for local engineering and surveying operations and therefore it is fitting that the cities themselves, rather than the Federal Government, should carry on such geodetic operations. It is possible, however, that some cooperative agreement may be entered into by which the engineers of the U. S. Coast and Geodetic Survey may take charge of the work for a city and make the observations, while the greater portion of the expense involved in the work will be borne by the city.

Much good has resulted from the creation, in January, 1920, of the Board of Surveys and Maps of the Federal Government, which is composed of representatives from 18 Government organizations that are vitally interested either in the making or in the use of surveys and maps. Monthly meetings are held at which the various problems connected with the surveying and mapping of the country are discussed and decisions are reached. The intimate contact between representatives of the various surveying and mapping organizations at the meetings of the board has prevented duplication of effort and has resulted in much helpful cooperation among these organizations.

In Alaska the first and second class triangulation and leveling, and the first-class observations for latitude, longitude, and azimuth, and for the value of gravity done during the past two years were by the U. S. Coast and Geodetic Survey.

In the Philippine Islands there was no first-class triangulation done, but the second-class triangulation done within its area was by the Coast and Geodetic Survey. As far as known there was no precise leveling in those islands during the two years.

No field work involving precise geodetic operations was done in the Hawaiian Islands during the two years covered by this report.

Geodetic work of a class lower than secondary will not be discussed in any detail in this publication. Such work is designed especially for local charting and mapping operations and is based on the first and second class triangulation, leveling, or other data.

Details of the field and office operations during the past two years, with statements of the results accomplished, are given on the following pages. The diagrams show the several classes of work accomplished prior to January 1, 1922, and the work done between that date and December 31, 1923.

GEODETIC ASTRONOMY

The number of observations and the required accuracy for each class of astronomic work are set forth in the report on geodetic operations in the United States to the meeting of the Section of Geodesy, at Rome, Italy, in May, 1922. They need not be repeated here.

AZIMUTH

Azimuth observations on Polaris were made at a number of precise triangulation stations in the United States and in Alaska during the two years 1922 and 1923. In all there were 68 precise azimuths determined, and of these 11 are Laplace points. In addition there was one Laplace azimuth determined in the latter part of 1921 which was not previously reported. Twelve of these azimuths are redeterminations at old stations in the earthquake region of California.

The positions of the azimuths are shown in Figures 1 and 2.

LATITUDE

Precise latitude observations were made at 12 stations in 1922 by a party which was engaged primarily in the determination of longitudes at Laplace stations along a line of precise traverse in the State of Wisconsin and along the one hundred and fourth meridian arc of precise triangulation extending from the vicinity of Pecos, Tex., northward to a connection with the thirty-ninth parallel arc of triangulation in Colorado. Each of these stations was connected with a traverse or triangulation station.

During the season of 1923 eight latitudes were determined in southeastern Alaska by a party which was determining the astronomic longitudes at a number of triangulation stations for the purpose of making Laplace stations. Four latitudes were also determined in California by the party making the measurements for the Michelson base near Pasadena, Calif.

There were no precise astronomic latitude stations determined in any other territory under the jurisdiction of the United States.

Only four of the latitude stations have been computed; therefore, no statement of size of probable error can be made.

The latitude observations were made with the Bamberg broken telescope transit and with a Troughton & Simms zenith telescope. The Talcott method was used and the observations at each station were made on 10 or more pairs of stars.

Locations of the latitude stations are shown in Figures 3, 4 and 5.

LONGITUDE

Astronomic longitudes, three in number, were determined in the State of Wisconsin at stations along a line of traverse recently completed, in order that Laplace azimuths might be available for controlling the azimuths in the traverse.

Four longitude stations were also established for Laplace stations along the one hundred and fourth meridian arc of precise triangulation, which extends from the vicinity of Pecos, Tex., northward to the arc of precise triangulation along the thirty-ninth parallel in Colorado.

In southeastern Alaska seven astronomic longitudes were determined for Laplace stations along the Alaska end of the arc of first-class triangulation, which extends from just below the forty-ninth parallel of latitude in the State of Washington northward along the coast of British Columbia and through southeastern Alaska. This arc of precise triangulation is discussed in another part of this report.

RADIO RECORDING APPARATUS

The important feature of the longitude determinations mentioned above is that they are the first determinations at field stations in the United States and Alaska made by means of radiotelegraphy.

AZIMUTH

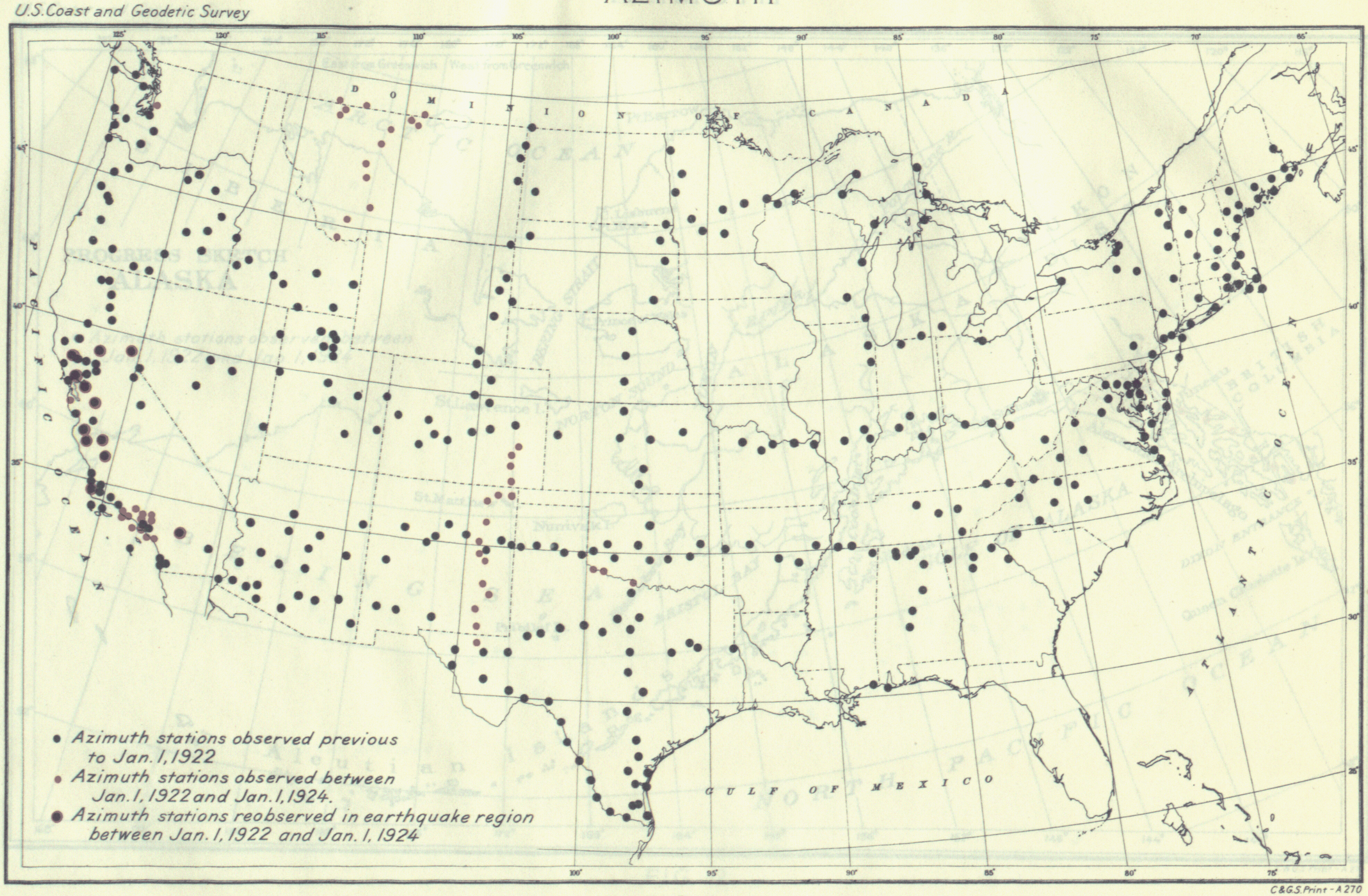


FIG. 1

U.S.Coast and Geodetic Survey

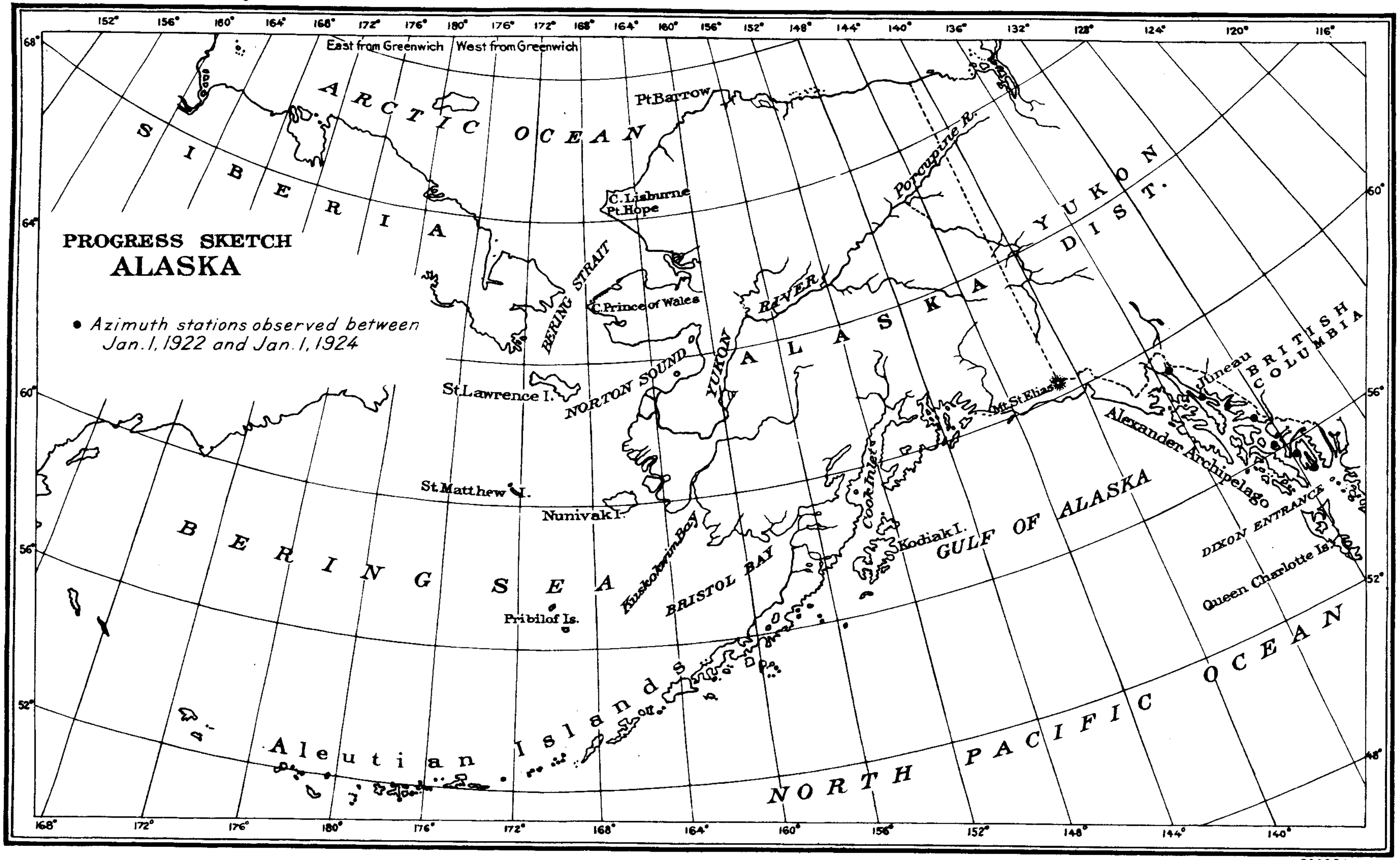
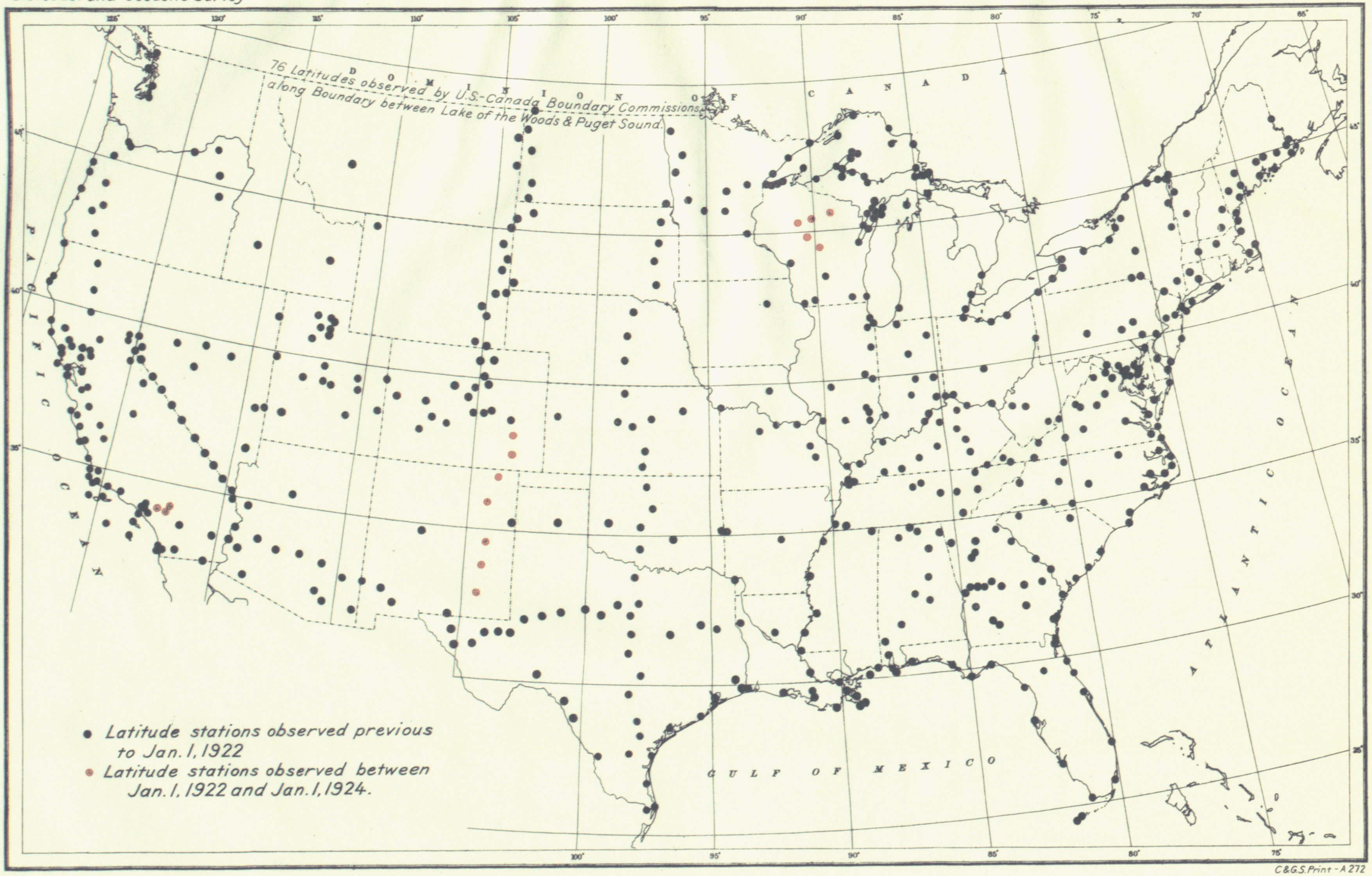


FIG. 2

C&G.S Print - A 271

LATITUDE

U.S.Coast and Geodetic Survey



C&G.S.Print - A 272

FIG. 3

LATITUDE

U.S.Coast and Geodetic Survey

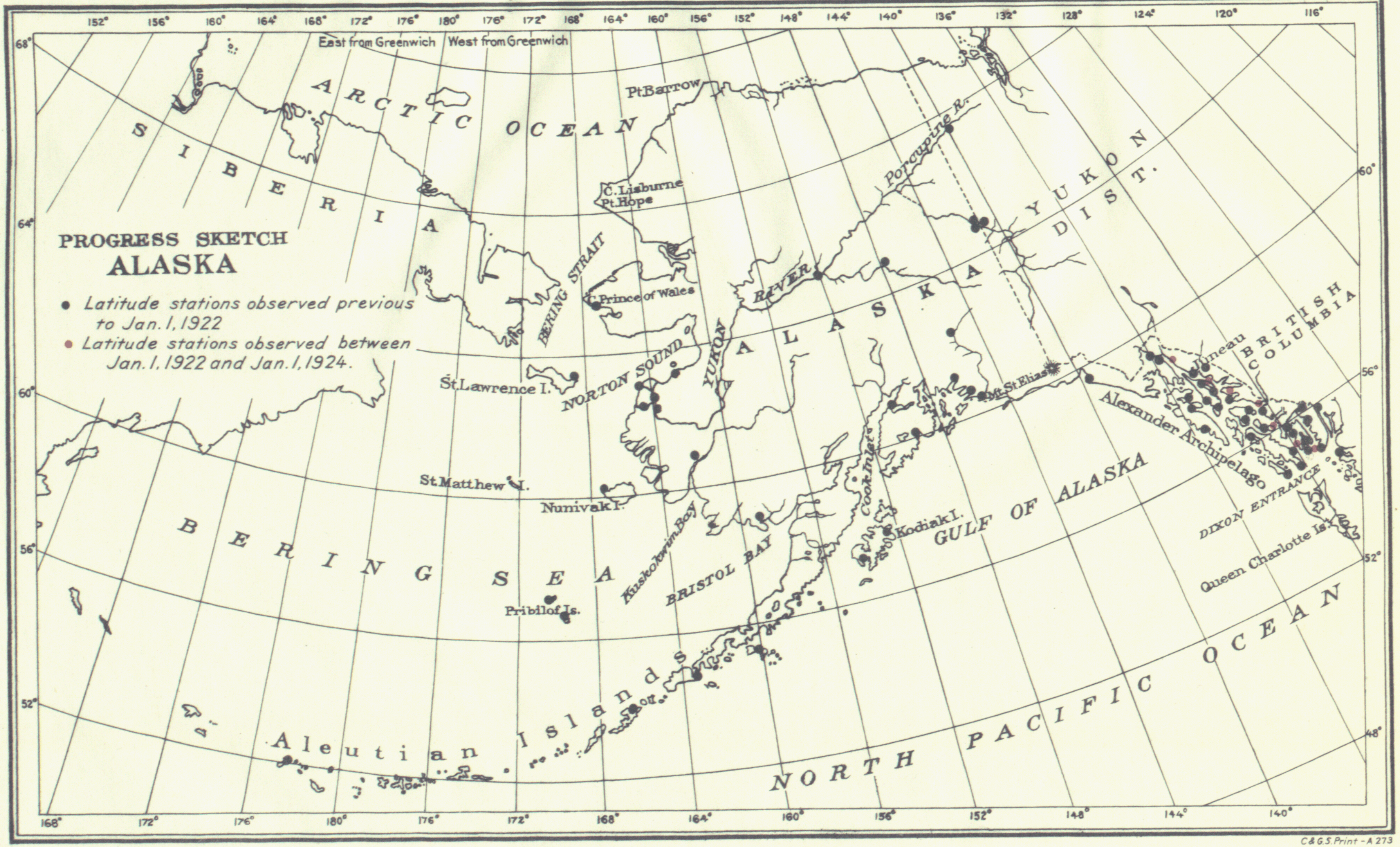


FIG. 4

LATITUDE

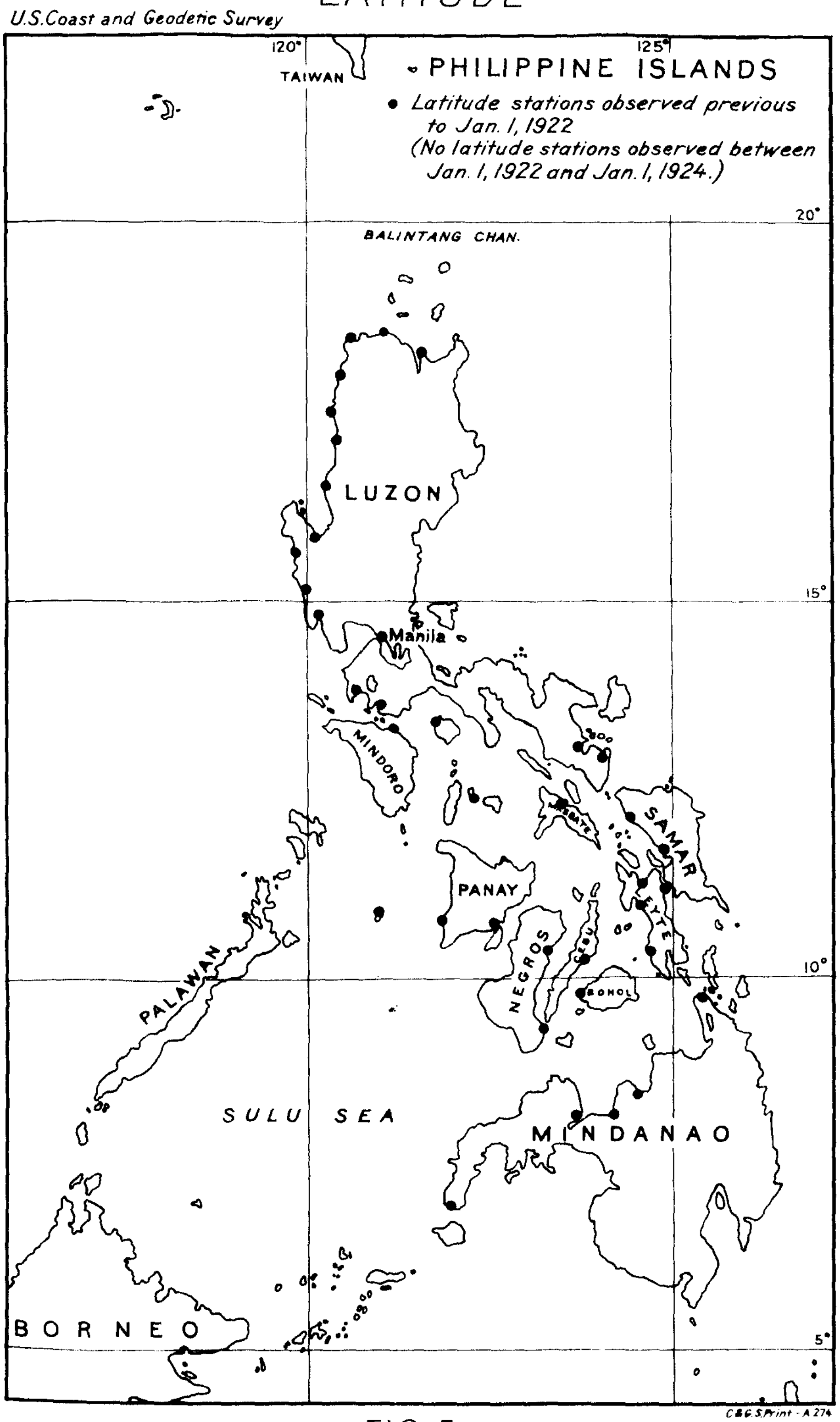


FIG. 5

The apparatus used for recording the time signals which are sent from the U. S. Naval Observatory at Washington through the high-powered radio station at Annapolis was mentioned in the report on Geodetic Operations in the United States made to the Rome meeting of the Section of Geodesy, in May, 1922. The apparatus was designed by Drs. E. A. Eckhardt and J. C. Karcher, of the U. S. Bureau of Standards, and was constructed under their direct supervision. A short article giving some information concerning this apparatus appeared in the Journal of the Washington Academy of Sciences, vol. 2, No. 13, 1921. A detailed report on the apparatus and its operations, by Lieut. G. D. Cowie, of the U. S. Coast and Geodetic Survey, and Doctor Eckhardt, is now (May, 1924) in press. It is expected that it will be available for distribution some time before the Madrid meeting.

The essential feature of the apparatus is that, although it is light and portable, it is not so delicate as to suffer serious injuries in transportation by railroad, boat, or other means of conveyance. Another important feature of the apparatus is that the local time observations with a transit equipped with a self-registering micrometer, the beats of the local clock or chronometer, and the radio time signals are all recorded by the same pen on the same chronograph sheet. This makes it possible to have a comparison of the times of these several events without any inaccuracy beyond the inevitable small errors of scaling.

The first test of the apparatus away from Washington was made by Lieut. G. D. Cowie in his work in the State of Wisconsin in the early summer of 1922. It had been confidently expected that the apparatus would be successful, judging from the results of very elaborate tests made in Washington, D. C., but it was a source of great gratification and enthusiasm when the reports were received at the Washington office from the field telling of the satisfactory way in which the apparatus performed at the first longitude station of the season.

There were a number of nights on which the apparatus failed to record the Annapolis signals due to static interference and other causes, but these difficulties were overcome by Lieutenant Cowie and occasioned very little delay to the progress of the party.

After having completed the determination of the astronomic longitudes at the stations in Wisconsin, the party moved to New Mexico and determined the astronomic longitude at each of four stations along the arc from Pecos, Tex., to the thirty-ninth parallel in Colorado. It was found that even at that distance from Washington, about 1,500 miles, the Annapolis radio signals could be received and recorded automatically.

During the season of 1922 the automatic radio receiving apparatus was used by a party determining the intensity of gravity at a number of places in Kansas, Oklahoma, and Texas. Some difficulty was at first encountered in receiving the Annapolis signals, but after Doctor Karcher, of the Bureau of Standards, had visited the party and made a few changes in the apparatus no serious difficulties were encountered during the remainder of the season.

Encouraged by the great success obtained with the Eckhardt radio apparatus during the season of 1922, a longitude party was equipped for operations in Alaska during the spring of 1923. This party was also under Lieutenant Cowie, with Lieut. D. B. Pheley and Mr. C. Pierce as assistants. The party was directed to determine, at each longitude station, the astronomic azimuth of a line of the precise triangulation, the astronomic latitude, and value of gravity. These four operations were carried out successfully at each of the stations.

It was found that the radio time signals from Annapolis could be received with sufficient strength to actuate the apparatus and to make the automatic record on the chronograph.

The success of the radio apparatus at stations in Alaska solved a very difficult problem for places where it is impossible to use cables and the ordinary telegraph. In all of southeastern Alaska there are very few places at which differences in longitude could be determined by wire methods. With the radio apparatus it seems feasible to determine longitude at any place in the United States or in southeastern Alaska by the recording of the Annapolis signals. Stations farther away from Annapolis than southeastern Alaska may have to depend on time signals sent from some other radio station.

It seems probable that the wire method of determining first-class differences of longitude will rapidly fall into disuse. At the same time it is also probable that even the very satisfactory

Eckhardt-Karcher apparatus will be somewhat improved and strengthened in the great development in the field of radio science.

U. S. NAVAL OBSERVATORY TIME SIGNALS

Since the Rome meeting, investigations by the officials of the U. S. Naval Observatory have resulted in a great increase of the accuracy of the time observations made there. A description of the time determinations at the Naval Observatory, together with the plan followed in sending the signals through the Annapolis station, was furnished by the superintendent of the Naval Observatory and is quoted below.

NAVY DEPARTMENT,
U. S. NAVAL OBSERVATORY,
Washington, D. C., March 12, 1924.

Subject: Request for information relative to determination of time at the Naval Observatory, and transmission of time signals.

DEAR SIR: Replying to your letter of March 5, 1924, asking for data to be used in answering the questionnaire of the Section of Geodesy of the International Geodetic and Geophysical Union, the data which pertains to the time signal system of the Naval Observatory is given herewith:

DETERMINATION OF TIME AT THE U. S. NAVAL OBSERVATORY

The observations for time are made with two instruments, the 6-inch transit circle of 72 inches focal length and a Prin transit of 3 inches aperture and 33 inches focal length.

Both instruments are equipped with impersonal micrometers, that of the 6-inch being hand driven and that of the Prin motor driven. The star transits are recorded on a chronograph, the same pen registering the clock beats and the instrument contacts through a break circuit relay.

Stars within 20° of the zenith, north and south, are observed and the star places which are used are those resulting from the Corrections to Star Places of the American Ephemeris, published in the American Ephemeris for 1925, pages 750–764.

The collimation of the 6-inch is determined each night by means of horizontal collimators; the collimation of the Prin is eliminated by reversal on every star.

The level of the 6-inch is determined over the nadir; the level of the Prin by means of a spirit level.

The azimuth of both instruments is determined from observations of circumpolar stars in conjunction with readings on the north marks. Any error in the azimuth is practically eliminated by observing stars both north and south of the zenith.

The 6-inch is reversed between successive nights when time is determined and corrections are applied to reduce to the mean of the two clamps.

Three Riefler clocks which are used as the standard clocks of the U. S. Naval Observatory are located in an underground vault which is maintained at constant temperature. These clocks are kept at constant pressure and are compared with each other daily.

One of the standard clocks operates a relay, which in turn operates the pen magnet of the chronograph. The beat of the chronograph of the 6-inch transit circle is adopted as the standard in place of the beats of the standard clock. The beats of the chronograph of the time service are compared with the beats of the 6-inch chronograph and the wireless signals emanating from the U. S. Naval Observatory are recorded on the time service chronograph. The published errors of the signals are such as to refer them to the beats of the chronograph of the 6-inch transit circle.

TRANSMISSION OF TIME SIGNALS FROM THE U. S. NAVAL OBSERVATORY

The Naval Observatory time signals are transmitted by the naval radio stations at Annapolis and Arlington and by various other naval and private stations. The signals from Annapolis are used by the U. S. Coast and Geodetic Survey, and generally by other institutions doing longitude work. That station is located east of the city of Annapolis and north of the Severn River, being about 27 miles from Washington. The antenna is erected on six towers, each 600 feet high. Continuous (undamped) oscillations are generated by an arc having a maximum power of 500 kilowatts. The sending wave has a length of 17,145 meters, and the spacing, or compensating, wave is about 100 meters shorter. Improvements are under way for the purpose of eliminating the spacing wave.

Time signals are sent twice daily, at noon and 10 p. m., eastern standard time, which corresponds to 17 hours and 3 hours Greenwich civil time. The signals are of the ordinary kind, consisting of a dash every second, beginning five minutes before the hour and ending on the hour, except that the twenty-ninth second of each minute, the fifty-fifth to fifty-ninth seconds, inclusive of the first four minutes, and the fiftieth to fifty-ninth seconds, inclusive, of the fifty-ninth minute are omitted. Exactly at the beginning of the hour is a longer dash. In all cases the beginning of the dash occurs at the beginning of the second, and the end of the dash is without significance.

TELEGRAPHIC LONGITUDE AND NET

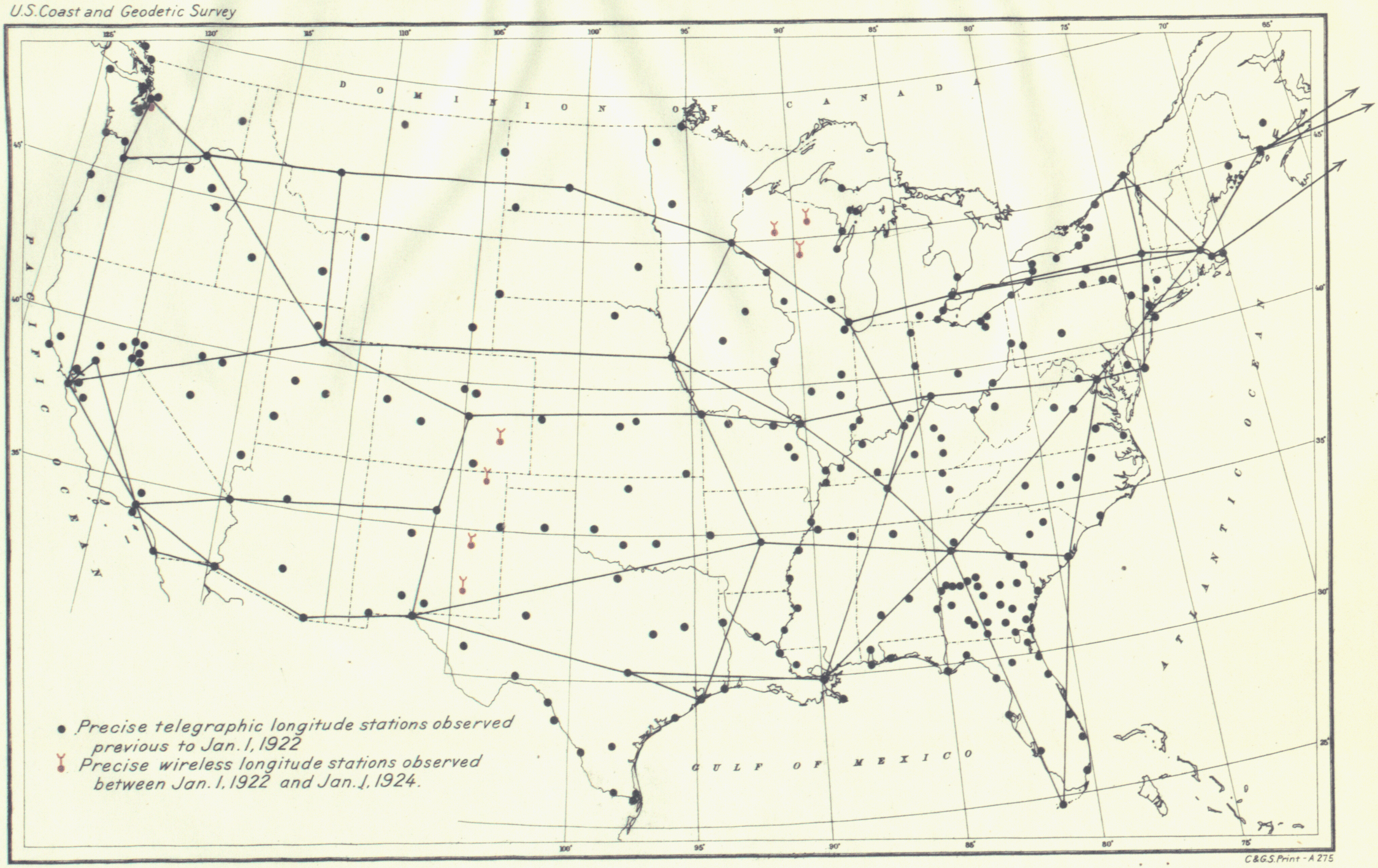


FIG. 6

TELEGRAPHIC LONGITUDE

U.S. Coast and Geodetic Survey

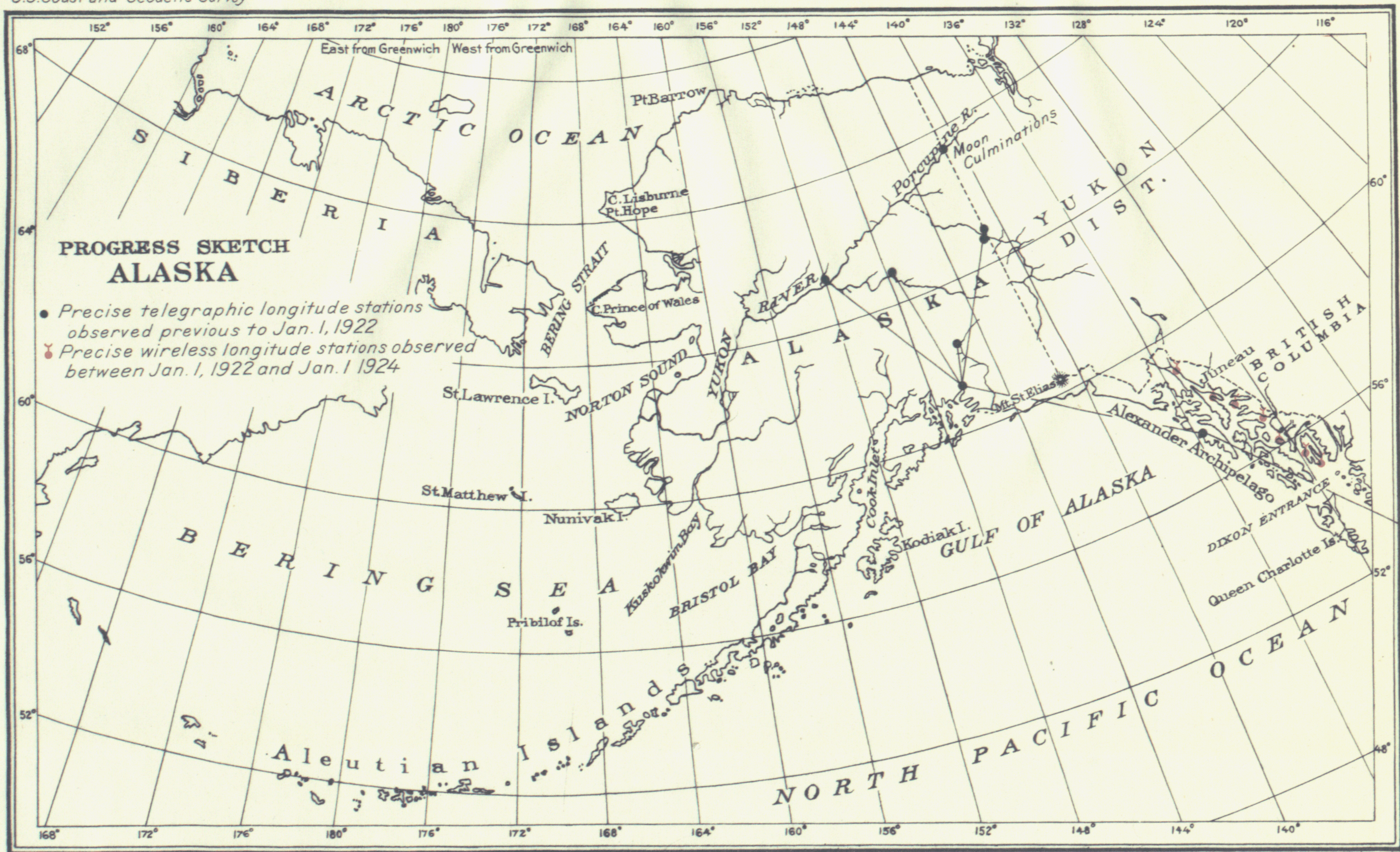


FIG. 7

TELEGRAPHIC LONGITUDE

U.S. Coast and Geodetic Survey

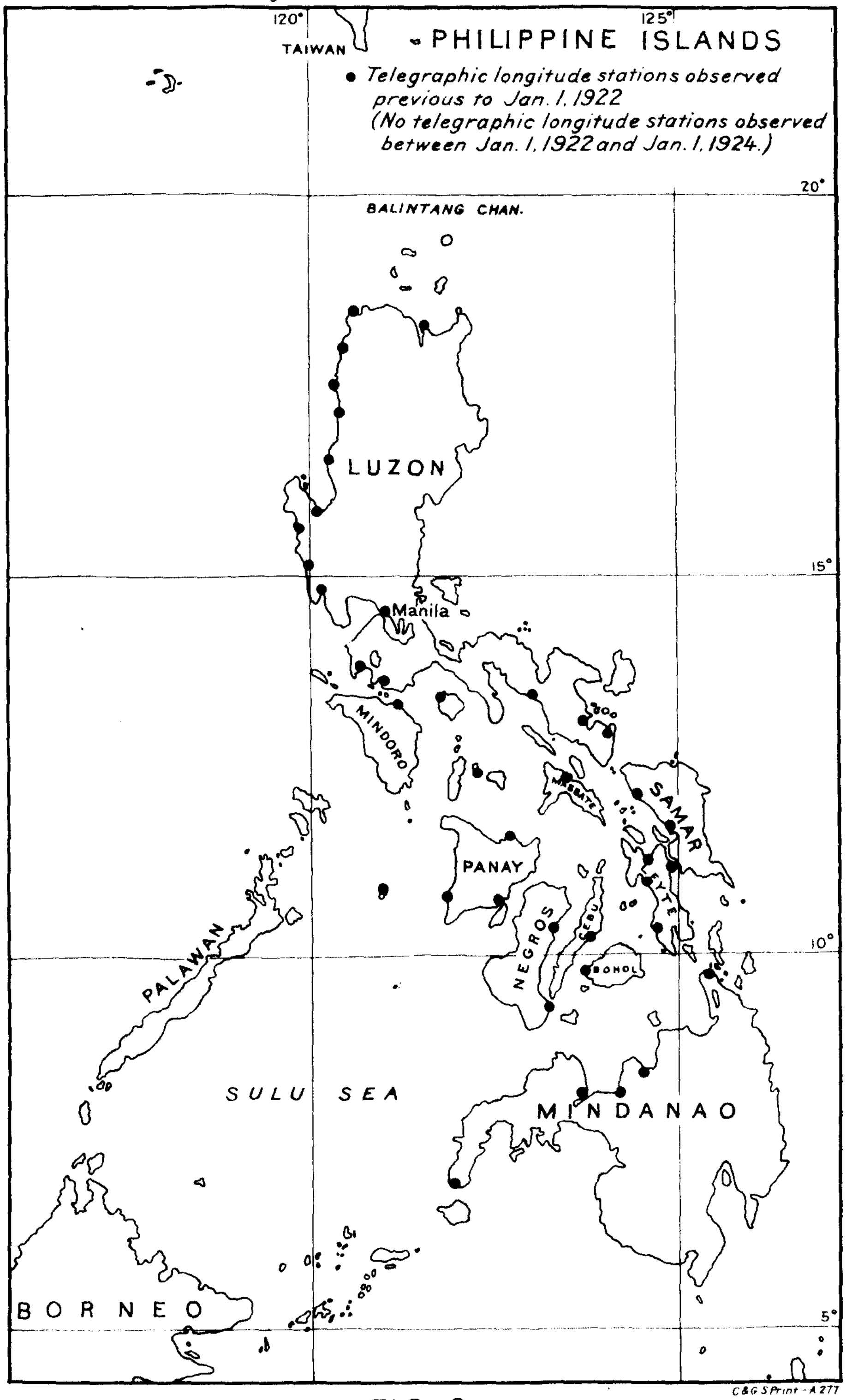


FIG. 8

The transmitting clock at the observatory operates the Annapolis radio station by means of a telegraph line. They are received back again at the Naval Observatory by an automatic radio recording device, so that the time service chronograph records the beat of the standard Riefler clock, the beat of the transmitting clock, and the returning radio signal on the same sheet. Allowance is made for the lag of the radio recorder in computing the lag of the transmitting station.

Very truly yours,

(Signed) EDWIN T. POLLOCK,
Captain, U. S. Navy, Superintendent.

Dr. WILLIAM BOWIE,
Chief Division of Geodesy,
U. S. Coast and Geodetic Survey, Washington, D. C.

LONGITUDE RESULTS

The closeness of the agreement of the values of the differences of longitude determined for the several nights at a station gives an idea of the accuracy obtained in the work. It is, of course, possible that there may be some systematic errors due to what may be called the transmission or sending time, but this has been quite carefully determined and it is believed that the errors arising therefrom are exceedingly small, probably not more than 0.01^s. Of course, definitive rather than preliminary values for the time signals as sent out from the Naval Observatory, Washington, D. C., were used in computing the differences of longitude.

There are given below data for the several differences of longitude for stations in the United States and Alaska (see figs. 6 and 7) established by the radio method, which will show the agreement of the several nights at each of the stations.

A publication entitled "Astronomic determinations by the U. S. Coast and Geodetic Survey and other organizations," by Sarah Beall, mathematician, U. S. Coast and Geodetic Survey, has been in preparation during the years 1922 and 1923, and is now practically ready for the press. In addition to other data this book will contain the deflection of the vertical for each station where there is a proper geodetic connection and for which the position is on the North American datum.

Differences of longitude determined by means of wireless signals

[Observer, Lieut. G. D. Cowie; instrument, Bamberg transit C. and G. S. No. 20]

Dates	Western station (new station)	Eastern station (base station)	Observed difference, mean	v, probable error
1922			h m s	s
June 20, 21, 22, 23	Wisconsin Rapids, Wis.	U. S. Naval Observatory, center of clock room	0 51 03.978 03.966 03.982 03.985	0.000 +0.012 −0.004 −0.007
			0 51 03.978	±0.002
July 1, 2, 8, 12	Ladysmith, Wis.	do	0 56 10.941 10.953 10.892 10.992	+0.003 −0.009 +0.052 −0.048
			0 56 10.944	±0.014
July 20, 22, 24, 25	Rhinelander, Wis.	do	0 49 22.737 22.698 22.687 22.632	−0.049 −0.010 +0.001 +0.056
			0 49 22.688	±0.015
Aug. 30, Sept. 13, 16, 20	La Lande, N. Mex.	do	1 48 16.295 16.311 16.313 16.261	0.000 −0.016 −0.018 +0.034
			1 48 16.295	±0.008
Sept. 27, 30, Oct. 1, 2	Artesia, N. Mex.	do	1 49 35.713 35.753 35.720 35.687	+0.005 −0.035 −0.002 +0.031
			1 49 35.718	±0.009

Differences of longitude determined by means of wireless signals—Continued

Dates	Western station (new station)	Eastern station (base station)	Observed difference, mean	v, probable error
			h m s	s
1922 Oct. 9, 10, 11, 15	Des Moines, N. Mex	U. S. Naval Observatory, center of clock room	1 47 02.494	0.000
			02.507	−0.013
			02.486	+0.008
			02.488	+0.006
			1 47 02.494	±0.003
Oct. 22, 23, 24, 25	Huey, Colo	do	1 44 43.654	+0.012
			43.694	−0.028
			43.692	−0.026
			43.624	+0.042
			1 44 43.666	±0.011
1923 May 24, 25, June 1	Percy Island, Alaska	do	3 38 05.825	+0.007
			05.846	−0.014
			05.824	+0.008
			3 38 05.832	±0.005
June 13, 20, 28	Ship Island, Alaska	do	3 40 33.303	+0.014
			33.299	+0.018
			33.348	−0.031
			3 40 33.317	±0.011
July 14, 23, 27, 28	Sukoi Island, Alaska	do	3 43 23.201	−0.012
			23.237	−0.047
			23.199	−0.009
			23.124	+0.066
			3 43 23.190	±0.015
Aug. 5, 6, 8	Eldred Rock, Alaska	do	3 52 37.974	−0.023
			37.952	−0.001
			37.927	+0.024
			3 52 37.951	±0.009
Aug. 16, 17, 18	Youngs Point, Alaska	do	3 49 58.010	+0.008
			58.036	−0.018
			58.007	+0.011
			3 49 58.018	±0.006
Aug. 25, 26	Astley Point, Alaska	do	3 46 20.980	+0.022
			21.025	−0.023
			3 46 21.002	±0.013
Sept. 10, 11, 12	Quiet Harbor, Alaska	do	3 42 22.678	−0.010
			22.633	+0.035
			22.694	−0.026
			3 42 22.668	±0.012
Oct. 9, 12, 13	Alki Point, Wash	do	3 01 24.596	+0.021
			24.629	−0.012
			24.626	−0.009
			3 01 24.617	±0.007

All differences have been corrected for lag and transmission time. Except for the stations in New Mexico and Colorado, the values given are preliminary.

The longitude of the U. S. Naval Observatory, center of clock room, is $5^h\ 08^m\ 15.784^s$.

HORIZONTAL AND VERTICAL CONTROL EXECUTED DURING THE YEARS 1922 AND 1923

FIRST-CLASS (PRECISE) TRIANGULATION

Precise triangulation was done in several parts of the United States and also in Alaska during the past two years as a part of the general network of triangulation which will eventually cover North America and furnish the basis for surveying, mapping, and other engineering work, as well as meet the needs of scientists.

On March 14, 1922, work was started on an arc of precise triangulation which runs approximately along the one hundred and fourth meridian and extends from the Texas-California arc of precise triangulation, near Pecos, Tex., northward to a connection with the arc of triangulation along the thirty-ninth parallel in Colorado. The reconnaissance for this arc had been done several years previously.

The party was in charge of Casper M. Durgin, who was assisted by E. B. Roberts. The party completed its work in the late fall after 191 days in the field, during which time 70 precise stations were occupied and 16 precise astronomic azimuths, including 4 Laplace azimuths, were observed. Connections were made with 40 General Land Office section corners.

At the close of the season two base lines were measured, one 7.5 miles and the other 12.5 miles in length.

Five motor trucks were used by the observing party. The use of trucks has greatly facilitated the progress of all recent geodetic operations.

A party under the direction of W. M. Scaife began observations about the middle of May, 1922, on the precise triangulation extending from the vicinity of Pocatello, Idaho, northward to the forty-ninth parallel. The southern end of this arc is connected with the precise triangulation of the arc extending from northern Utah to the Pacific coast, which was completed some years ago. The new work was carried to the vicinity of Butte, Mont., in latitude 46°, by the close of the season.

The observing on this arc was resumed during the season of 1923 by a party under William Mussetter, who carried the work northward to the Canadian boundary along the forty-ninth parallel.

Following out the plan agreed to by the Directors of the U. S. Coast and Geodetic Survey and the Geodetic Survey of Canada for the extension of an arc of precise horizontal control along the boundary from the Pacific coast to Lake Superior, the U. S. Coast and Geodetic Survey had two parties in the field for a part of the season of 1923, when observations were made at 31 stations along the boundary to the westward of the one hundred and ninth meridian. The western limit of the completed work is now in longitude 113° 30′. It is expected that this work will be resumed in the spring of 1924 and carried westward toward the Pacific coast.

A revision of the triangulation of Puget Sound in the vicinity of Tacoma was made by a triangulation party under William Mussetter during the spring of 1923 for the purpose of strengthening the horizontal observations and testing any earth movements which may have affected the length of the line of the triangulation in the vicinity of Tacoma, established in 1905, which was used as a base in carrying the precise triangulation northward through Puget Sound in 1921. It had been found in computing the Puget Sound triangulation that there was a large discrepancy between the measured length of the Tacoma base and the length as computed through the triangles from the new base in the vicinity of Seattle. Mr. Mussetter's observations show that there was no serious trouble with the horizontal angle work in the vicinity of the Tacoma base and, therefore, it was decided to have an auxiliary base measured between Tacoma and Seattle. This was done by Mr. Mussetter in 1923.

During the spring and early summer of 1923 a party under Earl O. Heaton made observations for precise triangulation along the boundary between Texas and Oklahoma, where there had been disputes as to the property rights in oil fields along the boundary. The triangulation was extended from stations of the ninety-eighth meridian triangulation in approximate latitude 34° westward to the one hundredth meridian, thence northward to the arc which runs westward approximately along the thirty-fifth parallel. The reconnaissance and preparation of the stations for the observing party on this Oklahoma-Texas work were executed by a party under Signalman Jasper S. Bilby.

During the years 1922 and 1923 precise triangulation was extended northward from the vicinity of Anchorage, at the head of Cook Inlet, toward Fairbanks, Alaska. Much difficulty was encountered owing to a lack of roads and the difficulty of fording streams and getting supplies to the triangulation stations and to the soft condition of the surface due to tundra. By the end of the season of 1923 the work had been carried northward to latitude 62° 30′.

The reconnaissance and preparation of the stations were done by the combined parties. In 1922 the work was under the direction of Leo C. Dyke, assisted by Earl O. Heaton and Sam O. White, and in 1923 under the direction of W. M. Scaife, assisted by A. H. Wagener and Sam O. White. Horses and dogs were used for transportation wherever practicable.

Precise triangulation was also done in southeast Alaska in Clarence Strait, Dry Strait, and Lynn Canal.

PRECISE AND PRIMARY TRAVERSE

In 1922 a party in charge of L. P. Raynor ran a short line of primary traverse in Virginia and North Carolina from Cape Henry south to the triangulation of Currituck Sound. It was found much more satisfactory to use traverse than triangulation, owing to the flat country through which the work had to be done. This line really supersedes a lower grade of traverse which had been run many years ago, the stations of which had all been destroyed. A small line of primary traverse was also run along the coasts of North Carolina and South Carolina to the southwestward of Cape Fear. This traverse is designed to supersede the triangulation and traverse executed many years ago along the coasts of North and South Carolina. The stations of the old traverse and triangulation had nearly all been lost and consequently there was need for the results of the new work for the control of hydrographic and topographic surveys.

During the summer and fall of 1923 a party, under the direction of C. M. Durgin, completed a line of precise traverse from Warroad, Minn., latitude 48° 55′ and longitude 95° 20′, eastward to International Falls, latitude 48° 38′ and longitude 93° 21′. This work was a part of the cooperative plan entered into by the Geodetic Survey of Canada and the U. S. Coast and Geodetic Survey previously mentioned. When the traverse had been completed to International Falls, angles were measured at a number of points along the shores of Rainy River and Rainy Lake, which form the boundary between the United States and Canada. It was planned to measure the distances between these points during the winter of 1923–24, when the ice had formed on the lake and river to such an extent that operations could be carried on without difficulty. The angle observations for the traverse were carried eastward as far as Namakan Lake, latitude 48° 25′ and longitude 92° 30′.

The traverse over the ice was made during the month of January, 1924, with great success. A detailed account of this operation will, however, be deferred until a subsequent report, as the measuring was done in the year 1924.

ESTABLISHMENT OF BOUNDARY BETWEEN YAVAPAI AND MARICOPA COUNTIES, ARIZ.

A number of State and county boundaries in the United States have been referred to parallels of latitude or to meridians. Prior to the extension of the precise triangulation net over the country these boundaries could not be established except by astronomic observations. The use of astronomic methods has caused some uncertainty in boundary lines between States or between counties, and especially where observers of the political units concerned used different stations at which to make observations for latitude or longitude.

One such case is the boundary between Yavapai and Maricopa Counties, Ariz., where there was a dispute as to the ownership of a strip of land some hundreds of meters in width. The importance of this strip was increased by the fact that through a certain part of it ran a railroad which was desired by each county for increasing the taxable property within its jurisdiction.

After futile attempts to settle the question of the boundary it was decided to leave the matter to the officials of the U. S. Coast and Geodetic Survey and to have the boundary, which is an east and west one, located in its proper geographic position by triangulation extending from the precise triangulation net of the country. This work was started in the fall of 1923 and was completed in April, 1924.

The success with which the work has apparently been accomplished leads one to believe that many of the boundaries of the subdivisions of the United States which are defined in terms of latitude and longitude will be located in a way similar to that employed for the boundary between these two counties.

TRIANGULATION

U.S. Coast and Geodetic Survey

FIG. 9

TRIANGULATION

U.S. Coast and Geodetic Survey

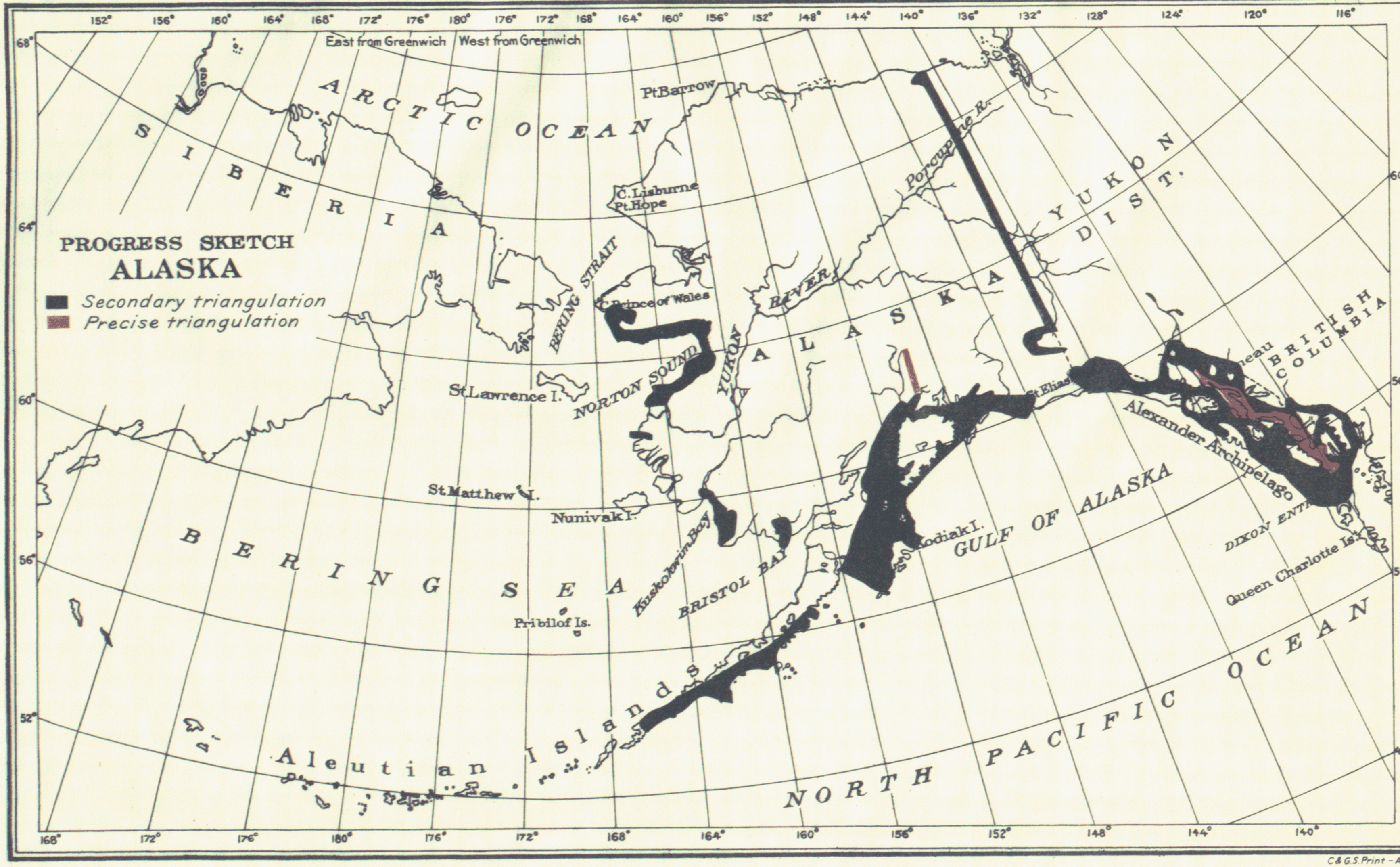


FIG. 10

TRIANGULATION

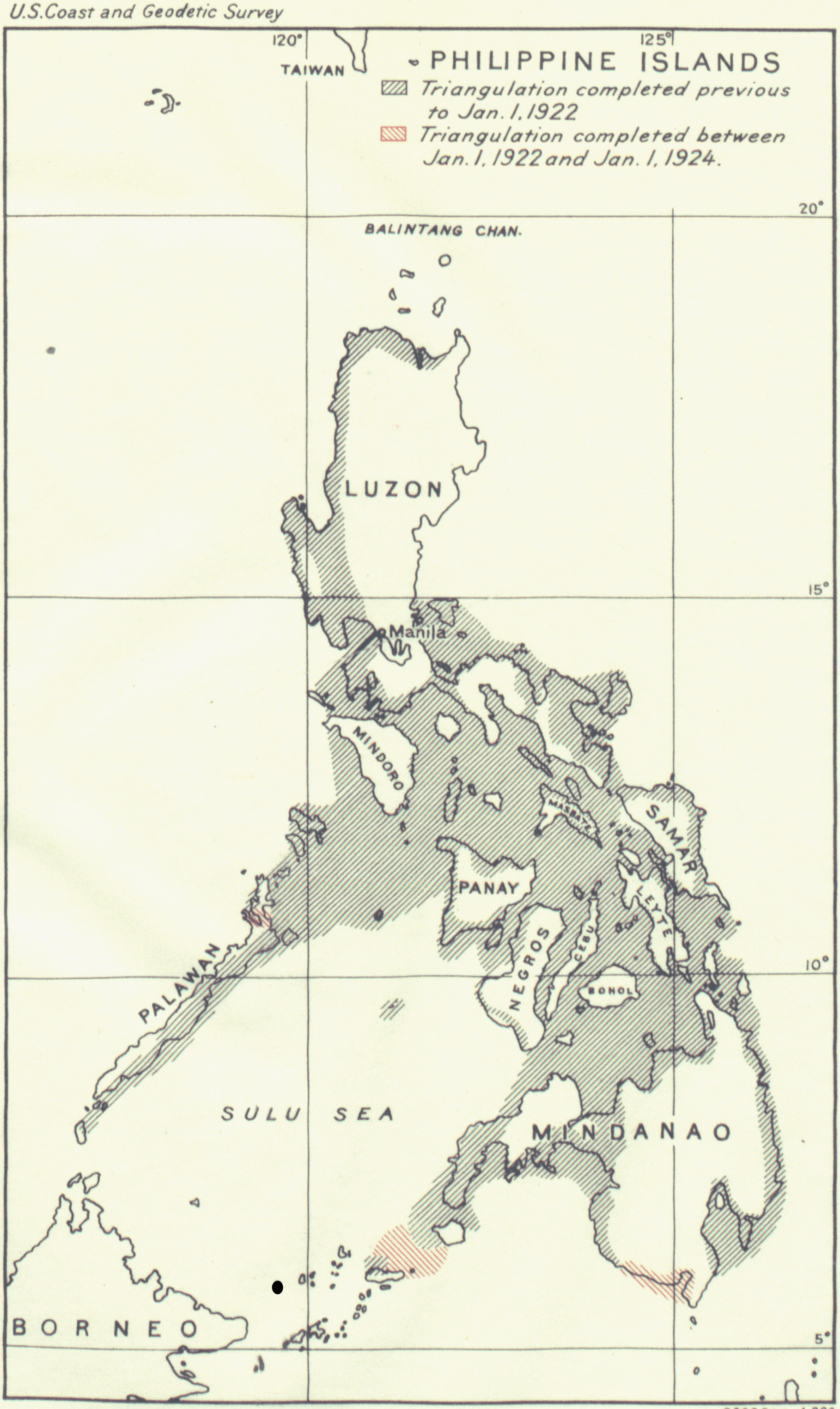


FIG. 11

TESTING THE STABILITY OF THE EARTH'S CRUST BY TRIANGULATION

Shortly after the San Francisco earthquake of 1906 observers of the U. S. Coast and Geodetic Survey reoccupied and remeasured the angles at many of the coastal triangulation stations which had been established many years before. In adjusting these new observations the geographic positions of triangulation stations Mount Diablo, latitude 37° 52′ 55″.482 and longitude 121° 54′ 48″.355, and Mocho, latitude 37° 28′ 39″.696 and longitude 121° 33′ 18″.781, were held fixed. Decided differences in geographic positions in the old and new work were shown and they have been used in a number of studies of the earthquake regions in California.

It was realized that possibly stations Mocho and Diablo were on ground which might have been affected by the same processes which caused the earthquake and changed the geographic positions of triangulation stations closer to the fault line. It was felt, therefore, that a connection should be made to triangulation stations much farther inland. This was especially the opinion of the chairman and members of the committee on seismology of the Carnegie Institution which had been appointed by the president of that institution, Dr. J. C. Merriam, to study the stability of the earth's crust and related phenomena in California. The chairman of that committee, Dr. Arthur L. Day, brought some of the problems of his committee to the attention of the director and the chief of the division of geodesy of the U. S. Coast and Geodetic Survey, with a view to securing the cooperation of that bureau in carrying on field operations in California. The director of the survey included an item for $15,000 in his estimates for the fiscal year 1923, which was approved by the President and granted by Congress, and operations were begun in the summer of 1922.

The first stations occupied were Mount Lola and Round Top on high peaks of the Sierra Nevadas near the intersection of the one hundred and twentieth meridian and the thirty-ninth parallel. Check observations were made from these two stations on station Mount Como in order to make certain that the marks at the two occupied stations had not been disturbed and that there had been no distortion of the triangle formed by the three stations due to earth movements since the original observations were made in the year 1879. It was found that the angles of the triangle had not materially changed during that interval.

During the season of 1922 observations were made at stations along the thirty-ninth parallel triangulation as far as the coast and thence southward in the coast triangulation to stations Mocho and Loma Prieta.

In the summer of 1923 observations were resumed where they had been discontinued in 1922 and carried southward along the coast arc of precise triangulation to stations Lospe and Tepusquet, just below the thirty-fifth parallel of latitude.

When the observing had reached this point, it was found that the weather conditions were unfavorable for making observations, owing to very heavy fogs. In order not to delay operations the party was moved to the southern end of the coast arc of precise triangulation, where observations were begun at stations Cuyamaca and San Jacinto. The work was continued westward along the coast to stations Chaffee and Laguna, where, owing to insufficient funds, work had to be closed for the season, leaving a small gap between the north and south portions of the arc. It is expected that in the summer of 1924 the intervening stations will be occupied for horizontal measurements, thus completing the reoccupation of the precise triangulation stations over an arc about 600 miles in length.

The base line which had been measured to furnish the distance between Wilson Peak and San Antonio Peak, for Prof. A. A. Michelson's determination of the velocity of light (see p. 11), was connected with the triangulation and thus furnished an independent check on the lengths of the old triangulation. The horizontal directions for this base connection were observed at each of the stations with extreme care and, wherever practicable, on two nights. The average closing error of the triangles was 0″.80 with a maximum closure of +1″.55, which was the only one greater than 1″.

The observers reported that there was no doubt as to the exact recovery of each of the old stations reoccupied during the two seasons. Any differences, therefore, in the geographic positions resulting from the old and the new observations are due to actual earth movements or to the unavoidable small errors in making horizontal angle observations or to a combination of these two causes.

On the assumption that the geographic positions of Mount Lola and Round Top remained fixed and unaffected by any earth movements since their establishment in 1879, it was found that the differences in positions between the old and new work for stations Marysville Butte, Pine Hill, Monticello, Vaca, and Mount Helena, all in the interior of California, were very small. The new position of Marysville Butte was about 3 feet to the northward of the old one, but the differences in the new and old positions for the other old stations were 2 feet or less. It was found that the direction of change for the five stations in question varied greatly, showing no systematic movement. The indications are that there had been no earth movements between stations Mount Lola and Round Top on the east and Mount Helena on the west or, at most, only exceedingly small movements. All of the changes in position for the five stations under discussion could have been caused by the accidental errors in the horizontal observations, except perhaps the one at Marysville Butte, which may possibly indicate a slight movement to the northward at that station.

Quite a different situation was found with regard to the stations along the coast and those just short distances inland from the coast. At Ross Mountain the movement is 5 feet to the southward, while at Point Reyes Lighthouse, only about 40 miles to the southward, the movement is 12 feet to the northward. These two stations are on the opposite sides of the San Andreas fault, along which the 1906 California earthquake occurred.

It is found that all of the stations from Mount Ross southward on the eastward side of the fault to station Santa Ana, in latitude 37° and longitude 121°, have had a southerly movement.

The stations on the western side of the fault, southward from Point Reyes Lighthouse to Santa Cruz station, have had varied movements, as indicated by the changes in geographic position. To the south of stations Santa Cruz and Santa Ana, all changes in the positions are to the northward and they seem to increase in magnitude with the distance to the southward from stations Mount Toro and Santa Ana.

A careful analysis has been made of the observations both of the old and the new triangulation to discover, if possible, in the observations themselves the cause or causes for these large changes in geographic positions to the southward of stations Mount Toro and Santa Ana, but nothing can be found to indicate that the changes in positions are due to the triangulation. Of course it is possible that the small accidental errors of the triangulation might cause a small gradual accumulation in the differences in position.

If the differences between the old and new work are not due to the triangulation, then they must have been caused by actual earth movements in horizontal directions. Undoubtedly a large part of each difference found at stations between Mount Ross and Mount Toro is the result of earth movements. It is rather remarkable that the directions of the movements are very diversified, showing that torsional forces are at work to distort the earth's surface rather than a force acting in a single direction.

It is expected that a special publication of the Coast and Geodetic Survey will be printed before the Madrid meeting of the Section of Geodesy, which will contain more data and more detailed discussion of the old and new triangulation discussed above.

It is interesting to note that the changes in the geographic positions between stations San Jacinto and Cuyamaca at the southern end of the scheme and Chaffee and Laguna are exceedingly small. The old and the new angles of the several triangles of the arc are very nearly the same, thus indicating that there has been little or no movement of the earth to distort the triangles. There is, of course, no way to tell from the horizontal angles alone whether or not the whole coast has moved as a unit.

It will be interesting to learn the results of the computation of the new geographic positions from stations Arguello and Gaviota southward to the Mexican boundary which can be made as soon as the small portion of the arc which remains to be completed is finished.

It is planned to continue the reoccupation of old triangulation stations in California until all those in regions of seismic activity have had their horizontal angles reobserved. It is also planned to rerun some of the precise leveling in the State of California and extend the nets of precise triangulation and leveling into regions where such work has not yet been carried. Those regions which have been most active, seismologically speaking, in recent times will be given first consideration.

At suitable intervals in the future the triangulation and leveling will be repeated in order that data may be available from which the rates of change of the earth's surface, in the horizontal and vertical direction, may be learned.

PRECISE BASE LINES

During the calendar years 1922 and 1923, seven precise base lines were measured in the United States and two precise base lines in southeastern Alaska, all by the U. S. Coast and Geodetic Survey, for the control of lengths in the precise triangulation. No precise bases were measured in the Philippine Islands.

The measurements were made with 50-meter invar tapes which were standardized by comparison with the 5-meter iced bar at the U. S. Bureau of Standards before and after each field season.

The position of each of the precise bases, with its length and probable error, is shown in the table below.

Precise bases measured in the United States and Alaska, between January 1, 1922, and December 31, 1923

Name of base and State	Latitude and longitude, center of base	Length in meters	Probable error	
			Millimeters	Proportional part
	° ′			
Clayton, N. Mex.	36 47 103 16	11,443.0669	±4.7	[illegible]
Artesia, N. Mex.	32 56 104 27	20,272.9680	±6.0	[illegible]
Pasadena, Calif.[1]	34 07 117 52	33,638.0775	±3.5	[illegible]
Des Moines, Wash.[1]	47 23 122 19	2,387.7216	±1.0	[illegible]
Bozeman, Mont.[1]	45 47 111 12	28,550.6077	±7.6	[illegible]
Havre, Mont.	48 52 109 36	19,335.2911	±9.9	[illegible]
Boundary, Alberta, Canada	49 00 112 51	13,767.6680	±2.5	[illegible]
Peters (Knik Arm), Alaska	61 27 149 27	7,607.4411	±5.7	[illegible]
Dry Strait, Alaska	56 37 132 28	6,256.8816	±5.8	[illegible]

[1] This is a broken base. The length given is the projected length of the base while the probable error given is for the sum of the actual measured lengths.

MEASUREMENT OF DISTANCE BETWEEN MOUNT WILSON AND SAN ANTONIO PEAK, CALIF., FOR USE IN THE DETERMINATION OF THE VELOCITY OF LIGHT

At the request of Prof. A. A. Michelson, director of the Ryerson Physical Laboratory of the University of Chicago, the U. S. Coast and Goedetic Survey undertook the determination of the distance between a point on Mount Wilson near the observatory of the Carnegie Institution and a point on San Antonio Peak, approximately 22 miles to the eastward, which is to be used as a base by Professor Michelson in a new determination of the velocity of light. The length of this line was desired with an accuracy at least as great as 1 part in 300,000.

It was impossible to secure a measurement directly between these two peaks, owing to the very mountainous terrain. It was necessary to measure the base line in the plain to the southward of the line joining these two peaks and by observations of horizontal angles in an overlapping series of quadrilaterals to compute the distance between Mount Wilson and San Antonio Peak. This work was done during the winter of 1922-23. The base could not be measured in a single straight line because of the configuration of the ground and because of the presence of buildings and valuable orchards. However, it was found possible to measure the base in a number of sections which were properly joined together by angle and distance measurements. Four stations were established along the base, two at the ends and two at intervening points, from which horizontal observations were made to connect the base with Mount Wilson and San Antonio Peak. Observations were also made from those peaks on all the base stations. The field work was in charge of C. L. Garner.

The probable error of the length of the base, as determined by the invar tape measurements, is ± 3.5 mm. and the actual error is believed to be not greater than 1/750,000.

In order that the horizontal angle observations might be free from systematic error resulting from station errors or deflections of the vertical, astronomic observations were made for azimuth and latitude at each of the stations of the scheme except at Mount Wilson, where only azimuth was observed, since both latitude and longitude were already known at this point. By means of the derived deflections of the vertical it was possible to calculate the corrections to be applied to the horizontal directions to reduce them to the spheroid.

The average closing error of the scheme of 20 triangles without regard to sign was $0''.55$, and the maximum closing error was $-1''.57$. Only two of the closing errors were greater than $1''$.

In order to be able to compute the distance between the two peaks with the greatest precision, very accurate trigonometric leveling was used to determine the elevations of the two stations.

A figure adjustment of the scheme was made and from the resulting geodetic distance between the two Michelson stations a straight line distance between the two points was computed. The length of the straight line between them was 35,385.53 meters, with a probable error of ± 5.2 mm., or 1 part in 6,800,000. It is estimated that the actual error should not be greater than 7 cm., or 1 part in 500,000. No correction was made for the curved path of a ray of light due to vertical refraction, as it was found, on computation, that the difference between a straight-line distance and the curved path would be only about 1/40,000,000 of the distance. The office computations were made by Dr. O. S. Adams.

Owing to the unfavorable weather conditions in 1923, Professor Michelson was not able to determine the velocity of light, but he expects to resume operations in 1924 and will use a more favorable time of the year.

It is expected that all essential details connected with the measurement of the base and of the computation of the distance between Mount Wilson and San Antonio Peak will be published conjointly with the discussion of Professor Michelson's observations and the results of his work.

PRECISE LEVELING IN THE UNITED STATES AND ALASKA

During the seasons of 1922 and 1923 about 700 miles of precise leveling were run by H. G. Avers and D. B. Pheley from Rouses Point, near the head of Lake Champlain, N. Y., eastward and southeastward to Portland, Me., and thence by E. B. Roberts and Herman Odessey along the coast through Boston, Mass., and Providence, R. I., to the vicinity of New York City. Three connections were made with the precise level net of Canada. Along the seacoast, connections were made with a number of bench marks to which tidal stations have been referred. The leveling was done along railroads, as usual, in order to facilitate operations.

About 215 miles of precise leveling were run in the States of New York, Rhode Island, and Connecticut by E. B. Roberts for the purpose of furnishing vertical control for highway operations and other engineering activities. This was in addition to the leveling along the coast mentioned above.

About 352 miles of leveling were run in the State of Wisconsin by Herman Odessey and G. H. Dell between Superior and Green Bay, following a line of precise traverse which had been previously measured in that State.

A line of precise leveling 115 miles in length was run in the southern portion of the State of Illinois by G. H. Dell in order to furnish elevations for topographic surveys of the U. S. Geological Survey. This line followed the same route as a previous line of this survey run in 1892. Very few evidences of the former work were found as practically all the bench marks had been destroyed.

During the season of 1923, 181 miles of double line and 250 miles of single line of precise leveling were run in the States of Montana, Wyoming, and Idaho by E. P. Morton. This leveling was done for the purpose of furnishing elevations for the highways of the Yellowstone Park, although the results were also used in connection with the description of many of the interesting natural features of the park.

A line of precise levels, 64 miles in length, was run by F. W. Hough over the Pasadena base, California, used in determining the distance between Mount Wilson and San Antonio Peak. (See p. 11.) This line was extended to the bench marks of the U. S. Geological Survey at Ontario and Pomona and was connected with the precise level net at Los Angeles, Calif.

In the State of Washington, a line of precise levels 25 miles in length was run by W. O. Manchester to connect the tide gauge at Anacortes with the precise level net. This tide gauge was established for the purpose of localizing the difference in the elevation of mean sea level at Vancouver, British Columbia, and Seattle, Wash., as indicated by the leveling between those places.

About 7 miles of precise levels were run in the District of Columbia by D. B. Pheley to connect a number of bench marks which had been used in tidal work on the Potomac River.

The precise leveling which had been done prior to 1922 in California, Oregon, and Washington showed some closing errors of loops which seemed to be larger than could be accounted for by the accidental and systematic errors of leveling which were usually encountered. It was suspected that some blunder had been made in the leveling between the vicinity of Weed, Calif., latitude 41° 26′, longitude 122° 23′, and a point near Seattle, Wash. In order to check that line a party in charge of G. H. Dell was sent to the field in the early part of 1923 with directions to run a single line of leveling over the line. Wherever the single line differed more than a specified amount from the mean of the two original runnings, an additional running of the section was made. The rerunning failed to disclose any blunders in the original measurements large enough to reduce the closing errors of the circuits to the average. This line will probably be adjusted into the precise level net by giving it a weight commensurate with the closing error of the loops of which it is a part.

About 890 miles of precise leveling were run in Alaska during the seasons of 1922 and 1923 by F. W. Hough and Herman Odessey. The line extends from Seward, latitude 60° 07′ and longitude 149° 20′, northward to Anchorage, at the head of Cook Inlet, and thence northward along the Alaska Railroad to Fairbanks, on the Tanana River. From there a line extends along the highway southeastward and southward to Valdez, which is on an arm of Prince William Sound. A tide gauge has been in operation for a total of six months during two years at Anchorage, while at Valdez, at the time of writing this report, the results of only two months of tidal observations are available. The gauge at each place was connected to the line of leveling. Preliminary computations indicate that the discrepancy between the elevations obtained by the leveling from Anchorage and an approximate value for mean sea level at Valdez is only 0.2 meter. This is a very close agreement, considering the length of the line involved.

It would seem that precise leveling is developing the fact that the planes of mean sea at adjacent tidal stations along the same coast are not necessarily in the same level surface. The first indication of this condition occurred when the tidal stations at Seattle, Wash., and Vancouver, British Columbia, were connected by precise leveling. The Geodetic Survey of Canada carried the leveling from Vancouver to Blaine, Wash., on the United States-Canada boundary

102222—24†——2

and the U. S. Coast and Geodetic Survey carried the leveling from Blaine to Seattle. The results of the leveling showed mean sea level at Vancouver to be 102.8 mm. higher than that at Seattle. The tidal stations at both places have been in operation about 20 years. The distance between them along the level route is 258 km.

In order to localize the difference in mean sea level between Vancouver and Seattle, an intermediate tidal station was established at Anacortes, Wash. Using the results of 19 months of tidal observations and assuming the precise leveling to be without error, mean sea level at Anacortes is 13.1 mm. lower than at Seattle. This small difference about equals the probable error of the leveling.

On the Atlantic coast the precise levels show the plane of mean sea level at Portland, Me., to be 169.4 mm. higher than the plane of mean sea level at New York City. The distance between these places along the level route is 359 km.

A further indication of the rise in mean sea level as one goes north on the Atlantic coast is shown by the disagreement of the elevations of Rouses Point, N. Y., as determined from three different places. Rouses Point has been connected by precise leveling with mean sea level at Father Point, on the Gulf of St. Lawrence, by the Geodetic Survey of Canada and with mean sea level at Portland, Me., and New York City by the U. S. Coast and Geodetic Survey. The difference in elevation between Rouses Point and mean sea level at Father Point is smaller than the difference between Rouses Point and mean sea level at Portland and this in turn is smaller than the difference between Rouses Point and mean sea level at New York City.

These differences in mean sea level are much larger than one can attribute to accidental or systematic errors in the leveling. The average closing error of circuits, composed entirely of modern leveling, in the precise level net of the United States, is at the rate of about ± 0.12 mm./km. A closure of about ± 70 mm. could be expected between New York and Portland and about ± 31 mm. between Vancouver and Seattle.

The total length of the leveling done in the United States during the last two years is 1,656 miles of double line and 250 miles of single line. In Alaska during the same period 891 miles of double line were run. The location of all this work is shown in Figures 12 and 14.

SECONDARY TRIANGULATION, TRAVERSE, AND LEVELING BY THE U. S. GEOLOGICAL SURVEY

The U. S. Geological Survey has executed third-class triangulation, traverse, and leveling in a number of States for the control of topographic surveying and mapping. Wherever it was possible to do so this triangulation was connected with stations of the precise triangulation net of the country or with stations which had previously been connected with that net.

The third-class triangulation in this country is available for investigations of the figure of the earth and for studies of the condition of isostasy in local regions. Of course, the astronomic latitude and longitude will have to be determined at a number of these stations to obtain deflections of the vertical if they are to be used in figure of the earth and isostatic investigations. The degree of accuracy to be maintained in this class of horizontal and vertical control is that prescribed by the Board of Surveys and Maps.

TRIANGULATION AND TRAVERSE BY CITIES IN THE UNITED STATES

There is increased use by cities in this country of geodetic horizontal and vertical control for use in connection with surveying and mapping of the city areas and in general city engineering operations. In particular has this increased use of geodetic control by cities been due to a demand for accurate maps on the part of city-planning engineers, representing one of the most rapidly advancing phases of municipal engineering in this country to-day.

The methods employed in city geodetic surveying have conformed very closely to those used by the U. S. Coast and Geodetic Survey. Triangulation is extended in a general scheme over the city area and precise traverses are run between triangulation stations in order to furnish numerous accurate horizontal control stations.

PRECISE LEVELING

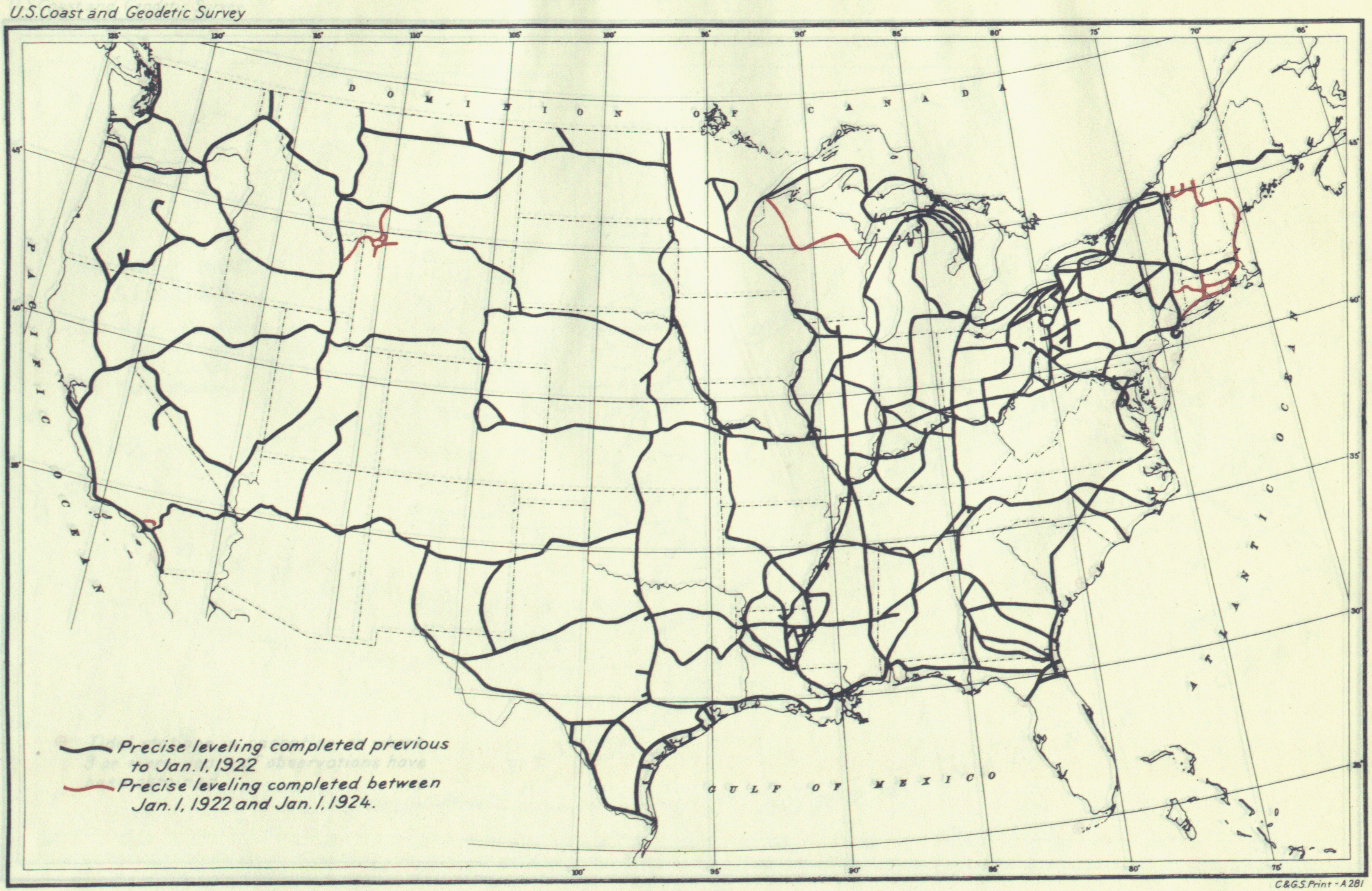
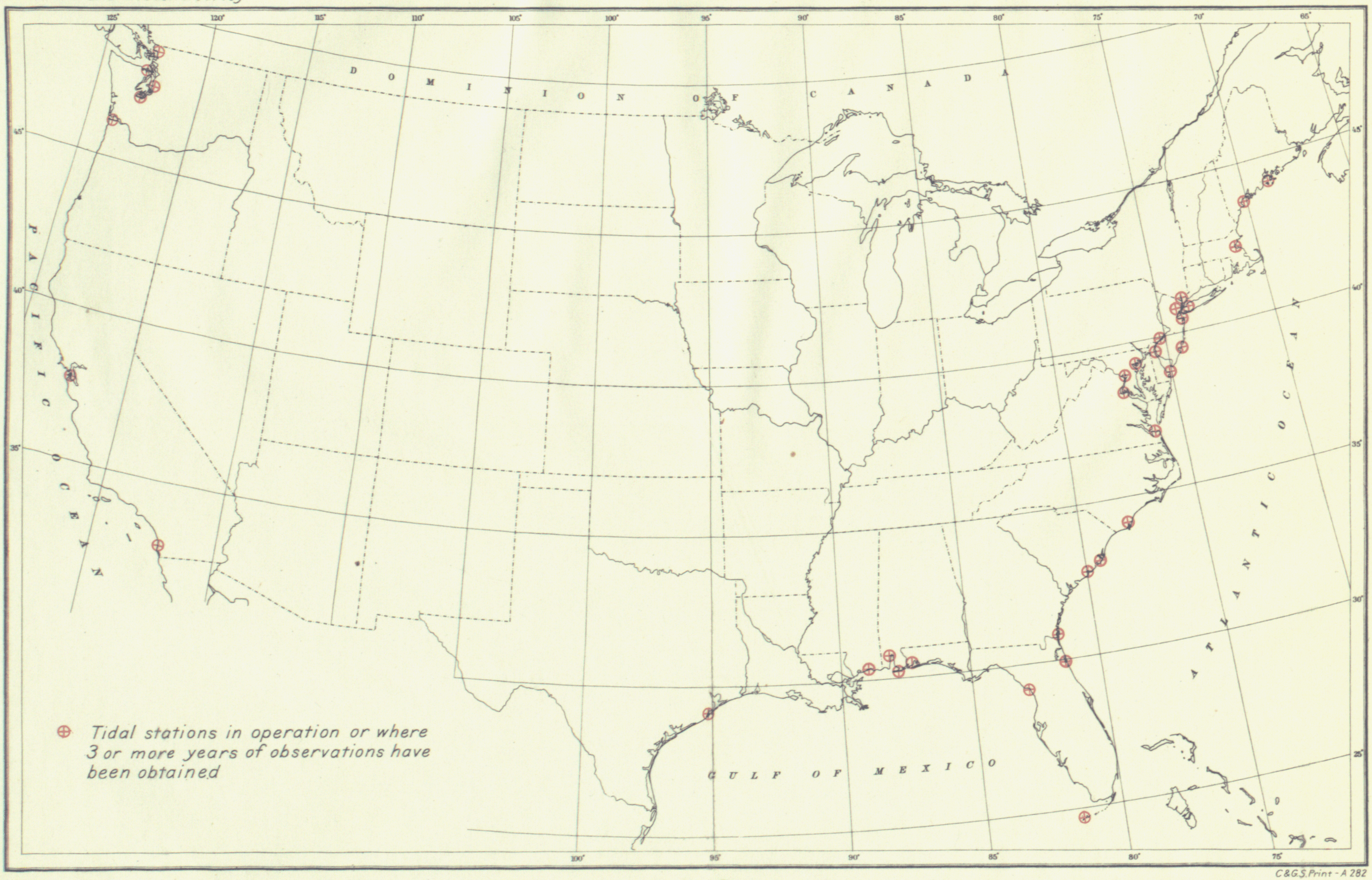


FIG. 12

TIDAL STATIONS

U.S.Coast and Geodetic Survey

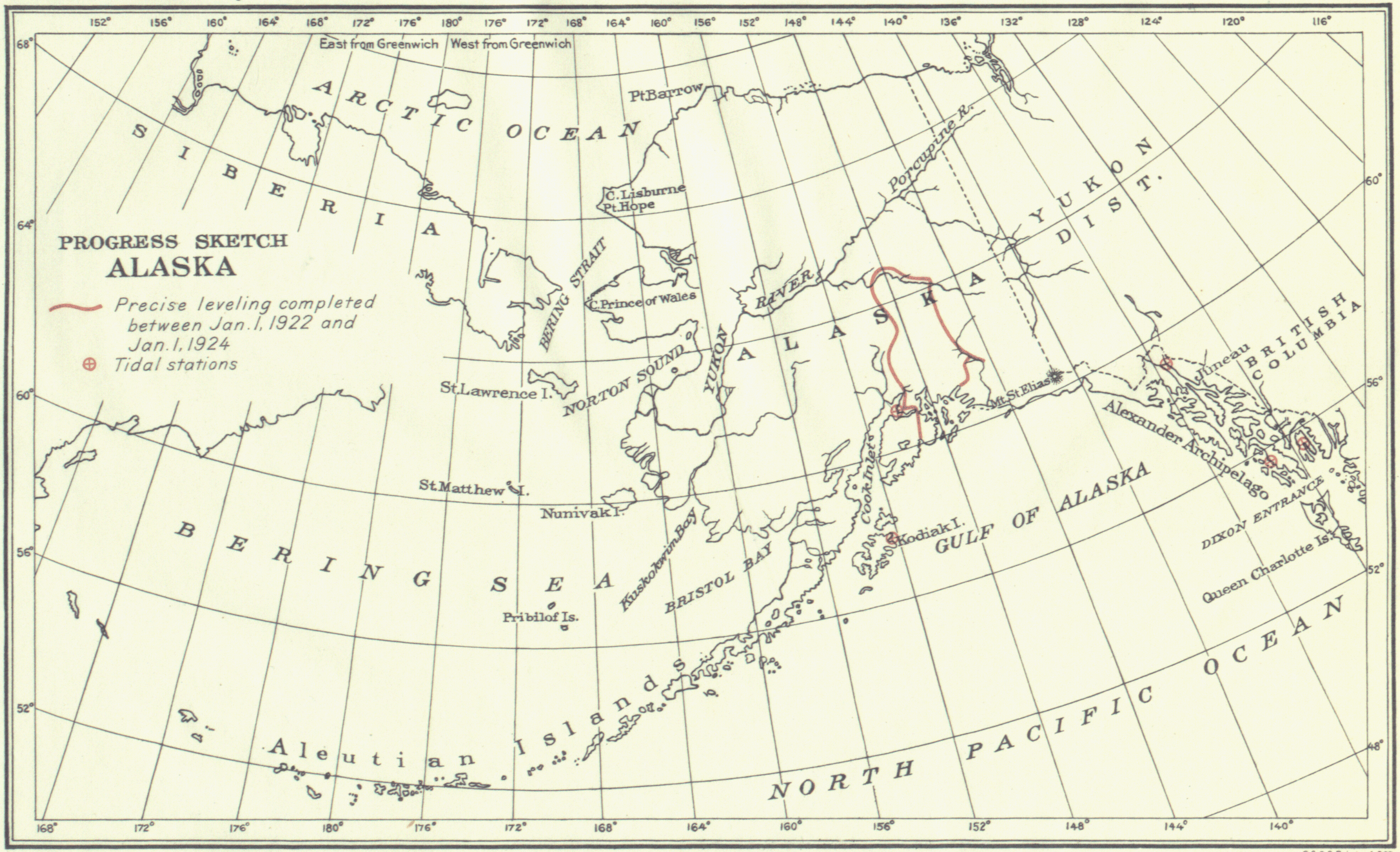


C&G.S.Print - A 282

FIG. 13

PRECISE LEVELING

U.S. Coast and Geodetic Survey



C&G.S Print - A 283

FIG. 14

Precise leveling has been used to a certain extent in city surveying, mapping, and other engineering work. The triangulation, traverse, and leveling are, wherever possible, connected with the precise control systems of the whole country in order that the city control points may be given standard or final geographic positions or elevations.

The cities which have been conducting geodetic surveys during the past two years are: Pittsburgh, Pa.; Yonkers, N. Y.; Flint, Mich.; Richmond, Va.; and Greensboro, N. C. Judging from the number of inquiries which are coming to the office of the U. S. Coast and Geodetic Survey, a number of other cities will be starting geodetic operations very soon.

An interesting report, Special Publication No. 91, entitled "Use of geodetic control for city surveys," by Hugh C. Mitchell, has been widely distributed among city officials and engineers and has received very favorable comment. It met a long-felt want, for there was little or nothing in print dealing with the use of geodetic control in city engineering and mapping operations.

PLANS ADOPTED FOR THE EXTENSION OF PRECISE HORIZONTAL AND VERTICAL CONTROL OVER THE UNITED STATES

There is always a difference of opinion between those who feel that the precise triangulation, traverse, and leveling should be rapidly extended in skeleton form over the area of a country and those who feel that all of the triangulation, traverse, or leveling which will ever be needed for even the most detailed mapping should be done at the time the precise control work is being established. It is probable that under some circumstances it would be more economical for the precise triangulation, traverse, or leveling party, at the time of doing the precise work, to fill in the lower-grade control work. This, however, could only be the case when detailed surveying operations for topographic maps or for other purposes immediately followed the establishment of the precise control. It seems to be most desirable, at least in the early stages of the establishment of precise control surveys, to extend the work as rapidly as possible into new areas in order to furnish geographic positions and elevations and not to delay the surveying parties by requiring them to fill in the detailed control work.

After the precise horizontal and vertical control systems have been completed to such an extent that every place in the country is within a reasonable distance of horizontal and vertical control stations, then it is possible that the lower grades of control work could be done by the party which is engaged on the precise work.

The plan adopted in the United States by the U. S. Coast and Geodetic Survey and heartily indorsed by the Board of Surveys and Maps of the Federal Government is to extend the horizontal and vertical precise control systems to such an extent that no place will be more than about 50 miles from precise control stations. It would be a very simple matter with such an amount of precise control available to run arcs of triangulation, or lines of traverse, and lines of leveling into any area in which detailed surveying operations were to be started. The intermediate areas between the precise arcs and lines will be covered by second and third class horizontal and vertical control.

It is not possible at this time for the U. S. Coast and Geodetic Survey to engage in much detailed triangulation or leveling, as there are still large areas which have no horizontal and vertical control extended through them. As far as possible the activities of the U. S. Coast and Geodetic Survey will be given to breaking up these large areas during the next few years, and after that is done the filling in of small areas will be begun.

PROBLEM OF PERPETUATING HORIZONTAL AND VERTICAL CONTROL STATIONS

Many thousands of triangulation stations and precise leveling bench marks established in the United States have been lost because of inadequate or improper methods of marking the stations on the ground. For a number of years rather obscure marks were used on the theory that they should not be made conspicuous and thus there would be less likelihood of their being destroyed through willfulness or thoughtlessness. This theory proved to be erroneous, for when a block of concrete or stone, with possibly only a copper bolt set in its center and a few letters cut roughly into its surface, was found the finder had his curiosity aroused and he was inclined to believe that the mark indicated hidden treasure. Many stations were lost as a result of such curiosity, the marks being dug up by the finders.

About 15 years ago the U. S. Coast and Geodetic Survey decided that all of its stations should be marked in a conspicuous way, and tablets with suitable inscriptions were used for bench marks, triangulation stations, and magnetic stations. These tablets were set into buildings, outcropping rocks, boulders, or in concrete. The result of this new method of marking stations has been that few are now destroyed and those only when some development of the area is undertaken. Even in such cases those engaged on the operations write to the Director of the U. S. Coast and Geodetic Survey and suggest some method by which the station can be transferred to a near-by location. The results of the last 15 years amply justify the method employed in the marking.

There is a phase of the marking which does not have to do with the willful or thoughtless actions of men. It is the action of nature which tends to disintegrate or dislocate the marks. Frost action is especially destructive. It is believed that each of the countries carrying on geodetic work should make known to the world the methods employed by it in preserving its horizontal and vertical control stations. What is needed, of course, is permanency with certainty of identification of the marks when found.

GRAVITY AND ISOSTASY

DETERMINATION OF THE INTENSITY OF GRAVITY IN THE UNITED STATES AND ALASKA

For some time it has been felt that the activities of the Survey in the determination of the intensity of gravity should be devoted to the testing or solution of specific geological or geophysical problems rather than to continue the general distribution of stations in unoccupied areas. With this in view, parties of the Coast and Geodetic Survey in charge of F. E. Joekel and E. J. Brown in 1922 and 1923 established 27 stations at the request of the officials of the U. S. Geological Survey for the purpose of showing whether the pendulum was capable of disclosing differences in densities of earth material close to the surface. It will be noted that in special publication No. 40 of the U. S. Coast and Geodetic Survey it is clearly shown that at least the larger gravity anomalies are due to the presence of abnormally light or heavy material close to the station. A number of the stations established at the request of the U. S. Geological Survey were located in regions where borings for oil had been made. It seems that the tests were successful but the details regarding the tests are not yet available. They are being prepared and discussed by Dr. David White, geologist of the U. S. Geological Survey, in a paper which will appear in the Proceedings of the Geological Society of America in the near future.

A few of the stations at which observations for gravity were made at the request of the Geological Survey were designed to test the effect of anticlines and synclines on the sign of the gravity anomalies. It had been clearly shown in special publication No. 40 and in other papers by the writer of this report that light or heavy material near a station affects the value of gravity and causes an anomaly. Following my written suggestions, Doctor White, in studying the relation between the size and sign of the gravity anomaly and the geological formation, discovered that the stations on geosynclines tend to have negative anomalies and the stations on geoanticlines tend to be positive. This, no doubt, is due to the fact that the synclines have in them recent material of light density while the anticlines have under them heavy material close to the surface. This is an extension of the idea that heavy and light material near a station affect the sign and size of the anomalies.

There were other stations established as an incident to the longitude work done in the United States and Alaska by parties in charge of G. D. Cowie. All of the observations during the past few years have been made with the invar pendulums. One set of the pendu-

GRAVITY

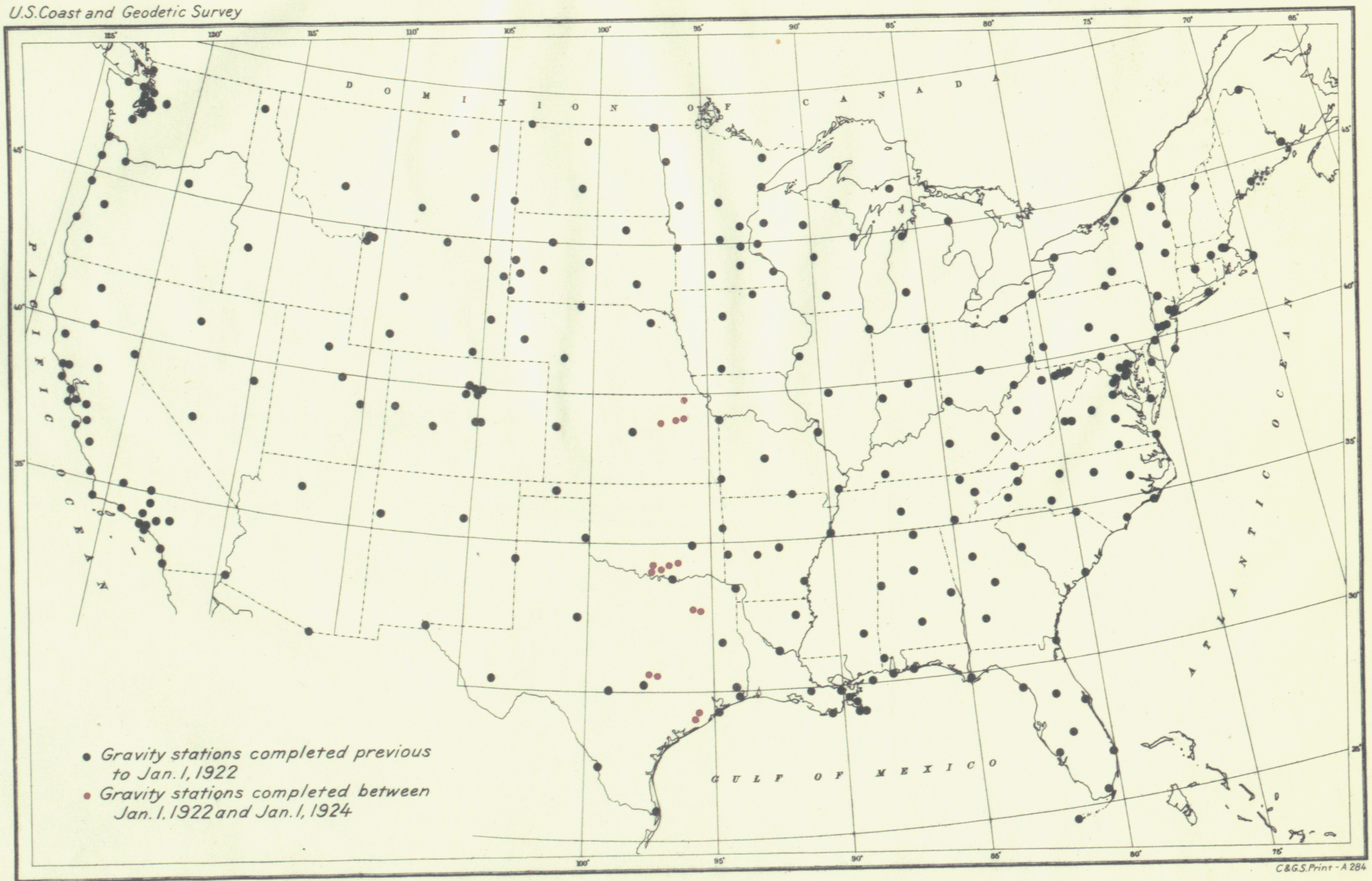


FIG. 15

U.S. Coast and Geodetic Survey

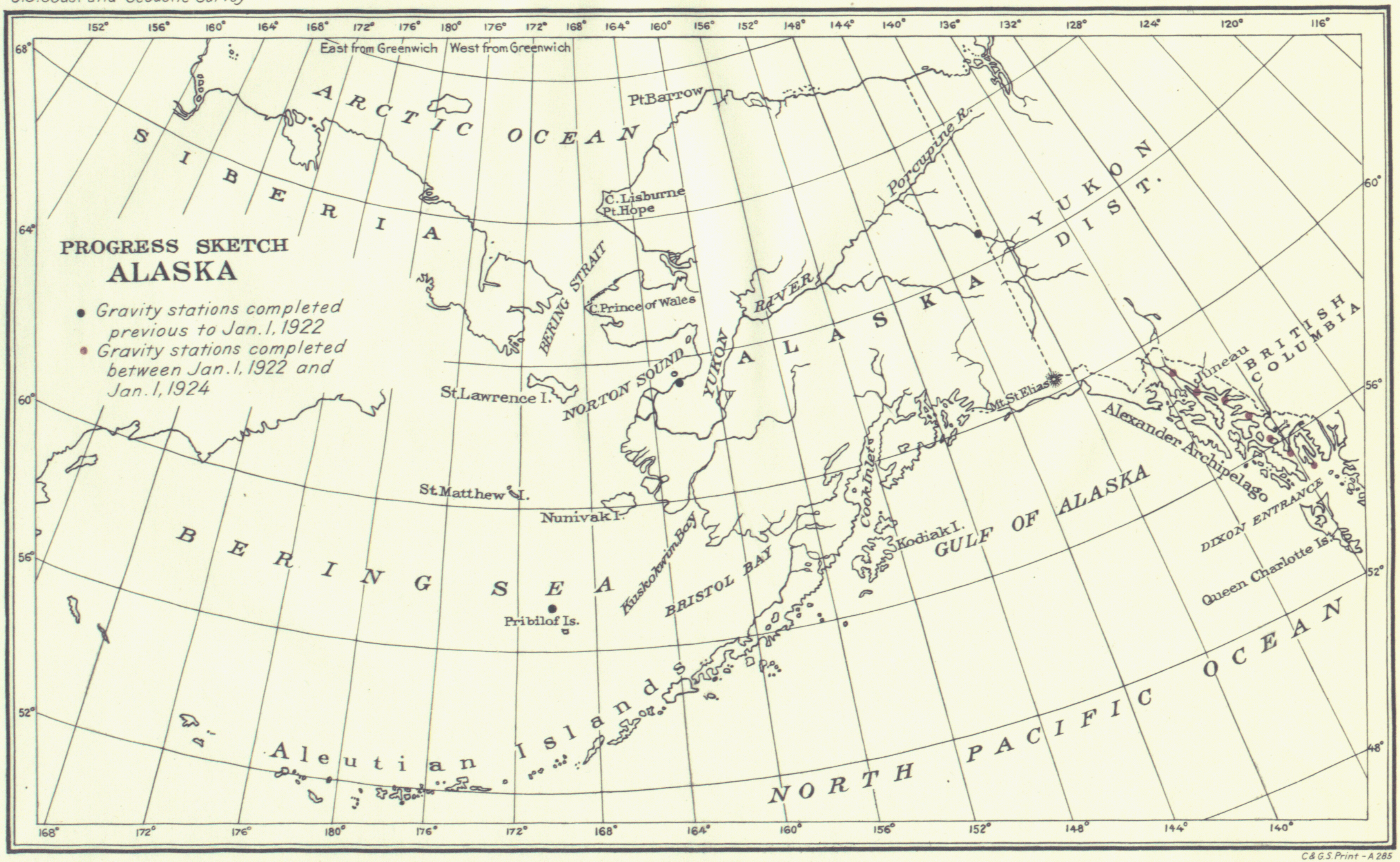


FIG. 16

lums has given very accordant results and the pendulums at the end of the season when restandardized were found to have very nearly the same periods as at the beginning of the season. On the other hand, the second set of pendulums, used in 1922, had quite a difference in period when restandardized at the base station from what they had before the field work began. The same set of pendulums was sent to the field in 1923 and again it was found that the periods were not the same at the end of the season that they were at the beginning. A further study of the observations made with these pendulums will be conducted and the results will appear in a publication of the Coast and Geodetic Survey in the near future.

All of the gravity stations established by the Coast and Geodetic Survey, except nine new stations in Texas, have been reduced for topography and compensation by the isostatic method.

NEED FOR NEW TYPE OF GRAVITY APPARATUS

The numerous calls made on the Coast and Geodetic Survey for the determination of the value of gravity in connection with certain geological studies and investigations indicate the need of an apparatus which will give the value of gravity referred to the base station at Washington, D. C., with an accuracy of about 1 part in a million, but will not require so much time nor be so heavy to transport as the present pendulum apparatus. It is true that the pendulum apparatus alone is not exceptionally heavy, but a number of accessories are required, such as an astronomic transit, for the determination of local time, or the apparatus for receiving automatically the time signals sent by radio from the Annapolis station, a chronograph, an interferometer, and several chronometers. It has been estimated that the total instrumental equipment for a gravity party weighs something over 1,500 pounds.

It is hoped that the development of the physical sciences since the designing of the quarter-meter invariable pendulum by Von Sterneck 35 years ago may make it possible to design a new type of gravity apparatus which will be light in weight and easy of operation. If such an apparatus becomes available, a number of stations can be established in the time taken for a single one by the pendulum.

Not only is an apparatus needed for the determination of gravity on land but it is hoped that an apparatus will soon be forthcoming which will make it possible to determine gravity at sea with a reasonable degree of accuracy, say, 5 or 10 parts in a million or better.

Undoubtedly every geodesist is much interested in the results of the observations made by Professor Meinesz on submarines with ordinary pendulum apparatus. Brief accounts of this work were given in copies of Nature between September, 1923, and March, 1924, by Professor J. J. A. Muller. Professor Muller states that a full report of Professor Meinesz's work will be forthcoming in the near future. It is hoped that other countries also may be able to engage on gravity work at sea on their submarines, following Professor Meinesz's method. Of course, gravity observations over the great areas of the oceans which are far from land would be rather too difficult and dangerous to be intrusted to submarines. It is there that an apparatus is needed which could be used on the ordinary passenger or freight steamer.

ISOSTATIC INVESTIGATIONS IN THE UNITED STATES

Isostatic investigations at the office of the U. S. Coast and Geodetic Survey during 1922 and 1923 consisted in the reduction, by the isostatic method, of 34 gravity stations established in this country and Alaska, No change in the methods employed in former years was made and the depth of 113.7 km. was used for the lower limit of the compensation. In addition to these reductions, a number of papers were written by the chief of the division of geodesy, which appeared in the scientific journals. (See list on p. 18.) Special publication No. 99, entitled "Isostatic investigations and data for gravity stations established in the United States since 1915," has just been printed and gives all the details for 85 gravity stations established since those included in special publication No. 40 entitled "Investigations of gravity and isostasy," which appeared in 1917. The application of the theory of isostasy to some of the major geological problems is discussed in some detail in special publication No. 99 and certain conclusions are outlined which seem to be inevitable in view of the practical proof of the existence of isostasy as the general condition of the earth's crust.

It is rather interesting that the nine stations established by the Dominion Observatory of Ottawa, Canada, in the Mackenzie Basin, extending as far northward as latitude 67°, give strong indications that that basin is in a high state of isostatic equilibrium, It is also of interest that the 51 gravity stations, reported on in a publication by Dr. F. A. Vening Meinesz, of the Dutch Geodetic Commission, indicate that the earth's crust under Holland is also in isostatic equilibrium.

As a matter of fact, every piece of added gravity data which is based on the isostatic reduction seems to increase the strength of the isostatic theory. It seems certain that it is necessary to take the theory of isostasy into consideration in all studies of dynamic and structural geology which deal with large surface movements of the earth's crust.

BIBLIOGRAPHY OF GRAVITY AND ISOSTASY FOR THE YEARS 1922 AND 1923

BOOKS

Bowie, Dr. William: Isostatic investigations and data for gravity stations established in the United States since 1915, U. S. Coast and Geodetic Survey Special Publication No. 99, quarto, 91 pp. and 25 figs., 1924.

ARTICLES

——— The yielding of the earth's crust (abstract of lecture), Jour. Washington Acad. of Sc., vol. 12, No. 11, June 4, 1922, pp. 269, 270.

——— Theory of isostasy—A geological problem, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 273–286.

——— The earth's crust and isostasy, Geog. Review, vol. XII, No. 4, October, 1922, pp. 613–627.

——— The present status of the geodetic work in the United States and its value to geology, Amer. Jour. of Sc., vol. 5, No. 29, May, 1923, pp. 378–382.

——— Review of Nansen's "The strandflat and isostasy," Amer. Jour. of Sc., vol. V, No. 29, May, 1923, pp. 428–432.

——— Some recent progress in isostatic investigations, Jour. Washington Acad. of Sc., vol. 13, No. 13, July 19, 1923, pp. 267–270.

Briggs, Dr. L. J.: Measurement of gravity at sea, Bull. Nat. Research Council, vol. 3, pt. 2, No. 17, Mar. 1922, pp. 3–11.

Burrard, Col. Sir Sidney: Folding of mountain ranges—The argument from isostasy, Bull. Geol. Soc. of Amer vol. 33, No. 2, June 30, 1922, pp. 333–336.

Daly, Dr. R. A.: The earth's crust and its stability, Amer. Jour. of Sc., vol. 5, No. 29, May, 1923, pp. 349–371.

Hayford, John F.: Isostasy, Nat. Research Council Bull., vol. 3, pt. 2, No. 17, Mar., 1922, pp. 11–16.

Jones, O. C., and Hubbard, Dr. George D.: Dynamics of the lithosphere, Ohio Jour. of Sc., Vol. XXII, No. 7. May, 1922, pp. 193–

Jones, Dr. William F.: A critical review of Chamberlin's groundwork for the study of megadiastrophism, Amer. Jour. of Sc., Vol. III, No. 18, June, 1922, pp. 393–413.

Kemp, Dr. James F.: Isostasy and applied geology, Bull. of Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 327–332.

Keyes, Charles Rollin: Minimum span of isostatic effect, Pan-Am. Geologist, vol. 37, No. 1, Feb., 1922, pp. 79–81.

——— Changing sphericity of our earth, Pan-Am. Geologist, vol. 37, No. 1, Feb., 1922, pp. 81–84.

——— Major telluric stresses initiated by diminishing rate of earth's rotation. Pan-Am. Geologist, vol. 37, No. 1, Feb., 1922, pp. 87–88.

——— Geological directrix of isostasy, geotectonic economy of thrust faulting; erosional agencies under variant climatic stimuli, Pan-Am. Geologist, vol. 37, No. 1, Feb., 1922, pp. 90–96.

——— Isostatic theory and applied geology, Pan-Am. Geologist, vol. 37, No. 2, Mar., 1922, pp. 97–106.

——— Isostatic aspect of southern Rocky Mountains, Pan-Am. Geologist, vol. 40, No. 2, Sept., 1923, pp. 139–150.

Lambert, W. D.: The Eötvös Balance, and The problem of the earth tides, Bull. Nat. Research Council, vol. 3, pt. 2, No. 17, Mar., 1922, pp. 17, 18.

——— The directive tendency of elongated bodies, Nature, vol. 109, Mar. 2, 1922, p. 271.

——— Gravity anomalies and their geological interpretation. (Review of Franz Kossmat's Die Beziehungen zwischen Schwereanomalien und Bau der Erdrinde, Geologische Rundschau, vol. 12, 1921, p. 165), Amer. Jour. of Sc., vol. 4, July, 1922, p. 78.

Lane, Dr. Alfred C.: Weight of sedimentary rocks per unit volume, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 353–370.

Lawson, Dr. Andrew C.: Isostatic compensation considered as a cause of thrusting, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 337–352.

Lee, Dr. Willis T.: Building of the southern Rocky Mountains, with notes on isostasy, by C. E. Van Orstrand, and elastic yielding of the earth's crust under a load of sedimentary deposits, by Walter D. Lambert, Bull. Geol. Soc. of Amer., vol. 34, June 30, 1923, pp. 285–308.

Putnam, G. R.: Condition of the earth's crust and earlier American gravity observations, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 287–302.

Reid, Dr. Harry Fielding: Isostasy and earth movements, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 317–326.

Shepard, Francis Parker: Isostasy as a result of earth shrinkage, Jour. of Geol., vol. XXXI, No. 3, Apr.–May 1923, pp. 208–216.

——— To question the theory of periodic diastrophism, Jour. of Geol., vol. XXXI, No. 7, Oct.–Nov., 1923, pp. 599–613.

Washington, Dr. Henry S.: Isostasy and rock density, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 375–410.

Williamson, Dr. E. D., and Adams, L. H.: Density distribution in the earth, Jour. Washington Acad. of Sc., vol. 13, No. 19, Nov. 19, 1923, pp. 413–431.

Willis, Dr. Bailey: Rôle of isostatic stress, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30, 1922, pp. 371–374.

Wood, Harry O.: Some considerations touching on isostasy, Bull. Geol. Soc. of Amer., vol. 33, No. 2, June 30 1922, pp. 303–316.

VARIATION OF LATITUDE OBSERVATIONS AT UKIAH, CALIF.

Following the plan agreed to by the representatives of adhering countries to the Section of Geodesy at Rome in 1922, the United States Government continued the observations for the variation of latitude at the international station at Ukiah, Calif., without interruption. The program of observations was furnished by Professor Kimura in accordance with the agreement made at Rome.

The observer from January 1, 1922, to June 30, 1922, was Dr. F. J. Neubauer, and from July 1, 1922, to December 31, 1923, was H. G. Wrocklage. Doctor Neubauer severed his connection with the observatory in order to accept a position at the Lick Observatory. Mr. Wrocklage was engaged upon the recommendation of Dr. A. O. Leuschner, director of the Students' Observatory, University of California, who has for many years taken a very active interest in the Ukiah station.

The station at Ukiah has been financed by appropriations made by Congress to the State Department and the money has been disbursed under the direction of the Director, U. S. Coast and Geodetic Survey. Grants of money from private individuals supplemented the funds made available by Congress and made it possible to improve the station as far as the comfort of the observer and his family is concerned.

Congress has provided that the U. S. Coast and Geodetic Survey shall carry on the work at the Ukiah station as a part of its regular geodetic activities.

ARTICLES ON THE VARIATION OF LATITUDE

Lambert, W. D.: The latitude of Ukiah and the motion of the pole, Jour. Washington Acad. of Sc., vol. 12, Jan. 19, 1922, p. 28.

——— The interpretation of apparent changes in mean latitude at the international latitude stations, Astron. Jour., No. 804, July 3, 1922, p. 103.

Littell, Dr. F. B.: Variation of latitude observations at the U. S. Naval Obsrvatory, Astron. Jour. No. 811, pp. 164–166.

——— Variation of latitude observations at the U. S. Naval Observatory, Astron. Jour. No. 822, pp. 49–52.

Schlesinger, Dr. Frank: On progressive changes in latitude, Astron. Jour. No. 798, pp. 42–44.

Tucker, R. H.: Meridian circle latitudes, Astron. Jour. No. 811, pp. 159–163.

——— Zenith telescope latitudes, Astron. Jour. No. 815, pp. 193–196

——— Variation of latitude at Lick Observatory, Astron. Jour. No. 816, pp. 202–207.

EARTH TIDE OBSERVATIONS

No observations were made for the determination of earth tides during the two years 1922–23, although the apparatus which had been used by Prof. A. A. Michelson and Prof. H. G. Gale, at Williams Bay, Wis., on the grounds of the Yerkes Observatory, had been installed in the grounds of the California Institute of Technology at Pasadena, Calif. It is expected that observations will be made at that place in the very near future.

NEW PORTABLE AUTOMATIC TIDE GAUGE[1]

The new field type automatic tide gauge was developed by the survey primarily for providing a portable, easily installed gauge which can be used to advantage by its hydrographic and tidal parties in the field at stations where it is necessary to obtain tidal observations extending over only a few days or weeks for the reduction of soundings taken during the survey, or for comparative purposes. In designing this instrument, the main objects sought were ease of installation and minimum size, commensurate with the desired accuracy.

The essential features of the gauge are its small size, its single drum on which the paper record is wound, a single clock movement installed within the drum, a cast base with sleeve to fit on top of a float tube of stock 3½-inch iron pipe. This pipe, in addition to serving as a float well, also acts as a support for the instrument, thus obviating the necessity of providing elaborate platform and cumbersome float well. This feature alone renders the gauge more adaptable for use by field parties, particularly in remote localities where wharves and docks are not available. Another departure from the usual design of automatic gauge is the use of a spring counterpoise instead of counterpoise weights for taking up the slack of the float wire on a rising tide.

The gauge is 10 inches square on the base and, with its weatherproof metal cover in place, is 10 inches high. The gauge base locks by means of two hook screws into the top section of the float well; the weatherproof cover is then locked in place by two padlocks, so that the mechanism is completely covered and can not be tampered with when the gauge is installed in exposed places.

The drum on which the paper record is wound is a single cylinder 7 inches long and 19.2 inches in circumference. This drum is geared to a clock movement carried within the drum, so as to rotate once in 48 hours, giving a time coordinate of four-tenths of an inch to the hour. Upon unclamping the milled head nut at the top of the standard on the right side of the instrument (fig. 17), the drum may be freely turned and the pencil set on cross-section paper to the nearest 10 minutes of the time coordinate of this cross-section paper. A tangent screw (added after photograph was taken) on the pencil arm permits of setting the pencil to the nearest minute.

The tidal graph is made on sheets of cross-section paper 7 by 19.7 inches, allowing in length for a half-inch overlap. The record paper is wrapped around the cylinder and held in place by a longitudinal spring clip similar to that on a barograph. The use of five different scales of cross-section paper permits the reproduction of tidal graphs to five reduced scales, allowing, therefore, for the accommodation to suitable scales of ranges of tide from zero to 24 feet. The time coordinates on these sheets of paper are lines ruled parallel to the short edge of the paper, consisting of moderately heavy lines four-tenths of an inch apart for the hours, with the spaces between the heavy lines equally subdivided into six spaces by lighter lines for the 10-minute intervals. The hour lines are numbered through two 24-hour periods, thus providing for the 48 hours of a complete rotation of the drum. For the height coordinates the sheets are ruled with lines parallel to the long edge of the paper, moderately heavy lines for the foot marks and lighter lines for subdivisions of two-tenths of a foot. The smallest scale, however, for a tide of 16 to 24 feet, is subdivided into one-half foot intervals only, omitting the two-tenths of a foot subdivision of the larger scales.

[1] Written by Lt. Com. G. T. Rude, chief, division of tides and currents, U. S. Coast and Geodetic Survey.

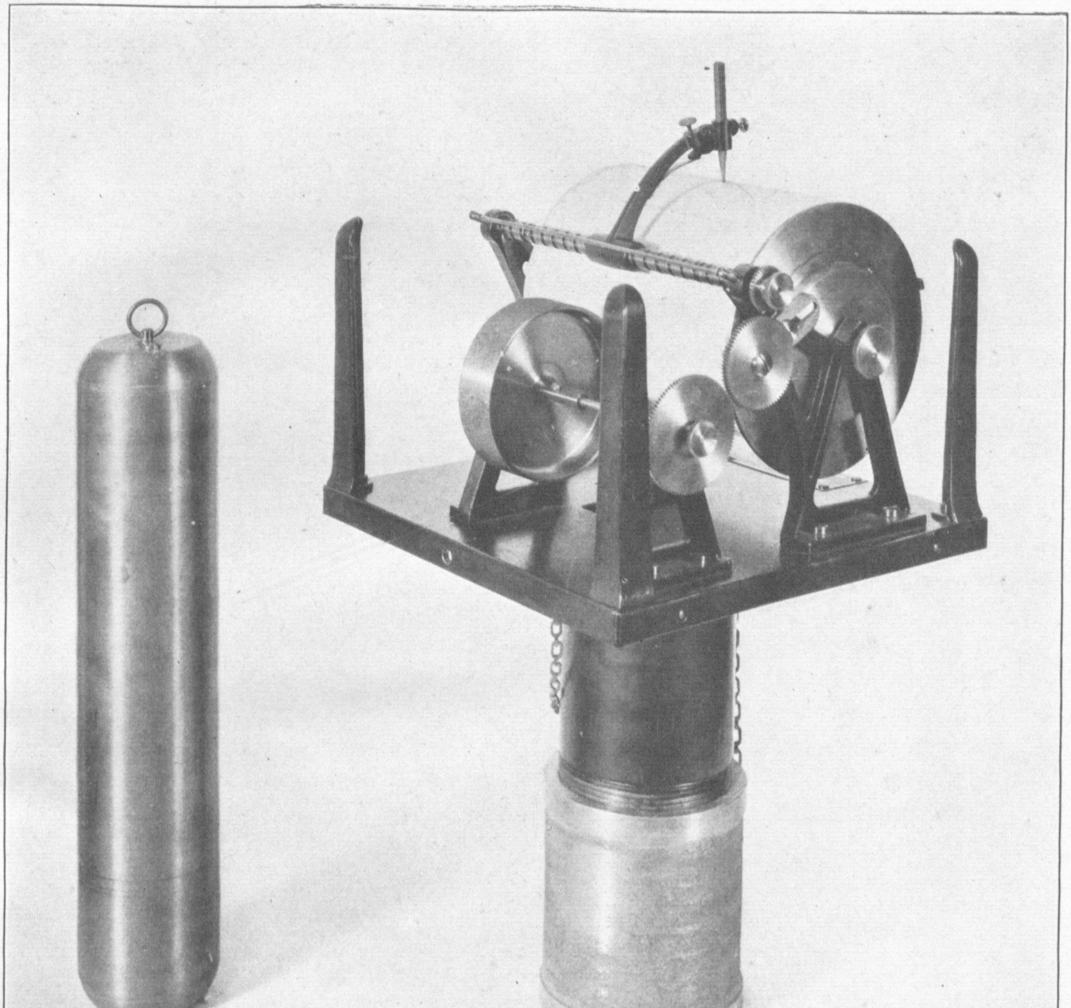


FIG. 17.—NEW AUTOMATIC TIDE GAUGE AND FLOAT

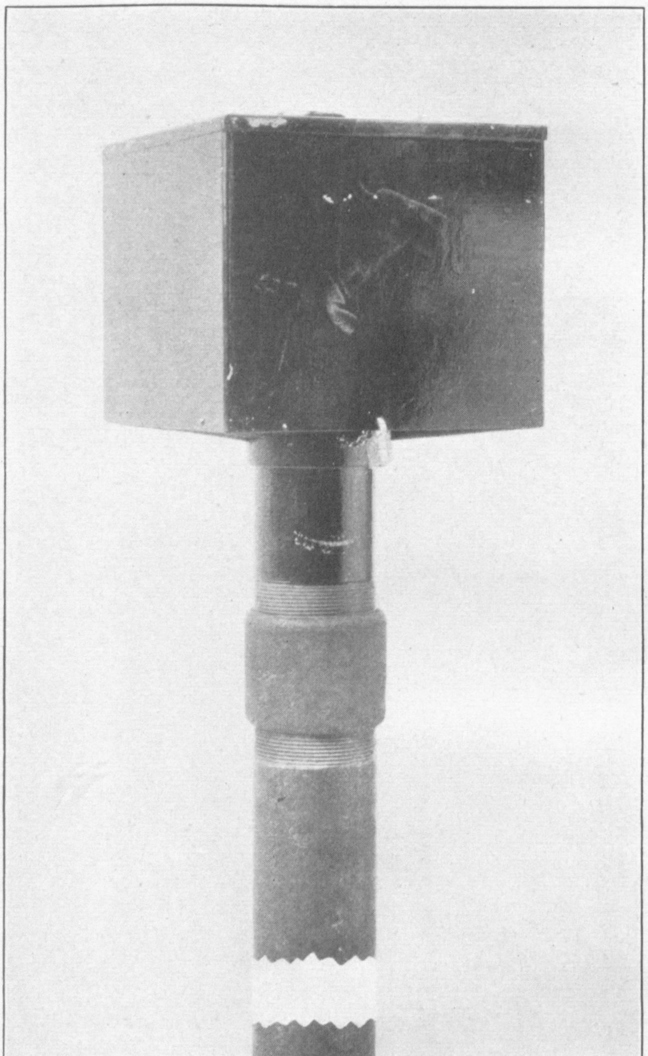


FIG. 18.—TIDE GAUGE PROTECTED BY COVER AND MOUNTED ON PIPE

The pencil screw of phosphor bronze has a pitch of four-tenths of an inch and is connected to the axle of the float pulley by means of two gear wheels and an idler gear wheel. Several sets of these gears are furnished so that the scale of reproduction of the tidal curve may be determined by the relation of the diameters of the two gear wheels employed. For adjusting the pencil when installing the gauge to the height of the tide as read on a fixed graduated tide staff, the milled nut holding the upper gear wheel to the pencil screw is unclamped and the pencil screw then turned freely without connection to the float pulley until the pencil point indicates on the cross-section paper record the height of the tide at that particular time on the graduated fixed staff. This milled nut is then clamped and the penciled curve will thereafter indicate on the record the reading at any instant of the water level on the fixed tide staff as the tide rises and falls.

Instead of employing the usual counterpoise weight for taking up the slack of the float wire on a rising tide, a coiled flat spring 18 feet long, 0.25 inch wide, and 0.010 inch in thickness is used. This spring is coiled within the case of the float wire pulley, one end fastened to the inside of the outer periphery of the metal case, the other end fastened to a separate extension of the pulley axle. This subsidiary axle extending to the left of the float pulley (fig. 17) is controlled by a ratchet and pawl, so that any desired tension may be put on the spring.

In actual practice the more accurate results may be obtained by using the middle of the spring. This is accomplished, when installing the gauge, by fully winding the spring, which requires 38 turns; it is then unwound 19 turns, provided the water level at the time is at approximate mean sea level. If the height of the water at the time is not at mean sea level, the spring is unwound or wound the same number of turns that the water is above or below mean sea level in feet.

The float, a hollow brass cylinder, 3¼ inches in diameter and 15 inches long, connects the water level to the mechanism by means of a phosphor-bronze wire 0.012 inch in diameter. This float is weighted with shot to float in kerosene oil with its upper end one-half inch above the surface, the oil preventing freezing of the water in the float well in winter. The weight of the float and shot is sufficient to wind the counterpoise spring on a falling tide and at the same time to actuate the recording pencil with a uniform motion.

The float pipe consists of a section or sections of ordinary stock 3½-inch iron pipe. A special bronze casting, having an inverted cone cast inside, is furnished with the gauge. A quarter-inch hole drilled at the bottom of this inverted cone allows ingress and egress of the tide to the float well. The inclined surface of this cone permits of easily cleaning the pipe of any obstructions which might affect the entrance of water to the pipe.

When it is necessary to install the gauge in a place at which no wharf or platform is available and to have the float pipe carry the weight of the gauge as a standard, another length of the pipe is screwed into this cone casting on its bottom end and perforated with a number of large holes to allow free access of the water to the opening in the casting.

The clock is an ordinary eight-day movement, mounted within the drum which carries the paper record. The gauge when properly adjusted, which does not require a high degree of skill in the use of instruments, will operate for eight days without attention in the meantime. The drum on which the paper record is wound turns once in two days; and, since the lunar and solar days are of different lengths, the tidal curve advances sufficiently from one turn of the drum to the next to obviate any interference of the curve for any day with that of the second day following.

The phosphor-bronze wire, connecting the float with the mechanism, is wound on a threaded float pulley exactly 12 inches in circumference. This pulley is rigidly fixed to that part of the axle which extends to the right (fig. 17), terminating with a gear wheel. The relation of the circumference of this pulley, the relative sizes of the uppermost and lowest gear wheels, and the pitch of the pencil screw determine the scale of reduction of the tidal curve.

A weather-tight galvanized-metal cover, with means for locking to the base of the instrument to prevent unauthorized tampering, protects the instrument from rain and spray. This cover fits closely around the base of the instrument and no other shelter is necessary. (See fig. 18.)

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

The observers of the Coast and Geodetic Survey are instructed to send all records to the office at Washington, D. C., as soon as possible after the field observations are completed. Here the mathematicians make the reductions and adjustments, and prepare the data for publication so that they may be available to the public. Much research work is also done by the mathematicians along the various lines of isostasy, projections for maps, variation of latitude, and other matters connected with geophysics. W. F. Reynolds has general supervision of the office computations, H. G. Avers has charge of the precise leveling computations, O. S. Adams of the triangulation computations, C. H. Swick of the gravity reductions and computations, Miss Sarah Beall of the astronomic computations, and W. D. Sutcliffe of the base line and traverse computations. W. D. Lambert is engaged almost continuously in original research on geophysical problems.

A noteworthy accomplishment in the computation of triangulation during the years 1922 and 1923 was the adjustment of the large net in the form of a cross, extending through, or partly through, the States of Arizona, New Mexico, Texas, Oklahoma, and Colorado. This net includes the arc along the one hundred and fourth meridian from Pecos, Tex., to a connection with the triangulation along the thirty-ninth parallel in Colorado and the triangulation along the thirty-fifth parallel from the vicinity of El Reno, Okla., to the vicinity of Phoenix, Ariz. The adjustment of this triangulation in one piece required 345 condition equations consisting of 232 angle, 87 side, 8 length, 12 azimuth, 3 latitude, and 3 longitude equations.

It is believed that this adjustment establishes a record both as to the number of equations involved and as to the time taken for their solution. The solution of the 345 equations was made in about 85 days of seven hours each, or a total of 595 hours. In the arithmetical work electric calculating machines were employed. With such machines a skillful computer can solve the equations at a rapid rate.

The statement below shows the extent of the activities of the geodetic work done at the Washington office of the U. S. Coast and Geodetic Survey during the two-year period covered by this report. The work done at the Manila, P. I., office is not included.

Triangulation and traverse of first class: 1,400 geographic positions computed and adjusted.
Triangulation of third class: 3,200 geographic positions computed and adjusted.
Precise base lines: 9 computed and adjusted.
Precise leveling: 3,293 miles (5,300 km.) computed and adjusted.
Astronomic work: 41 azimuths, 12 latitudes, 16 differences of longitude computed and adjusted.
Gravity observations: Values at 34 stations computed and adjusted.
Preparation of manuscript for printing: Manuscript for 709 printed pages prepared.
Proof reading: 804 printed pages compared with manuscript.

INVESTIGATION OF THE EFFECT OF VARIATIONS IN THE ASSUMED FIGURE OF THE EARTH ON THE MAPPING OF A LARGE AREA

An investigation has recently been made by W. D. Lambert, mathematician of the Coast and Geodetic Survey, as to the effect on the computation of triangulation of changing from one spheroid to another. The report of this investigation is given in Special Publication No. 100, now in press.

The publication opens with a table showing the elements of the terrestrial spheroid determined by various authorities since 1799 and another table showing the elements of the spheroids used by various nations for geographic purposes. Reasons are given for believing that the Hayford spheroid of 1909 is an excellent approximation to the earth's mean figure. The distinction is made between the scientific and the practical geographic aspects of the problem.

The effects of a change of spheroid are traced through the usual routine of geodetic computation and are found to be negligible for individual directions or triangles, except perhaps the correction to the horizontal angles for the noncoincidence of the normal to the spheroid with the plumb line. In a chain of triangulation, however, the effects may be cumulative. In the circuit closed by the Texas-California arc of triangulation the effects of a change from the Clarke spheroid of 1866, which was actually used, to any spheroid that could be accepted as probable are less than the closure corrections actually found in the adjustment; but if a circuit were to inclose the whole United States, the effects of a change of spheroid might be comparable in size with the effects of errors of observation.

The conclusion reached is that the Clarke spheroid of 1866 is at present adequate for geographic purposes and is likely to remain so; the labor and confusion entailed by a change of spheroid are strong arguments for retaining any spheroid once extensively adopted, unless it should be found extremely erroneous, which the Clarke spheroid is not. In the scientific problem however, if the network of triangles used to determine the figure of the earth were to extend over nearly the whole of North America, it would probably be desirable to adopt refinements of computation not hitherto deemed necessary.

An appendix contains the accurate formulas for the so-called principal geodetic problem and its inverse, namely, the problem of direct and inverse position computation, the lines being assumed to be so long that the usual approximate formulas will not suffice.

MAP PROJECTIONS [2]

By reason of the renewed activity during the World War in that branch of mathematical cartography which embraces the subject of map projections, considerable advance has been made in the production of maps better suited to meet the various demands of military cartography and economic geography.

The Lambert quadrillage or grid system of military mapping first used in the war zone was a decided step forward in simplifying the work of the artillery orientation officer and military engineer. It was soon followed in the United States by a similar system based on the polyconic projection. For the purpose of limiting errors of scale and azimuth to a minimum allowance in an area as large as the United States, it was deemed advisable on military maps to employ the polyconic projection in a successive series of seven zones extending north and south, each covering a range of 9° of longitude with an overlap of 1° of longitude with adjacent zones. Every grid in this system has therefore the advantage of being geographically accounted for by reference to the system of lines of latitude and longitude, as well as being a unit of a larger system of squares specially adapted to the quick computation of distances and azimuths.

The many advantages of the grid system having been recognized in cadastral and other surveys, its extension to the work of harbor improvements by the Corps of Engineers, U. S. Army, was a natural sequence. In the various units under their control, the work is based on a system of convenient squares on one datum referred to an initial point in every locality in which their operations are conducted.

The adoption of more suitable projections to cover such extensive areas as the United States, Alaska, the North Atlantic and the North Pacific Oceans has resulted in the publication of maps in which errors of scale, area, and azimuth have been greatly reduced. Base maps of the United States have been issued on the Lambert conformal conic projection and on the Lambert equal-area projection, each of which serves the purpose indicated by its name; that is, conformality in the one and equal-area representation in the other. A base map of Alaska has been prepared on the Lambert conformal conic projection which was especially suited to the wide extent of longitude covered by this locality. By the employment of two standard parallels and a suitable system of projection, the scale error, which in former maps of Alaska reached as much as 10 per cent in the most essential areas, was reduced to less than one-half of 1 per cent.

[2] Written by C. H. Deetz, cartographer, U. S. Coast and Geodetic Survey.

GENERAL MAPS OF THE UNITED STATES

The Board of Surveys and Maps at Washington, D. C., has authorized the U. S. Coast and Geodetic Survey to begin the preparation of a new map of the United States on a large scale to supersede the present wall maps issued by several departments of the Government.

The map is to embody the latest information as to surveys and other geographic data and will be constructed on a more suitable system of map projection than was formerly employed. The original drawing is in nine sheets, to be joined so as to form one continuous map, size 5 by 8 feet, scale 1:2,000,000; the published map will appear on a reduced scale of 1:2,500,000, which is about the size of the present issue of the U. S. Geological Survey.

The system of map projection employed is one that was devised by Albers over a century ago, although it has seldom appeared, doubtless due to the mathematical difficulties involved in the computation of the coordinates. The projection is of the conical type, in which the meridians are straight lines that meet in a common point beyond the limits of the map, and the parallels are concentric circles whose center is at the point of intersection of the meridians. The cone intersects the spheroid at parallels 29° 30′ and 45° 30′, which become the standard parallels of the map, and along which the scale of the map is true. The distance between the parallels is determined by the law of equal area.

The advantage of this projection for a map of the United States with its predominating east-and-west extent consists in a reduction of the scale error practically to a minimum; that is, to 1¼ per cent at the upper and lower borders as compared with a 7 per cent error of scale and area in the wall maps in present use. Even in the vicinity of New York the present wall maps have a scale error of more than 4 per cent.

Besides the two standard parallels of true scale, there are in the Albers projection at any point two diagonal lines or curves of true length scale, approximately at right angles to each other, termed isoperimetric curves. The projection thus offers more true scale properties than any other system of mapping.

Another interesting and useful feature of this projection is its equal-area representation, which is one of the modern requirements for maps. This means that any portion of the map bears the same ratio to the region represented by it that any other portion does to its corresponding region. It follows, then, that measurements in different parts of the map, planimetric or otherwise, can be directly compared.

The work of the U. S. Coast and Geodetic Survey on this map ends with the construction of the projection and the compilation of the shore line, both of which have been accomplished. The mapping of the interior of the country and the other details of the map will be done by the U. S. Geological Survey.

The publication of this equal-area map of the United States will doubtless bring on demands for a better equal-area map of the world, a problem which has always been a most difficult one to solve, in that the shapes of countries naturally become greatly distorted when the whole surface of the earth is shown on one sheet. Interesting solutions of this problem have been offered, but better ones will surely be devised as more time is given to a thorough study of the subject.

In the preparation of maps of single States or groups of States in the United States the Board of Surveys and Maps approved the recommendation of the U. S. Coast and Geodetic Survey, and adopted the Lambert conformal conic projection.

This projection was chosen by reason of the property of conformality which permits the construction of a graphic scale for each State or group of States, so that any scale error is automatically applied, although the local numerical scale only approximates the general numerical scale. In the Albers projection the scale error in the north-and-south direction is of opposite sign to what it is in the east-and-west direction, but the equal-area advantages of this projection, combined with its true-scale properties in diagonal directions across the map, make this projection preferable to the Lambert projection for a general map of the United States in a single sheet.

Possibilities of the extensive use of the gyroscopic compass and the employment of radio signals in the fixing of positions by wireless directional bearings present new problems in the navigation of ships and aircraft. The various uses and tests to which nautical and aerial charts are subjected may still further try the patience of the mathematical cartographer in devising more suitable systems of projection, or in supplying short-cut mathematical or automatic expedients as convenient adjuncts to the Mercator chart. Additional special charts on the gnomonic projection or the azimuthal equidistant projection may serve a useful purpose in the solution of the various problems of great-circle sailing or in determining true distances and azimuths.

There is a modern tendency in many places of exploiting projections of various types, generally known as "balance of error," or "minimum error" projections, projections sacrificing conformality and other useful properties, and for which there is no easy geometric accounting. These degenerating types can serve no useful purpose other than picture maps, which become untrustworthy in the derivation or application of spherical relations.

The day may come when the preparation of our charts and their use may be further simplified by the employment of the centesimal system for the graduation of the circumference of the circle, and for the expression of latitudes and longitudes, in place of the sexagesimal system of usual practice. In this the French have taken the lead as they did in the introduction of the metric system, the commensurable advantages of which are universally recognized.

On all maps and charts the name of the projection should appear in the margin. As different projections have different distinctive properties, this information is of no small value, and may serve as a guide to an intelligible appreciation of the map.

RHOMBIC CONFORMAL PROJECTION

A new conformal projection has been devised by Dr. Oscar S. Adams, mathematician of the Coast and Geodetic Survey, that maps a hemisphere within a rhombus, the acute angles of which are equal to 60° and the obtuse angles equal to 120°. The projection is defined by a functional relation of the complex variable determined by the stereographic projection. The function employed is an elliptic function that has a period parallelogram determined by the given rhombus. The method is similar to that employed by C. S. Peirce in the definition of the quincuncial projection. The functional relation is analytically defined by the integral

$$w = \int_0^z \frac{dz}{(1-z^3)^{\frac{2}{3}}}$$

In this integral $z^{\frac{2}{3}}$ is the complex variable of the stereographic projection and w is the complex variable of the rhombic projection. This integral is inverted in the usual way by the functional relation defined by the equation.

$$z = sm\ w$$

The properties of this function have been investigated and from them formulas have been derived for the arithmetic computation of the coordinates of the new map. A table of the functions has been prepared that may be employed in the computation of the coordinates.

The diagram given in Figure 19 has the poles located in the obtuse angles, but, by a simple transformation of the stereographic projection, the pole can be located at any desired point within the rhombus. Tables are being computed for two other projections, one locating the poles in the acute angles and the other with the pole at the intersection of the diagonals.

Since the projection depends upon an elliptic function, the configuration is repeated indefinitely in all directions, thus entirely filling up the complex plane.

Full development of the theory, together with tables for the three projections, will be published at a later date.

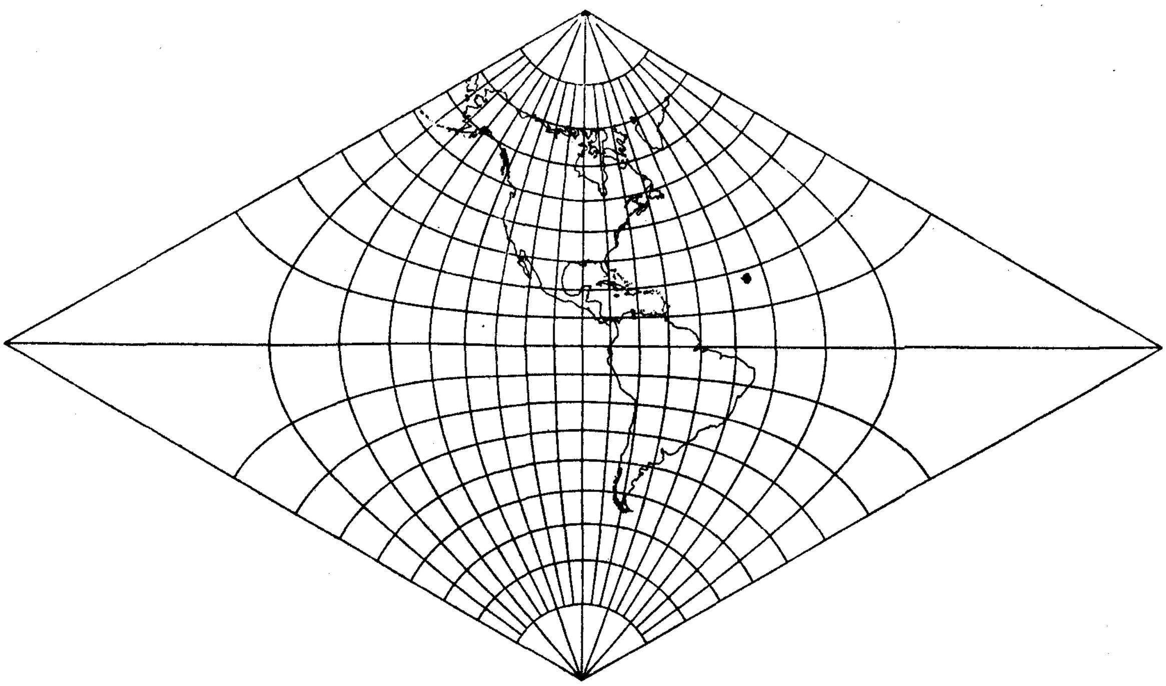


FIG. 19.—Rhombic conformal projection of a hemisphere

LIST OF GEODETIC PUBLICATIONS BY THE U. S. COAST AND GEODETIC SURVEY ISSUED SINCE JANUARY 1, 1922

California-Oregon arc of precise triangulation. Hugh C. Mitchell. Special Publication No. 84, 1922.
Precise traverse, Racine, Wis., to Vandalia, Ill. C. A. Mourhess and W. D. Sutcliffe. Special Publication No. 86, 1922.
Use of geodetic control for city surveys. Hugh C. Mitchell. Special Publication No. 91, 1923.
Study of time errors in precise longitude determinations by the Coast and Geodetic Survey. William Bowie. Special Publication No. 92, 1923.
Reconnaissance and signal building. J. S. Bilby. Special Publication No. 93, 1923.
Precise leveling in Georgia. H. G. Avers. Special Publication No. 95, 1923.
Isostatic investigations and data for gravity stations established in the United States since 1915. William Bowie. Special Publication No. 99, 1924.
Some elementary examples of least squares. Oscar S. Adams. Serial No. 250, 1923.
Effect of variations in the assumed figure of the earth on the mapping of a large area. Walter D. Lambert. Special Publication No. 100, 1924.
Precise triangulation, traverse, and leveling in North Carolina. Walter D. Sutcliffe and Henry G. Avers. Special Publication No. 101, 1924.

INVESTIGATION OF COAST EROSION [3]

With the development of better transportation facilities, the automobile, the motor boat, and the trolley, with the tremendous progress in highway construction of recent years, and with the better standards of living to which we are gradually attaining, the people of the eastern section of the country are annually flocking in ever-increasing numbers to the beaches of our Atlantic coast. While many thousands go to the big resorts, Atlantic City, Palm Beach, and the like, many others are acquiring land and building their own summer homes, so that certain sections of our coast are rapidly coming to be fringed with a succession of communities where our people seek rest and refreshment from the rigors of summer in the cities.

The ocean is engaged in an unceasing attack on these beaches, sweeping up and carrying away the materials of which they are composed. A large part of this material is deposited in a position favorable to its subsequent return, but a considerable remainder is transported to

[3] Written by Com. R. S. Patton, chief, division of charts, U. S. Coast and Geodetic Survey.

resting places in deep waters where its reclamation is impossible. In consequence, these communities, as a rule, have not been in existence many years before they have found themselves confronted with the necessity of taking effective action to protect themselves from the encroachment of the ocean, and vast sums of money have been spent by municipalities, boroughs, or individual owners in the fight to check this relentless advance of the hungry waters.

In these conflicts the ocean in a deplorable percentage of cases has been the victor. Costly protective structures have been swept away with almost the same ease as in the case of the unconsolidated sands of the beaches themselves. One of the principal reasons why our resistance to these attacks has not been more successful is that in this country we have not yet devoted to the fundamental problems involved that intensive study which alone will enable us to so devise our defense as to have reasonable assurance that it will be successful.

In other words, this problem of coast erosion and protection has not yet passed from the field of the physiographer, whose function it is to ascertain the basic laws involved, to that of the engineer, who makes concrete practical application of the principles established by his predecessor.

As the years pass, these beaches are going to become of constantly increasing importance. One section after another will be improved and populated, and this development must inevitably be followed by the demand for extensive beach protection.

Here, then, is an alluring field inviting the attention of the physiographer, a field in which the academic interest in the problems to be solved is fully equaled by the immediate practical value which the solutions will have.

Geodesy must play an important part in the solution of these problems. An extensive and well-distributed system of precisely determined reference points is a most desirable prerequisite to any comprehensive study of this character. Such a system furnishes a convenient basis for measurements of fluctuations in the changeable features of the coast. At present our knowledge of the subject has progressed to a state where such measures are particularly to be desired. Our qualitative studies are already well advanced. We know with reasonable certainty the broader fundamental principles underlying coast erosion. The present need is for quantitative studies; for data which we can study in the hope of establishing a mensurable relation, for example, between attack by a gale of known direction, velocity, and duration, and its results upon a beach of characteristic composition, profile, and exposure.

Another factor of importance in an investigation of this character is a study of possible uplift or subsidence of the shore. With the gentle slopes which characterize the profile of a sand beach, a vertical movement of a few inches may materially shift the limit of accessibility to wave action. Therefore, the determination of mean sea level at a few widely separated points, with an accuracy possible only as a result of a number of years of continuous observations, and the extension of this plane by means of precise levels to numerous intermediate points along the coast and in the interior, will afford a reliable means of determining the stability in elevation of the areas studied.

Reliable evidence of this character is greatly to be desired, as in the past conclusions regarding presumptive changes in level have been based on data so inadequate as to justify serious question as to their validity.

As an example of the importance of this problem, we may take the case of the beaches of the New Jersey coast. The assessed value of this narrow strip of land increased from $57,000,000 in 1899 to over $300,000,000 in 1922, a valuation in the latter year exceeding that of all the farms and farm property in the State.

The beaches of this State have suffered from attack of the kind indicated. Here, as elsewhere, efforts at protection had fallen so far short of adequate success that eventually the State assumed control of the problem. In addition to making appropriations to be used in conjunction with those by municipalities in the protection of specific localities, it made a special appropriation for the study of the fundamental principles underlying the problems of coast erosion and protection.

One of the first acts of the State authorities in this matter was to seek the cooperation of the Coast and Geodetic Survey. At their request one of the survey engineers was designated a member of an engineering advisory board created to make the necessary studies. Under the direction of this engineer, data accumulated by the survey during the century of its activities, and consisting of resurveys at frequent intervals of localities where changes are most rapid, were analyzed and coordinated to form one of the principal bases of fact upon which the conclusions of the committee were predicated. This committee, after an exhaustive study, submitted a report which has resulted in standardizing the engineering practice in beach protection in this locality.

○