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LEO OTIS COLBERT, Director

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GEODETIC OPERATIONS IN THE UNITED STATES JANUARY 1, 1936, TO DECEMBER 31, 1938

[Report to the International Association of Geodesy of the International Union of Geodesy and Geophysics, International Council of Scientific Unions]

BY

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PREFACE

With the organization of the Coast Survey in 1807, Ferdinand R. Hassler, first superintendent of the new Bureau, laid plans for geodetic work in this country. Field work was begun in 1817 in northern New Jersey, in the vicinity of New York City, and was designed to provide a framework of triangulation for the control of hydrographic surveys required in the production of nautical charts for use by ships entering what was to become one of the largest ports in the world. This was the beginning of the horizontal control net of the United States, which at first was confined to the extension of triangulation along the coastal regions for immediate use in hydrographic surveys, and for the coordination of nautical charts of coastal waters and ports which depended upon those surveys. In 1871, Congress authorized the Bureau to extend its geodetic work to the interior of the country in order to provide a connection between the Atlantic and Pacific coasts and to supply geographic positions for State surveys. The importance of geodetic work as a major function of the Bureau was fully recognized in 1878, when the name of the Bureau was changed to Coast and Geodetic Survey.

Even before its name was thus changed, the Coast Survey had accomplished a great deal of geodetic work in this country, although it was only natural that in the beginning progress in such work should be slow. The country was new and growing rapidly, but interest in research and its practical application to engineering and mapping had to depend upon an initial economic and commercial development. Due to the great scientific ability and keen foresight of its first superintendent, the Coast Survey soon established standards of work and rates of progress which kept pace with the country's development in other lines. But all previous accomplishments in the field of control surveys were surpassed in the years 1932 to 1935, during which years, through the use of emergency funds applied to the relief of unemployed engineers, the geodetic work of the country was more than doubled in quantity.

This outstanding accomplishment was due largely to the efforts of Dr. William Bowie, Chief of the Division of Geodesy from 1911 until his retirement in 1936 after a distinguished service in the Bureau of more than 40 years. Dr. Bowie's well-known enthusiasm and unflagging energy in the advancement of the work which was so dear to him has greatly influenced the advances made in geodetic surveying both in this country and abroad, and has promoted a widespread interest in surveying and mapping generally over a period of several decades. Retirement from active duty in the Coast and Geodetic Survey has in no way diminished Dr. Bowie's interest in this work, but rather, by relieving him of routine duties, has given him opportunity to continue where choice may dictate.

Tribute is also paid to Dr. O. H. Tittmann, whose death on August 21, 1938, at the ripe age of 88 years, marked the passing of one who, in an active association of 48 years with the Coast and Geodetic Survey, contributed much to the progress of geodetic surveys in this country. Dr. Tittmann served as Superintendent of this Bureau for 14 years, when he also represented the United States on the International Boundary Commission; he was several times the representative of this country at meetings of the International Geodetic Association; and through his membership in various societies, he contributed to advances made not only in geodesy, but also in the related fields of metrology and geography.

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By CLEMENT L. GARNER, *Chief, Division of Geodesy, United States Coast and Geodetic Survey*

GENERAL STATEMENT

Although considerable advances have been made in the geodetic operations in this country during the period covered by this report, they are much smaller in scope and volume than for the 3-year period immediately preceding. There is much evidence, however, to show that interest in such geodetic surveys as first- and second-order triangulation and leveling is not decreasing, but has steadily increased during the period. Requests for data resulting from such surveys, already heavy at the beginning of the period, continue to grow from year to year. This is not at all surprising when one considers the function of geodetic work in its practical application to problems of engineering which are dependent upon accurate surveys and maps, such as flood control, reclamation work, highway planning, and for scientific investigations and studies which must often precede or go hand in hand with the engineering plans.

Geodetic control is a fundamental, basic necessity to all surveying and mapping if continuing uses and lasting values are to be obtained. Its function is, to coordinate into one national system all surveys which are adaptable to the general plan. Without geodetic control, detached surveys could not later be brought together and joined to form a uniform and coordinated whole. Today there are many State-wide engineering and planning projects which require such fully coordinated maps of the areas which they cover. Geodetic control is also of particular value in investigations of important scientific problems, such as, for example, those dealing with movements of the earth's crust caused by earthquakes, the settlement of areas due to seepage of water, drainage, or other causes, and location of structures associated with oil and other minerals by geophysical methods.

Geodetic control is a separate and distinct operation which, for greatest effectiveness, should precede the surveying and mapping operations which are dependent upon it; the geodetic control of an area should be completed before other surveys of the area are undertaken. While much the greater part of the geodetic control survey of the country is being executed by the Coast and Geodetic Survey, the pressing needs of our complex Federal organization for controlled maps on which to plan various types of Federal and State public-works projects has resulted in the extension of control surveys of various degrees of accuracy by other agencies to meet their own special requirements.

The program of geodetic work in the United States described in the report for 1933–35 was the most expansive in our history. It came to an end on July 31, 1935, and from that time on, through the years covered by this report, geodetic operations have been drastically curtailed except during the period June 1938 to December 1938 when, with a grant of $490,000 of emergency funds, the Bureau extended control surveys in 34 States. This enabled the Coast and Geodetic Survey to close many loops and circuits of triangulation and levels which were left unfinished when the enlarged program was suddenly terminated in July 1935. Somewhat more than one-half of this allotment was used during the latter half of the calendar year 1938, and it is expected that the remainder of the funds will be exhausted by September 1939.

In addition to the foregoing, work has been accomplished through cooperation with other agencies. In 1938 the Mississippi River Commission transferred $26,500 to the Coast and Geodetic Survey with which to complete the level net in the alluvial valley of the Mississippi River, and make the computations and adjustment of the data obtained on the sea-level datum of 1929. In this work the Coast and Geodetic Survey furnished supervisory personnel and instrumental and other equipment. The work was completed near the end of the year (1938), and it is expected that the adjustment of the entire vertical control net in this region will be completed in the near future. It will combine the leveling of several organizations, including that of the Coast and Geodetic Survey and of the United States Engineers.

The Bureau has also cooperated with the Soil Conservation Service in the extension of first- and second-order triangulation in the mountainous regions of several western States. This work furnishes control data for aerial photographic mosaics used in the study of soil-erosion problems. For this work the Soil Conservation Service contributed the sum of approximately $207,000 during the 3-year period.

GEODETIC COMPUTATIONS

At the end of 1935 there remained not only considerable field work to be completed, but also a large volume of field observations resulting from the expanded program of geodetic work which it had not been possible to process. Unclosed circuits of triangulation and of leveling render it impracticable in many instances to make the final adjustments of the field observations; they must wait until the gaps in the field work have been closed, a work that is proceeding slowly because of limited funds.

The office work in connection with the processing of survey observations has also presented a very difficult problem. The amount of work to be done in that processing is very great in relation to the size of the permanent force available for it. There is naturally a considerable lag between the securing of field data and the office processing thereof, since it is necessary that the field work in large areas be completed before the final adjustments can be made. Many requests are received for data resulting from the field surveys, but such data can be furnished only in preliminary form. Supplying survey data to the public already requires more than half the time of the regular office personnel, and as these demands continue to increase, the personnel engaged in this work must be increased, with a corresponding decrease in the number of persons who can continue on the work of processing the field records.

A statement of the adjustment of the control triangulation by Walter F. Reynolds, Chief of the Section of Triangulation, will be found on page 20 of this report.

Late in 1936, through cooperation with the Works Progress Administration, the Bureau established a computing office in New York City. This office is in charge of a field officer of the Coast and Geodetic Survey, the technical work being directed by men detailed from the regular staff of the Washington office. Within a short period of time about 75 men were engaged in the New York office, and this number was gradually increased to about 160 by the end of the first year, since which time the number has remained nearly constant. The operation of this office has alleviated very considerably the situation with regard to unprocessed field records, making satisfactory progress in the computation and adjustment of much of the triangulation and leveling executed several years ago.

At the close of 1938 a similar office was in process of being established in Philadelphia, Pa., where it is anticipated that some 200 employees will eventually be engaged on geodetic and other work in connection with the computation and distribution of data and information by the Bureau.

A description of the control survey activities of the Works Progress Administration by H. W. Hemple, Assistant Chief, Division of Geodesy, appears on page 22 of this report.

THE TRIANGULATION NET

On December 31, 1938, the triangulation net of the United States comprised about 75,000 stations distributed along approximately 73,500 miles of first- and second-order triangulation as measured along the axes of the arcs. Of this, approximately 7,800 miles are of second-order

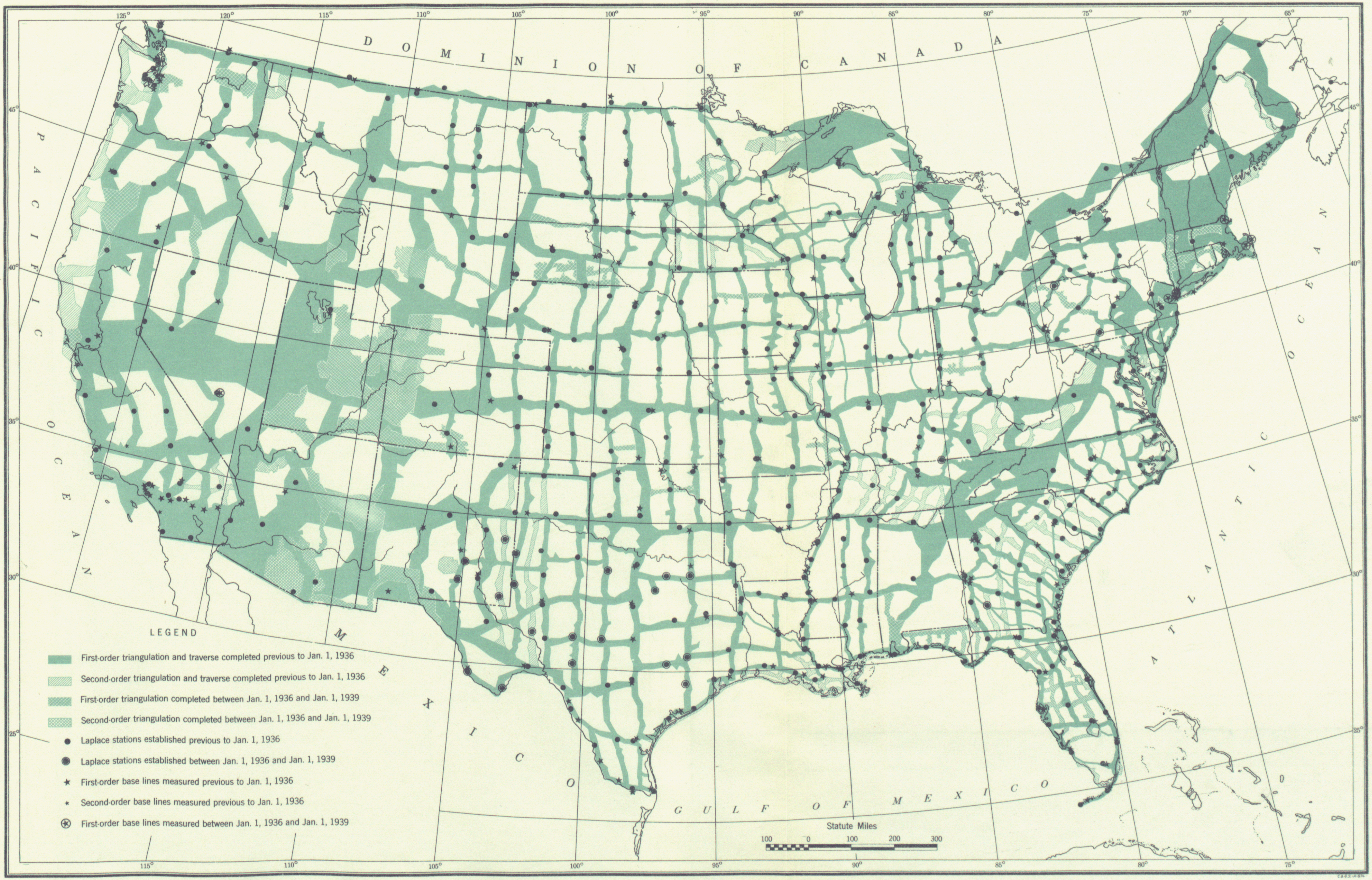
DOMINION OF CANADA
PACIFIC OCEAN
MEXICO
GULF OF MEXICO
ATLANTIC OCEAN
LEGEND
First-order triangulation and traverse completed previous to Jan. 1, 1936
Second-order triangulation and traverse completed previous to Jan. 1, 1936
First-order triangulation completed between Jan. 1, 1936 and Jan. 1, 1939
Second-order triangulation completed between Jan. 1, 1936 and Jan. 1, 1939
Laplace stations established previous to Jan. 1, 1936
Laplace stations established between Jan. 1, 1936 and Jan. 1, 1939
First-order base lines measured previous to Jan. 1, 1936
Second-order base lines measured previous to Jan. 1, 1936
First-order base lines measured between Jan. 1, 1936 and Jan. 1, 1939
Statute Miles
100 0 100 200 300

FIGURE 1

accuracy. The lengths are controlled by 211 first-order and 54 second-order base lines distributed according to rigid requirements of strength of figure to insure the required accuracy within the net.

The first-order base lines were measured with an accuracy which gave probable errors of better than 1 part in 1,000,000; the probable errors of the second-order base lines were 2 parts in 1,000,000 or better. In 1906 an extensive test of invar tapes for measuring base lines was made, resulting in the adoption of such tapes as standard equipment in geodetic work. The base lines are measured in daytime, under all conditions except during rain or wind greater than 20 miles per hour. For several years, the closer distribution of triangulation stations required in supplying control data for mapping operations has resulted in a shortening of the lines of the main triangulation net, with a corresponding simplification of the base-line expansion figures.

In recent years many bases have consisted of lines of the main triangulation which were measured directly. For a study of requirements of strength of figure and distribution of base lines along the arcs of triangulation, the reader is referred to the following special publications of this Bureau: No. 93, Reconnaissance and Signal Building, and No. 120, Manual of First-Order Triangulation.

During the early days of the Coast Survey it was necessary to supply control for coordinating surveys in many parts of the country as rapidly as possible, and this was accomplished through the use of as long lines as the general topography and local conditions of a region would permit. Consequently the distribution of stations resulted in lines varying in length from a few miles to, in many cases, over 100 miles, while a few lines are more than 150 miles in length. The early work in many mountainous areas gave a distribution of stations that is entirely inadequate for mapping, engineering, or other general purposes, and as the net is extended, additional arcs composed of much shorter lines are required in those areas.

The present practice in the distribution of fundamental horizontal-control survey stations in the United States is such as to satisfy the requirements of the various Federal organizations using the control for mapping, engineering, and scientific purposes. Under the adopted plan, the distribution of horizontal-control stations in the eastern part of the country will be such that no point will be more than about 6 miles from such a station. In the western part of the country the same distribution as for the eastern part will be required for areas of intensive development or of great commercial or economic importance, though in certain mountainous regions and in areas of small economic importance, the distribution may be such that 12 miles is the limiting distance.

The present practice of this Bureau is to provide, wherever practicable, a distribution of stations which will fulfill the above requirements. Obviously, the placing of main-scheme stations is governed by the nature of the topography of the region in which they are located. There are some regions in which short lines can be used, while in others economic considerations require that main-scheme stations be governed by the nature of the topography of the region in which they are located, with main-scheme lines up to 20 or even 30 miles in length. In the latter regions, the required distribution is obtained by placing additional stations within the quadrilaterals of the main scheme or along the sides of the scheme. Lines of greater length than indicated above are now used only for making ties to earlier triangulation, or where demanded by special conditions. The added cost of a triangulation party's going into the same general region a second time makes it very important that such additional surveys be avoided by securing on the first visit, if feasible, sufficient data to provide a distribution of stations that will satisfy basic requirements.

In extending schemes of triangulation it is the practice to use quadrilaterals wherever practicable to do so without additional cost. Where the character of the terrain makes it difficult to use the standard figures, or where, as occasionally happens, an obstructed line is encountered, field parties are authorized to use single triangles under precise limitations with regard to strength of figure and triangle closure.

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Supplemental stations, both within and along the main scheme, are established as the party progresses to provide the proper distribution of stations. On about two-thirds of the work in the United States, portable steel towers are used for mounting theodolites and signal lamps, making the expense of repeating observations at such stations particularly heavy. It is especially important, therefore, in areas where towers are used, that all supplemental stations required for a proper distribution, both within and along the main scheme, be secured as the party progresses along the arc.

MEASUREMENT OF BASE LINES

During the period covered by this report seven first-order base lines have been measured in the United States by the engineers of the Coast and Geodetic Survey. The total length of these bases is 31.4 miles, the average length being 4.5 miles.

No recent changes have been made in the method of measuring base lines, the method used being described in our Special Publication No. 120, Manual of First-Order Triangulation, except that when a base is along a railroad track, the tape is supported at four points over one of the rails. This is described with some detail on page 8 of the report Geodetic Operations in the United States, 1933–35, which is Special Publication No. 207 of this Bureau.

The tapes used are of invar, 50 meters in length, and are restandardized at frequent intervals at the National Bureau of Standards. Automobile trucks are used to transport the personnel and equipment engaged in making base measures.

The locations of the base lines, with their lengths and probable errors, are shown in the following table:

Base lines measured in the United States

[Jan. 1, 1936, to Dec. 31, 1938]

Location (State)	Name of base	Length in miles	Probable error—1 part in—	Location (State)	Name of base	Length in miles	Probable error—1 part in—
New Jersey	Elizabeth	4.9	2,100,000	Florida	Matecumbe	3.5	1,700,000
Massachusetts	Yarmouth	2.2	1,500,000	New York	Amsterdam Avenue	4.0	4,300,000
	Wellfleet	2.7	2,100,000	Arkansas	Lonoke (remeasurement)	9.3	2,600,000
	Newbury	4.8	2,400,000				

STATISTICAL DATA FOR TRIANGULATION EXECUTED

A list of arcs of triangulation which have been executed in this country during the period covered by this report is given below.

Arcs of first- and second-order triangulation

[Jan. 1, 1936, to Dec. 31, 1938]

	Length, miles
First-order arcs:	
Elizabeth, N. J., base net	5
Colville and Spokane Indian Reservations, Wash	100
Pine Ridge and Rosebud Indian Reservations, S. Dak	390
Fort Hall Indian Reservation, Idaho	60
Uintah-Ouray Indian Reservation, Utah	130
Upper Rio Grande, Colo	90
Southern Ute Indian Reservation, Colo	160
San Juan River, Utah	120
Little Colorado River, Ariz. and N. Mex	220
Lower Rio Grande, N. Mex. and Tex	200
Yarmouth, Mass., base net	4
Wellfleet, Mass., base net	5
Newbury, Mass., base net	1
Bohlen-West Hills, N. Y., connection	2
Northern New Jersey	32
First-order arcs—Continued.	
Hartford, Conn., to Providence, R. I	82
Amsterdam Avenue base net, New York	4
Vicinity of New York, N. Y	10
Soil Conservation area, Utah, Colorado, and Wyoming	495
Connecticut-Rhode Island boundary, Connecticut and Rhode Island	45
Reed, Nev., base net	12
Colquitt, Ga., to Mobile, Ala	325
Hudson River—New York to Albany, N. Y	210
Baltimore County, Md	22
Earthquake investigation:	
Maricopa, Calif	16
Palmdale, Calif	15
Gorman, Calif	24
Hartford to Torrington, Conn	24
Virgin River area, Utah and Arizona	180

Arcs of first- and second-order triangulation—Continued

First-order arcs—Continued.	Length, miles
Erie to Boalsburg, Pa	155
Weber River area, Utah and Wyoming	115
Grantsville-Tooele area, Utah	45
Frazee to Remer, Minn	70
Long Prairie to Bemidji, Minn	115
Manti area, Utah	85
Minot to Westhope, N. Dak	60
Beaver River area, Utah	95
Muddy River area, Utah	140
Waverly to Pocahontas, Iowa	120
Thomson to Polo, Ill	15
Circleville to Fairhaven and Wilmington to Springfield, Ohio	125
Dudley to Saint Marys, Mo., and Scopus, Mo., to Elco, Ill	130
Fredericktown to Ironton, Mo	40
Mobile to Demopolis, Ala	155
Fields to Crane, Oreg	90
Vicinity of Crater Lake, Oreg	240
Lookout Mountain to Stanley, Idaho	50
Earthquake investigation: Point Reyes to Petaluma, Calif	50
Manville to Thermopolis, Wyo	170
Forest City to Mason, S. Dak	165
Kingman to Greensburg, Kans	50
Winslow to Winkelman, Ariz	110
Silver City, N. Mex., to Nogales, Ariz	220
Marshall to Claremore, Okla	90
Total, first-order arcs	5,683
Second-order arcs:	
Papago Indian Reservation, Ariz	565
Hualapai Indian Reservation, Ariz	115
Mescalero Indian Reservation, N. Mex	100
Pawcatuck River, Conn. and R. I	10
Clarcona to Titusville, Fla	35
Shoshone Indian Reservation, Wyo	75
Orlando to Okeechobee, Fla	140
York to Lee, Fla	150
Shady to Lily, Fla	160
Northern Idaho	90
Arcadia to Fort Ogden, Fla	17
Lake Okeechobee to Fort Myers, Fla	70
Lower Merion Township, Pa	10
Highland to Francis, Fla	60
Soil Conservation area, Utah, Colorado, and Wyoming	950
Carrabelle, Fla., to Colquitt, Ga	80
Early to Campbellton, Fla	60
Queen Creek area, Arizona	60
Total, second-order arcs	2,747
Total, first- and second-order arcs	8,430

SKETCHES

Figure 1 shows the location of all arcs of triangulation which composed the horizontal control net on January 1, 1939. Different symbols are used to distinguish between first- and second-order work, and also between work done prior to January 1, 1936, and that done during the period covered by this report. Areas in which the earlier triangulation was composed of unusually long lines were later filled in with much shorter lines. This condition is shown by superimposing one symbol on another, that for the older work naturally being somewhat obscured in so doing.

Figure 2 shows the location of all first- and second-order leveling in the United States prior to January 1, 1939. It has not been practicable to show by distinctive symbol the leveling done during the period covered by this report, inasmuch as it was along lines already identified with the earlier work.

THE LEVELING NET

During the period from January 1, 1933, to December 31, 1935, in which the leveling program was very much expanded, over 37,000 miles of first-order leveling and 152,000 miles of second-order leveling were run. The field work was completed much faster than the computations and adjustments could be made, even with greatly increased office personnel in Washington and New York. This resulted in a great accumulation of field records for which no computations had been made when the office forces were suddenly reduced.

From January 1, 1936, to December 31, 1938, 505 lines of levels were computed and 75 adjustments were made. Notable among the adjustments was that of the first-order leveling in the southeastern part of the United States involving all or parts of the States of Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, and Kentucky. This adjustment required the solution of 47 equations. Other adjustments ranged in size from simple

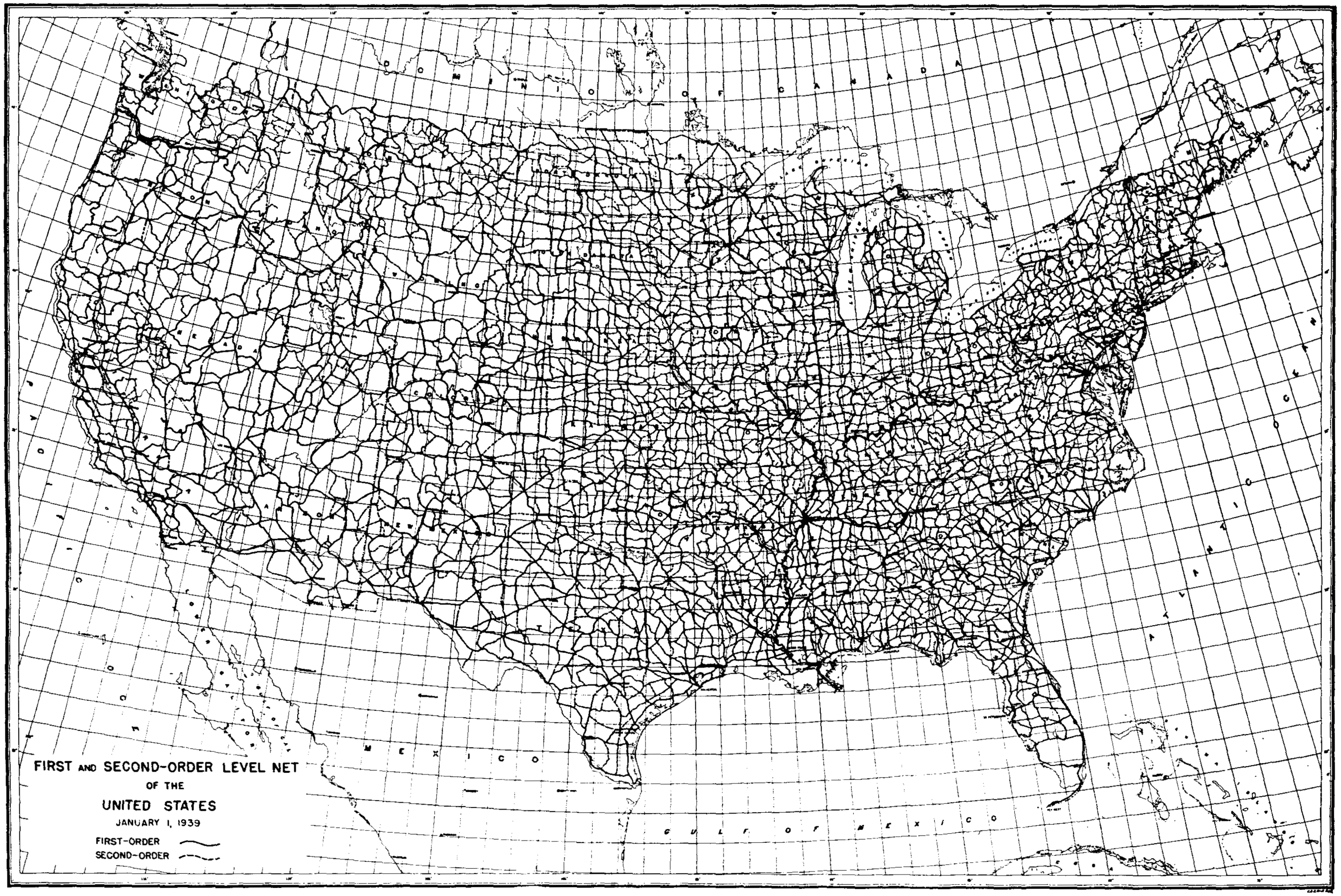

FIGURE 2.—First- and second-order level net of the United States.

weighted means to 28 equations. The Washington office was assisted by Works Progress Administration cooperative field offices in Little Rock, Ark., and Oklahoma City, Okla., in making computations; and by others in New York, N. Y., and Atlanta, Ga., in making both computations and adjustments.

The leveling net now consists of upwards of 150,000 bench marks distributed along about 106,950 miles of first-order and 154,980 miles of second-order level lines. In the eastern part of the country the level lines are about 25 miles apart and usually follow highways and railroads because of the transportation facilities thus afforded and the greater progress made possible, and also because in such locations the bench marks are more readily accessible and therefore more conveniently placed for the use of local engineers and surveyors.

GEODETIC PUBLICATIONS ISSUED SINCE JANUARY 1, 1936

MISSISSIPPI RIVER COMMISSION

Triangulation Along the Mississippi River, New Orleans to the Delta, by the United States Coast and Geodetic Survey and the Corps of Engineers, United States Army. 320 pages, 7 illustrations, octavo. 1936.

UNITED STATES COAST AND GEODETIC SURVEY

Geodetic Operations in the United States, January 1, 1933, to December 31, 1935. William Bowie. Special Publication No. 207. 28 pages, 2 illustrations, quarto. 1936.

Tables for determining the form of the geoid and its indirect effect on gravity. Walter D. Lambert and Frederic W. Darling. Special Publication No. 199. 137 pages, 1 illustration, octavo. 1936.

First- and Second-Order Triangulation in California (1927 datum). Hugh C. Mitchell. Special Publication No. 202. 554 pages, 45 illustrations, octavo. 1936.

First- and Second-Order Triangulation and Traverse in Minnesota (1927 datum). Walter F. Reynolds. Special Publication No. 203. 415 pages, 30 illustrations, octavo. 1936.

A Determination of the Relative Values of Gravity at Potsdam and Washington. E. J. Brown. Special Publication No. 204. 17 pages, 3 illustrations, octavo. 1936.

Triangulation in Utah (1927 datum). Henry G. Avers. Special Publication No. 209. 169 pages, 11 illustrations, octavo. 1937.

Leveling in North Carolina. Norman F. Braaten and Charles E. McCombs. Special Publication No. 210. 415 pages, 4 illustrations, octavo. 1938.

Triangulation in Wyoming (1927 datum). Charles N. Claire. Special Publication No. 212. 233 pages, 20 illustrations, octavo. 1938.

Azimuths From Plane Coordinates. Oscar S. Adams. Serial 584. 14 pages, 6 illustrations, octavo. 1936.

STATE PUBLICATIONS

In a number of States, surveying organizations sponsored by the Works Progress Administration have published bulletins containing control survey data, usually in the form of plane coordinates and elevations. In several of these bulletins geodetic positions are also included. Among these States are the following: Arkansas, Connecticut, Florida, Georgia, Louisiana, Massachusetts, New Jersey, and Oklahoma. Similar bulletins are also being published by the Tennessee Valley Authority.

GEODETIC DATUMS

The triangulation net of the United States is adjusted to the North American datum of 1927, which is described in a number of earlier publications of this Bureau. In 1913, because of the international character acquired through its adoption by Canada and Mexico, the name of the datum in use in this country was changed from United States Standard to North American datum, and this in turn was given its present form following a general readjustment of the triangulation net of the country. Its international character attests a recognition of the greater usefulness and wider benefits which result from having a geodetic datum of such broad extent.

The closeness of the spheroid of reference to the actual surface of the geoid, and the large amount and wide extent of the observational data entering into the establishment of the present datum furnish complete assurance that geodetic positions based on the North American datum of 1927 are final and will not be changed except for some very extraordinary conditions in very restricted areas. Engineers and others to whom such data are furnished may use them with fullest confidence that, except only in areas where earth movements or some peculiar conditions may make small readjustments necessary, there will be no changes. Since its adoption, all triangulation executed in this country is being adjusted to it as rapidly as the resources of the Bureau permit, in order that there may be no avoidable delay in furnishing interested persons the data provided by such adjustment.

New adjustments of the level net have also been made from time to time, as it was extended into new sections to meet engineering and other needs, and as additional connections to the basic datum, mean sea level, and better values for that datum became available. The latest adjustment was made in 1929 and is based on what is generally referred to as the "Sea-Level Datum of 1929." Results of this general adjustment will be held fixed indefinitely with the following possible exceptions:

1. Those areas where new leveling discloses blunders in the old work and necessitates readjustment of a limited portion of the net in order to eliminate the effect of the blunder.

2. Those areas where readjustments of limited portions of the net are required because of earthquakes, or other earth movements which are proved to have taken place.

3. Areas affected by the introduction of new tidal stations and connections to the net. These will be handled by fitting the new work to the net in the usual manner, but not necessarily holding the tidal datum planes in determining the geodetic elevations. We must either keep readjusting the net, especially along its edges, or else admit that an actual difference exists between the geodetic datum and the local tidal planes. As we cannot keep readjusting the net, the only alternative seems to be to admit differences between the geodetic and local tidal planes.

On page 28 of this report is a special paper entitled "Sea-Level Datum" by Paul Schureman, senior mathematician in this Bureau, in which changes produced in that datum by additional observational data are discussed.

OTHER GEODETIC WORK

As a result of reduced field work and other causes, there has been a comparatively small number of latitude, longitude, and azimuth determinations and base line measurements made during the 3 years covered by this report. The principal reason for this is that the fundamental net of the country has become so extended that need for such additional work is greatly reduced. The meshes of that net are being filled in with short arcs of triangulation tied into earlier triangulation at both ends and requiring neither astronomical determinations nor measured base lines to control azimuths and lengths.

One party engaged on gravimetric work has been in the field almost continuously during the period covered by this report. Its accomplishments are described in a special article by C. H. Swick, Chief, Section of Gravity and Astronomy. See page 26.

The Coast and Geodetic Survey has also cooperated with the Works Progress Administration, as far as was practicable within the limits of its resources, in personnel, instruments, and equipment, in the extension of local control surveys in 15 States. This work was executed as a relief measure, and was under the direction of State organizations. This Bureau's interest in such work was to obtain coordination and correlation between the Federal survey nets and the local surveys wherever reasonably possible to do so, and to help those in charge of the local work to follow uniform procedure and standard practices and thus produce results of prescribed accuracy which would be of the greatest possible public use and value. In many regions field personnel has been detailed to supervise and direct certain operations, while in others, lack of resources has compelled us to limit the cooperation to the loaning of instruments and equipment, and to technical advice regarding procedure. This was particularly true of first-order surveys extended over metropolitan and county areas, where the adjustment of the work required the advisory service of mathematical experts of the office staff.

SPECIAL GEODETIC WORK IN CALIFORNIA

Good progress has been made in the extension of triangulation along three fault zones in southern California, in the general area north of Los Angeles. These surveys were for use in studying earth movements that may result from seismic causes. The report on geodetic operations in the United States for the period 1933–35 contains a description of this work which was executed along the axis of the main San Andreas fault running southeastward from the vicinity of San Francisco. In 1934 and 1935 lines of levels were extended over some 1,300 bench marks established in the fault zones for distances of about 5 miles on both sides of the main fault. The monuments were spaced at 100-foot intervals near the main fault, increasing to 500-foot intervals at the outer limits of a zone. The plan, which is now only slightly more than half completed, is to extend accurate horizontal and vertical control over the entire 1,300 monuments in order that evidence with regard to movements that may have occurred can be obtained at any time by repeating the observations. At the present time the leveling has been completed in all of the eight fault zones, while the triangulation has been completed in only three zones. This work is being done in cooperation with the advisory committee in seismology of the Carnegie Institution of Washington, which is in close contact with the investigations being made of seismic problems. It is planned to complete the horizontal control surveys in the other zones as rapidly as the required funds become available.

VARIATION OF LATITUDE

Observations, with especial reference to an international program for the study of variation of latitude, have been continued at observatories located at Ukiah, Calif., and at Gaithersburg, Md.

SPECIAL GEODETIC AND GEOPHYSICAL STUDIES

The Bureau has continued its investigations of various problems connected with its work in geodesy and geophysics. The principal studies in this field were made by W. D. Lambert, senior mathematician of the Division of Geodesy, who, during the years covered by this report, published the following articles dealing with the earth's field of force:

The Figure of the Earth from Gravity Observations. Journal of the Washington Academy of Sciences, vol. 26, 1936, page 491.

The Analogue of Stokes' Formula for the Prey and Bouguer Gravity Anomalies. Gerlands Beiträge zur Geophysik, vol. 49, 1937, page 199.

Density, Gravity, Pressure, and Ellipticity in the Interior of the Earth, being chapter XIII of a bulletin of the United States National Research Council. (In page proof, but at this writing not as yet published.)

The External Gravity-Field and the Interior of the Earth. Transactions of the American Geophysical Union, eighteenth annual meeting, 1937, page 33. (Part of a symposium on theoretical and observational considerations of importance to future studies of the depths of the earth.)

Formulas and Tables for the Deflection of the Vertical (F. W. Darling, associate mathematician, joint author), Bulletin Géodésique, No. 57, January, February, and March 1938, page 29.

In connection with the above, an article by Mr. Darling alone appears in the same number of the Bulletin Géodésique, page 1, entitled:

"Notes on the Computation of *Elliptic Integrals in Some Special Cases.*"

These last two articles are to be considered together. They provide a set of factors for the reduction of observations of deflections of the vertical on the assumption of complete isostatic compensation at various depths. These factors differ systematically from those given by Hayford. In addition, formulas are given that enable deflections to be computed on other hypotheses; also some specimen tables. It is hoped that a full set of tables will eventually be computed. These tables would do for the horizontal component of gravity what the tables of Cassinis and Dore do for the vertical component.

Mr. Lambert also did some work on a Report on Earth Tides, which he will present at the Washington meeting (September 1939) of the International Union of Geodesy and Geophysics.

PRESENT FIELD PRACTICES

TRIANGULATION

Plans for the fundamental triangulation of the country, adopted a number of years ago, called for first-order arcs placed at intervals of approximately 100 miles between the sides of the schemes, or about 120 miles between the axes of the arcs. Second-order triangulation was to be used for supplementary arcs placed between the first-order arcs, at intervals of 50 miles or 25 miles as might be required for general mapping or engineering purposes. In recent years it has been the practice to require an appreciable increase in the accuracy of the second-order triangulation. The increased accuracy is desirable because of the present demands for basic control for surveying and engineering projects which require high accuracy, and which may be at such distances from the main-scheme stations as to require considerable supplemental control in making a connection therewith.

In filling in the meshes of the main-scheme net, and supplying stations at the now desired spacing required for air photographic work, a great deal of observational data must be secured, and many triangulation figures established; it is, therefore, becoming very important that the basic control to which these detail control surveys are fitted approach first-order accuracy. This increase in accuracy is obtained at no additional cost. Ordinarily, all observations at a first-order station are completed in a single night, but it is not practicable for the observing party to visit a second station on the same night, because of difficulties relating to transportation, average observing conditions, and matters connected with party administration.

The specifications for first-order work require an average triangle closure of not more than 1 second and permit maximum closures not to exceed 3 seconds. To maintain this accuracy it has been the experience that from 5 to 10 percent of the stations must be occupied a second night. Second-order specifications required that the average triangle closure must not exceed 3 seconds, while maximum closures of 5 seconds were allowed. Second-order accuracy can be obtained with observations on eight positions of the circle, which is one-half of the number required for first-order work. Since, under average conditions, it requires only 2 to 4 hours on one night to complete the first-order observations at a station, very little time can be saved by limiting the observations to second-order requirements, and that time can be put to no practical use.

Our present practice in writing instructions for second-order triangulation is to call for observations made in accordance with first-order requirements, with a provision that no station need be reoccupied in order to improve triangle closures of 5 seconds or less. Long field experience has shown that, with the care oridinarily used in first-order work, these specifications will give triangle closures averaging between 1.2 and 1.5 seconds, and very seldom will a station have to be reoccupied in order to reduce closures which are above 5 seconds. These instructions also permit the observer, in case of interference by weather or other conditions, to consider the observations at a station completed if he has obtained satisfactory observations from 10 positions of the circle. With the flexibility thus allowed, an observer may accelerate his observing and complete a station in the face of an approaching storm.

Obviously, the first requirement in the execution of work such as is described above is for instruments of a high order of accuracy, having circle graduations reliable within precise limits. In the United States such instruments are obtained only by special manufacture.

The second requisite is that great care be used in mounting instruments and lamps over station marks, and in pointing the lamps properly so that there will be no eccentricity or phase. When effects of eccentricity and phase have been eliminated, it becomes a fairly simple matter to obtain satisfactory triangle closures, even with very short lines, except where there are unusual conditions of atmospheric disturbance. It sometimes happens that erratic triangle closures have been obtained over a period of several days or weeks, during which it was not possible to secure acceptable triangle closures. Fortunately, occasions when such conditions persist are quite rare.

In making recommendations for mapping programs in recent years, interested organizations have invariably recommended that the mapping of the country be based on first- and second-order control. With property values high in many parts of the United States, and with extensive public works and industrial projects being planned and constructed, it is obvious that the surveys and maps which are required should be based on control of such a high order of accuracy as to satisfy all future requirements. In large metropolitan regions, property values may be so high that the minimum requirements of first-order work are not satisfactory, and control surveys of much greater accuracy are required. These can be secured by measuring several base lines within the area under survey and taking unusual pains to eliminate or reduce errors in every part of the work.

Surveys for all such projects as those named above should be tied into the main triangulation net of the country and fully adjusted thereto so that the coordinates of all control stations, national and local, will be harmonious on a single datum. Unless this is done, great confusion may arise at future times through the use, by engineering and mapping organizations, of stations which are not fully coordinated to control important surveys and maps.

In the extension of the triangulation and level nets of the country, there are many points which must be carefully considered throughout all phases of the work. Some of these points are as follows:

1. Triangulation stations and bench marks should be placed as near public roads and highways as is practicable so that they will be readily accessible to engineers and surveyors wishing to make use of them.

2. They should be placed in locations where they will not be in the way of public or private construction projects, and where they are not liable to be disturbed.

3. At all triangulation stations there shall be two reference marks so placed as to aid in the recovery of the station, and if necessary, its reestablishment, and one azimuth mark to furnish an accurate azimuth for local surveys.

4. The azimuth mark shall be at least one-quarter mile distant from the station and so placed that it may be observed on from the station, using an instrument mounted only on its own tripod. In other words, no building of scaffolding or signals shall be required for the local engineer to obtain a satisfactory azimuth at any triangulation station.

5. In the vicinity of towns and cities, stations should be so placed as to serve as control points from which to extend local control surveys over the district. In the larger cities, two or more stations should be established within the boundaries of the city for control purposes.

6. In the extension of control surveys, connection should be made with all work of acceptable accuracy executed by Federal, State, or other organizations, thus providing a means of bringing the whole into full coordination with the national net.

7. Since the preservation of triangulation monuments and bench marks in extensive national control nets can be secured only with the cooperation of engineers and other interested citizens, the Coast and Geodetic Survey solicits the cooperation of all persons, who have occasion to visit such stations, to make reports to the Washington office on the conditions of the marks and to furnish such information as may be needed for maintaining up-to-date descriptions.

The Bilby steel towers have now been in use by the Coast and Geodetic Survey for about 12 years, and have proved very efficient and economical in the extension of control work, especially in the eastern half of the United States. However, it is only in mountainous regions that they are not required at all. Some of the towers have been used more than 100 times, that is, the same tower has been set up and used at more than 100 different stations. Wherever practicable, towers not more than 90 feet high are used. Such a tower weighs approximately 6,000 pounds and can be hauled with a single 3½-ton semitrailer truck. Additional height of tower can be obtained with 10-foot vertical extensions. As many as three such extensions have been added to one tower. Where more than one such extension is used, guys of wire cable are required to prevent excessive vibration from the wind. Where steel towers are used, it is of course necessary that station sites be selected which can be reached by trucks.

Observations along main-scheme lines are nearly all made at night. For daytime observations, heliotropes are used except on very short lines where targets are satisfactory. During very overcast weather electric signal lamps are used in the daytime on lines of about 10 miles or less in length. Stations are occupied in the afternoon prior to the night work in order to make observations on prominent natural or artificial objects which may be used as supplemental control. Such objects may be cupolas, water towers and tanks, church spires, flagstaffs, chimneys, windmills, rock pinnacles, and various other features characteristic of the region.

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LEVELING

The specifications for first-order leveling require that the lines shall be run in both forward and backward directions under conditions of refraction, direction of the sun, etc., which tend to balance out errors arising from these causes, and with the further requirement that the lack of agreement between such runnings shall not exceed 4 mm. $\sqrt{K}$, where K is the length of the section in kilometers. Second-order level lines are run with the same care as are the first-order lines, but only one running of a section is made. As originally adopted and still being followed, the program for the fundamental leveling of the country requires the placing of first-order lines at distances not greater than 100 miles apart. Second-order leveling is used to divide the first-order loops into much smaller meshes.

As with horizontal control, it has been necessary from time to time to modify the instructions relating to the distribution of bench marks. Such modifications are brought about by conditions which develop as the work progresses, or are the result of demands for elevations for mapping, engineering, and general-utility purposes. Instructions for field work at present call for bench marks placed at an average distance of 1 mile along the lines of leveling. In some regions, topographic and other conditions make it impracticable to place the marks this close together, but in metropolitan areas this distribution is compensated by a much closer spacing of marks.

There is a steadily increasing demand for accurately determined elevations in all sections of the country, coming from many sources. Reliable elevations of monumented points are required for many purposes: They are indispensable for mapping, and for the planning, construction, and maintenance of general engineering projects for irrigation, reclamation, flood control, drainage, water power, and other public- and private-works undertakings. They are also essential in various scientific studies, such as the displacement of terrain caused by earthquakes, settlement of areas resulting from water seepage or drainage, or other causes.

During the past few years, through cooperation with the advisory committee in seismology of the Carnegie Institution of Washington, lines of leveling have been run across a series of fault lines in southern California. The monuments along these lines are closely spaced, so that at any future time, by rerunning the lines, it may be possible to determine the amount of movement that has occurred in the elapsed interval. Since 1930, the Coast and Geodetic Survey has cooperated with officials of the State of California, in rerunning at seven different times, 275 miles of levels in the Santa Clara Valley for the purpose of studying earth movements. Settlement as great as 5 feet was noted in one place, though in very recent years all settlement has appeared greatly retarded, and the latest rerunning indicated a slight rise since the next previous work was done. These latest results are only preliminary and subject to some change when final adjustments are made.

Lines of leveling were rerun in the vicinity of Helena, Mont., following the earthquake in that region, as a means of detecting any earth movements resulting therefrom. New lines of leveling were extended in the same region so that, when and if desirable, these lines could also be rerun in order to detect any changes that might occur.

It may be noticed that neither the triangulation nor the level net shows a regular pattern. In the western part of the country, where cultural development naturally follows the rectangular pattern of the public-land surveys, the arcs of triangulation and main level lines have a general east-west and north-south trend, and the meshes of the nets have a somewhat rectangular form. In the eastern part of the country, where land lines are irregular, and wherever the arcs of triangulation and lines of leveling, for convenience of transportation, and for economic, and other reasons, followed railroads, rivers, and older highways, the pattern of the meshes is much more irregular.

PLANE-COORDINATE SYSTEMS

The plane-coordinate systems established by the Bureau for all of the States and described in Geodetic Operations in the United States, 1933–35, have already proved of much practical benefit in many parts of the country. The States of New Jersey, Pennsylvania, New York, North Carolina, and Maryland have adopted their State systems by legislative acts, and other States are working toward the same objective. The Federal Board of Surveys and Maps has recommended the use of the State-coordinate systems by its member organizations. Some years ago the Tennessee Valley Authority substituted the use of State plane-coordinate systems for the local projections which they had previously been using in surveying and mapping work. At the present time, not only are the State projections shown on the maps produced by this organization, but descriptions of lands involved in its engineering undertakings contain the plane coordinates of the land corners. So extensive is this work, that the plane-coordinate systems of seven States are thus used. The use of the State plane-coordinate systems for small surveys, and especially for cadastral surveys, has been urged by surveyors and engineers in a number of States, and a joint committee of the American Society of Civil Engineers and the American Bar Association has issued a preliminary report favoring the use of these coordinate systems in describing property corners and recommending State legislation to that effect.

Large demands are being made on the Bureau for plane-coordinate data for the control stations which it has established throughout the country. These demands come from other Federal bureaus, State agencies, and engineers of large private organizations engaged in extensive surveys such as are required in geophysical exploratory work and oil-field developments. Plane coordinates of the triangulation stations established by the Bureau are being computed as rapidly as is practicable with the resources of personnel and equipment now available. Triangulation publications now issued by the Bureau contain both the geographic position and the plane coordinates of each station reported on. Some six State publications containing both geographic and plane-coordinate positions have appeared so far.

INSTRUMENTS AND APPARATUS

The utmost efficiency and economy in the conduct of field work can be obtained only through the use of superior instruments. Our personnel are constantly on the alert to suggest improvements in design and technique in order to obtain instruments of high order of accuracy which are adaptable for use under the various climatic and other conditions encountered during field work in any climate.

The Parkhurst first- and second-order theodolites (9-inch and 6½-inch circles) were developed in the instrument shop of the Bureau, and embody the most desirable features from a number of instruments previously adopted as best suited for use on the basic control survey of the country. A theodolite testing room in the basement of the Department of Commerce Building has been in use for about 6 years. Located well inside the exterior walls of the building, temperature effects in this room are very small. It has proven of inestimable value in testing out newly graduated theodolite circles, and in examining circles sent in from the field which have shown indications of being faulty, possibly warped, or otherwise distorted. The equipment in this testing room consists of a rigid metal instrument stand insulated from the foundations of the building, and five collimators permanently mounted on the foundations. With one set of observations using 16 positions of the circle it is possible to detect systematic errors of even comparatively small size in the circle graduations.

Through the courtesy of the Bell Telephone Laboratories of New York City and of Dr. Richard M. Field, chairman of the committee on geophysical and geological study of oceanic basins, American Geophysical Union, the Coast and Geodetic Survey was loaned a crystal chronometer for use in making gravity observations on both land and sea during 1936 and 1937. This chronometer is so accurate that, from a practical standpoint, it may be said to furnish absolute time measurements for gravity observations. In previous years, there has been some question regarding the accuracy of the chronometer corrections used in the gravity computations. With this source of error practically eliminated by means of the crystal chronometer, it has been possible to analyze other classes of error, to know their magnitudes, and consider their control. In particular, much progress has been made in determining more accurate corrections for arc, temperature, and pressure.

During the past year the Brown gravity apparatus has been redesigned to obtain thermostatic control of temperature through the use of storage batteries and electric coils. One set of the apparatus has been rebuilt according to this new design, and it is planned to equip all other sets with similar thermostats.

With the increased accuracy made possible by the instrumental changes described above, it is expected that gravity values of a very high degree of reliability will be obtained in any region to which the Brown apparatus can be transported.

OTHER ORGANIZATIONS INTERESTED IN MAPPING

There exists a close and cordial relationship among the many Federal, State, and private organizations that are working toward common objectives; the establishment of standard surveying and mapping procedure, the extension of control surveys, and the completion of the base topographic map of the country.

CORPS OF ENGINEERS, UNITED STATES ARMY

The Corps of Engineers extends control surveys for use in making maps needed in the improvement of rivers and harbors, in dredging operations, for flood-control projects, and in the training of certain troops. A statement of the work accomplished by the Corps of Engineers during the years 1936–38 is given later (p. 16) in this report. That statement includes work done by the United States Lake Survey and by the Mississippi River Commission.

UNITED STATES GEOLOGICAL SURVEY

The United States Geological Survey also engages in control work of such accuracy as is required to meet its own special requirements. Such control work is of a local character and extends and supplements the basic control net executed by the Coast and Geodetic Survey. A statement by the Director of the Geological Survey appears on page 19 of this report.

GENERAL LAND OFFICE

The major purpose to be served by the surveys made by the General Land Office do not require that precise geographic positions of corner monuments be known. Accordingly, only a relatively small number of such monuments have been connected to the triangulation systems of the United States Coast and Geodetic Survey and the United States Geological Survey. These positions are useful in connection with the compilation of State maps and of the large wall map of the United States, which are based upon the public-land survey under the rectangular ssystem.

In recent years, when practicable, the General Land Office has assigned survey parties to cooperative work with the Coast and Geodetic Survey. These parties identified public-land survey corners, re-marked them with permanent monuments, and constructed witness corners and accessories for their future identification. The monuments were tied in to the national triangulation net, and their geographic positions were used in platting the points on the maps published by the General Land Office.

In Alaska, the engineers of the General Land Office have used geodetic azimuths determined by the Coast and Geodetic Survey to provide azimuths of lines in the survey of small areas where weather conditions prevented normal procedure. In Alaska, reference is also made to the triangulation stations of this Bureau to determine the calculated position of the initial point to control lines of the rectangular system of public-land surveys in areas far removed from the governing meridian and base line to which such rectangular surveys are referred.

SOIL CONSERVATION SERVICE

The Soil Conservation Service reports that very effective use has been made of the triangulation stations established by the Coast and Geodetic Survey, the ground control for more than 25,000 square miles of areas mapped by them in the past 3 years having been based upon such stations.

The ground control used in such surveys is created through the extension of radial triangulation. The amount of such control which must be executed by the Soil Conservation Service and the efficiency of their radial triangulation is, of course, dependent upon the accuracy and density of the ground control which is available from other Bureaus. In an effort to reduce the amount of their own ground work, and also avoid the use of control which may not measure up to the standards obtained by the Coast and Geodetic Survey, the Soil Conservation Service has made use of the nine-lens camera of the Coast and Geodetic Survey, thereby bridging the gaps between existing control stations of the national triangulation net with a reasonably small number of aerial photographs. It is anticipated that this will effect a material saving in the cost of their own control work and allow the use of the Coast and Geodetic Survey control exclusively for the larger areas.

FEDERAL BOARD OF SURVEYS AND MAPS

The Federal Board of Surveys and Maps was established by Executive order in 1919, for the purpose of coordinating the activities of bureaus and independent organizations of the Federal Government engaged in surveying and mapping, thereby avoiding duplication of effort among such organizations, and also for making their products of greatest value and usefulness to the map-using public.

As constituted on January 1, 1939, the Board consisted of representatives of 25 Federal organizations, and of an advisory council comprising representatives of 22 map-publication and map-using establishments outside the Federal Government. The powers of the Board are advisory, not mandatory, but its determinations are closely adhered to by its member organizations.

The Board meets once every month from September to May, both inclusive, and functions through an executive committee and a number of standing committees. Special committees are set up for various purposes as needed. The most important actions taken by the Board have been directed toward the initiation of a national mapping plan, definite in its annual budget proposals but flexible in its time estimate, and recommending methods and standards to which the Board has previously given approval. An important report adopted during the period 1936–38 recommended the use by members of the Board of the State plane-coordinate systems established by the United States Coast and Geodetic Survey. Where feasible, these systems are to be shown on maps either as full-line graticules or, for supplementary projections, by means of marginal ticks.

The proceedings of the Board are distributed by means of mimeographed copies of its minutes and of its reports. On January 1, 1939, the officers of the Board were as follows: C. L. Garner, chairman; J. G. Staack, vice chairman; J. H. Wheat, secretary.

The Board maintains a map information office, in charge of its secretary, located in the Interior Department, Washington, D. C. Here a large file of maps is available for consultation purposes, and considerable additional map information is carried on cards. This office serves as a liaison agent for exchange of survey and map information among the various Federal organizations, and between the Federal Government and the general public.

SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

The National Research Council was organized in 1916 at the request of the President by the National Academy of Sciences under its congressional charter and with the cooperation of the national scientific and technical societies of the United States. The American Geophysical Union is a committee of the National Research Council, established with the object (in part) of promoting and coordinating the study of the various branches of geodesy and geophysics in the United States and its outlying territories. It is divided into seven sections, as follows: (*a*) Geodesy; (*b*) seismology; (*c*) meteorology; (*d*) terrestrial magnetism and electricity; (*e*) oceanography; (*f*) volcanology; and (*g*) hydrology.

The Union and its sections meet annually, in the spring, for administrative purposes and for the presentation and discussion of technical papers and reports in the fields of science covered by their activities.

During the years 1936–38 the Section of Geodesy heard progress reports on the geodetic surveys of the United States, of Canada, and of Mexico; also papers on the collection and interpretation of geodetic and geophysical data in the United States and nearby oceanic waters. Other papers described improvements in methods and instruments used in geodetic work.

These reports and papers are issued annually as publications of the National Research Council. In the beginning of the year 1939 the Section of Geodesy had a membership of over 200 and its officers were: C. H. Swick, president; R. M. Wilson, vice president; and W. D. Sutcliffe, secretary. The American Geophysical Union has a membership of about 1,100, and its officers are: R. M. Field, president; W. C. Lowdermilk, vice president; and J. A. Fleming, general secretary.

SURVEYING AND MAPPING DIVISION, AMERICAN SOCIETY OF CIVIL ENGINEERS

The division of surveying and mapping of the American Society of Civil Engineers has been active in promoting an interest in mapping, especially with reference to the extension of adequate control surveys over the United States, and the completion of the basic topographic map of the country. The division has sponsored the publication by the Society of the following manuals of engineering practice:

No. 10, Technical Procedure for City Surveys.

No. 15, Definitions of Surveying Terms.

A third manual entitled "Horizontal Control Surveys to Supplement the Fundamental Net" was prepared, but has not as yet been published.

Each year there are one or more meetings of the division, at which papers on surveying and mapping are presented and discussed.

The officers of the division are: William Bowie, chairman, and Henry G. Avers, secretary.

SPECIAL ARTICLES

GEODETIC OPERATIONS, CORPS OF ENGINEERS, UNITED STATES ARMY

By P. H. Timothy, *Captain, Corps of Engineers, Chief, Intelligence Section*

Relative to a report on geodetic operations in the United States for the 3-year period ending December 31, 1938, the following reports have been submitted by the United States Lake Survey, Detroit, Mich.; the president, Mississippi River Commission, Vicksburg, Miss.; and the commanding officer, Twenty-ninth Engineers, Portland, Oreg.

UNITED STATES LAKE SURVEY

A summary of the geodetic work accomplished by the Lake Survey in the 3-year period ending December 31, 1938, follows:

(*a*) In 1937, to determine the present differences in level between Lake Huron and Lake Erie, and between Lake Erie and Lake Ontario, lines of first-order levels were run between Lexington and Port Huron, and between Algonac and Detroit, all in Michigan, and between Buffalo and Olcott, N. Y.

(*b*) In connection with these level lines 50 new bench marks were established in Michigan and 48 in New York.

(*c*) Continuous graphic records of the water levels of the Great Lakes and the connecting and outflow rivers are being obtained at the following stations:

Marquette, Mich.	Harbor Beach, Mich.	Cleveland, Ohio.
Point Iroquois, Mich.	Port Huron, Mich. (three stations).	Buffalo, N. Y. (two stations).
Mackinaw, Mich.	Roberts Landing, Mich.	Niagara Falls, N. Y.
Milwaukee, Wis.	Detroit, Mich.	Oswego, N. Y.
Calumet Harbor, Ill.	Gibraltar, Mich.	Ogdensburg, N. Y.

MISSISSIPPI RIVER COMMISSION

A summary of the geodetic work accomplished by the Mississippi River Commission in the 3-year period ending December 31, 1938, is furnished by engineer districts as follows:

Memphis district

The survey work (third-order or higher) in which this district has been engaged during the 3 years ending December 31, 1938, is listed below:

Operations, 1936–38

	Triangulation	Traverse	Levels
	Miles	*Miles*	*Miles*
Basic control along Mississippi River between Cairo, Ill., and Rosedale, Miss.	30	260	285
Basic control along north bank of Arkansas River between Pine Bluff and Gillett, Ark.		50	65
Basic control on White River between Augusta, Ark., and mouth of river		185	215
Basic control for St. Francis River project (St. Francis, Little, and Tyronza Rivers)		610	660
Total	30	1,105	1,225

Vicksburg district

The geodetic work performed by the Vicksburg engineer district during the 3-year period consisted of basic control (precise levels, third-order levels, third-order triangulation and third-order traverse) in Mississippi, Louisiana, and Arkansas; Mississippi River third-order triangulation survey; Eudora floodway survey; Arkabutla Reservoir survey; Bayou Bodcau Reservoir survey; Sardis Reservoir survey; Sulphur River hydrographic survey; Mississippi River hydrographic survey; Little Missouri River hydrographic survey; Red River levee location; and Wallace Lake Reservoir survey. The number of permanent marks established by these surveys, together with the corresponding miles of third-order traverses, third-order levels, and precise levels, are shown in the following tabulation:

Operations, 1936–38

	Third-order triangulation	Bench marks established	Third-order traverse	Third-order levels	Precise levels
	Miles	*Number*	*Miles*	*Miles*	*Miles*
Basic Control in Arkansas, Louisiana, and Mississippi		67	341		214
Mississippi River third-order triangulation survey	225	70			
Eudora floodway survey		64	538	538	
Arkabutla Reservoir survey		42	220	100	
Bayou Bodcau Reservoir survey		20	130	75	
Sardis Reservoir survey		45	204	204	
Sulphur River hydrographic survey			25		
Mississippi River hydrographic survey			80	160	
Little Missouri River hydrographic survey			170		
Red River levee location			25		
Wallace Lake Reservoir survey		2	12	12	
Total	225	310	1,745	1,089	214

Second New Orleans district

The summary of geodetic work accomplished by this district during the 3-year period ending December 31, 1938, is as follows:

(*a*) First-order levels: First-order levels were run from Angola, La., to Fort Adams, Miss.; on east and west banks of Atchafalaya River from Krotz Springs, La., to the downstream ends of levees; Simmesport Bridge to Smithland, La., via Old River; Alabama Bayou to Grand River via Whiskey Bay Pilot Channel Dyke, and Raceland, La., to Morgan City, La., a total distance of 115 miles.

(*b*) Alluvial Valley quadrangle control: Approximately 200 square miles of third-order triangulation and about 60 miles of traverse were run in the Lorman quadrangle. Twenty-four permanent marks were established in connection with this work.

(*c*) Levee and hydrographic control: Approximately 96 miles of third-order control were run between Vicksburg, Miss., and Cerro Gordo Landing, Miss.; 275 new control points were established.

(1) Third-order traverse of 303 miles of levee and hydrographic control was run from Plaquemine, La., to the Head of the Passes, La. Permanent markers were set at all levee angles.

(2) Nineteen miles of third-order traverse and levels were run in the Homochitto Swamp.

(3) Five hundred and forty miles of third-order traverse were run in the Atchafalaya Basin, permanent markers being placed at all angles in completed levee.

(4) Two hundred and sixty-five miles of third-order levels were run along the Mississippi and Atchafalaya Rivers, 125 permanent marks being set.

(*d*) Automatic tide gages: The automatic tide gage at Biloxi was maintained during the 3-year period. In 1938, this gage was moved to a new location near the highway bridge. Automatic tide gages were also maintained at Morgan City, La., and in the upper and lower ends of Grand Lake, La.

In addition to the above, approximately 621 miles of first-order levels were run within the district by the United States Coast and Geodetic Survey, payment for this work being made by this office.

TWENTY-NINTH ENGINEERS

The following is a summary of geodetic work accomplished by the Twenty-ninth Engineers during the 3-year period ending December 31, 1938:

(*a*) Basic control executed in mapping the following quadrangles in Washington:

	Triangulation	Transit traverse	Levels	Monuments (stations)
	Miles	*Miles*	*Miles*	
Dungeness	36	190	270	60
Port Townsend				
Quilcene				
Point Misery				
Deception Pass				
Coupeville				
Port Gamble				
Port Orchard				
Potlatch		376	337	102
Allyn				
Gig Harbor				
Shelton				
Lake Nawatzel	87			
Mobray				
Montesano				
Willapa				
Ford				
Gate				
Walville				
Meskill				
Cape Shoalwater		59	16	4
South Bend				
Cape Disappointment				
Fort Columbia				
Brookfield				
Skamokawa				
Olequa	72	139	132	51
Kalama				
La Center				
Yacolt				
Lookout Mountain				
Fort Lewis	24	101	90	34
Moclips		18	3	7
Grayland				

(*b*) Basic control executed in mapping the following quadrangles in Oregon:

	Triangulation	Transit traverse	Levels	Monuments (stations)
	Miles	*Miles*	*Miles*	
Astoria		233	141	57
Svenson				
Cathlamet				
Cape Falcon				
Vernonia				
Clatskanie				
St. Helens				

(*c*) Basic control executed in mapping the following quadrangles in California:

	Triangulation	Transit traverse	Levels	Monuments (stations)
	Miles	*Miles*	*Miles*	
Point Reyes; Petaluma	14			
Carquinez	6	87	56	34
Half Moon Bay; Ano Nuevo Point; Boulder Creek; Palo Alto	24			
Total of (*a*), (*b*), and (*c*)	263	1,203	1,045	349

GEODETIC OPERATIONS OF THE UNITED STATES GEOLOGICAL SURVEY

By W. C. Mendenhall, *Director, United States Geological Survey*

The Geological Survey, a Bureau of the United States Department of the Interior, conducts geodetic surveys including spirit leveling, transit traverse, and triangulation. Although the fundamental purpose of this work is to establish control for the topographic mapping done by the Geological Survey, the results of these control surveys are used extensively by other organizations—Federal, State, and local—and by engineers and other individuals.

The greater part of the work is of third-order accuracy as defined by the Board of Surveys and Maps of the Federal Government, but first- and second-order levels are run when it becomes necessary to extend the work a considerable distance away from lines of the basic first-order net. In the execution of this work the Geological Survey establishes permanent marks which are available to define standard datum in any local engineering project for which third-order control is sufficiently accurate.

During the calendar years 1936, 1937, and 1938 the Geological Survey completed 29,319 miles of third-order spirit leveling, 709 miles of first-order leveling, and 23,693 miles of transit traverse and established 702 occupied third-order triangulation stations from which many more were located by intersection for the control of topographic mapping. These figures include the leveling done in connection with Works Progress Administration projects in Louisiana and Missouri under the supervision of and with equipment furnished by the Geological Survey.

Publication of results of control surveys was resumed in 1937, after a lapse of 12 years, with the release during the calendar year of Bulletins 881, Spirit Leveling in Connecticut; 882, Spirit Leveling in Massachusetts; and 883-A, Spirit Leveling in Texas, Part 1, Western Texas. Bulletins published in 1938 were 888, Spirit Leveling in Vermont; 889, Spirit Leveling in Kansas; and four parts of 898, Spirit Leveling in Missouri, namely: A, Southeastern; B, South-Central; C, East-Central; and D, Northwestern. The manuscript for Bulletin 898 is in the hands of the printer and when completed will consist of eight parts.

GEODETIC WORK OF THE INTERNATIONAL BOUNDARY COMMISSION, UNITED STATES, ALASKA, AND CANADA

By Thomas Riggs, *United States Commissioner*

During the 3-year period January 1, 1936, to December 31, 1938, the International Boundary Commission, United States, Alaska, and Canada, published the final report upon the reestablishment of the boundary between the United States and Canada along the forty-ninth parallel of north latitude from Georgia Strait to Lake of the Woods and thence to the northwesternmost point thereof. This report contains 2,238 geographic positions of triangulation stations and boundary monuments of which there are listed 475 first-order stations and supplementary points of the United States Coast and Geodetic Survey and the Geodetic Survey of Canada which were used to control the major and minor triangulation schemes of the International Boundary Commission. There are 1,372 major and minor boundary triangulation stations of which 572 are boundary monuments. There are 391 monuments located by primary traverses that are adjusted into the triangulation schemes. The report also contains accurate descriptions of 1,020 stations of all kinds. The total length of this section of the international boundary is 1,296.9 miles and it is marked by 963 monuments and markers.

The Commission has determined by geodetic surveys and marked by bronze tablets, the exact location of the international boundary line on 10 bridges between the United States and Canada; marked the boundary crossing of 31 international highways by concrete monuments; marked the boundary across Tarr Inlet, Glacier Bay, Alaska; and determined the geographic positions of 152 triangulation stations and boundary monuments by special surveys.

Special retracement surveys were made in 1938 along a part of the St. Lawrence River to recover triangulation stations that had been established in 1910 and marked by wooden hubs with nails for center marks. On this work, 71 station sites were inspected and, of these, 29 center marks were recovered and permanently marked. In most cases where the ground had not been disturbed the center marks were recovered.

ADJUSTMENT OF THE CONTROL TRIANGULATION

By Walter F. Reynolds, *Chief, Section of Triangulation, United States Coast and Geodetic Survey*

Despite the fact that the corps of mathematicians and computers engaged in the computation and adjustment of the triangulation of the United States and Alaska was greatly decreased in numbers, considerable progress was shown in the execution of this work during the period January 1, 1936, to December 31, 1938.

Since the adjustment on the North American datum of 1927 of the framework of all the control triangulation of the United States had been previously completed, the work during the period covered by this report consisted in adjusting those arcs of first- and second-order triangulation which have been executed to fill in the areas between arcs composing the framework.

It is not possible in a report of this character to specify individually all the arcs of triangulation which have been adjusted. A general idea of the large amount of work accomplished may be obtained from the fact that 215 arcs of first- and second-order triangulation extending over 39 States and southeast Alaska have been finally adjusted on the North American datum of 1927.

Important contributions to the control survey were the adjustments of field observations made in cooperation with State, county, and city engineers. Notable among these was the adjustment of the triangulation of Mercer County, Pa. The principal adjustment was much involved due to the fact that the survey was in the nature of area triangulation and covered the entire county, and all main scheme stations were included.

Another adjustment of importance was that of the triangulation of the metropolitan district of Baltimore County, Md., the field work for which was done by a private corporation under the direction of a field officer of the Coast and Geodetic Survey. The triangulation was executed as a control for the cadastral survey of this area.

An adjustment of the Hudson River triangulation, the lower part of which controls the Westchester County, N. Y., control survey was in progress. Upon the completion of this adjustment, Westchester County will be able to adjust all its local triangulation which controls the county cadastral survey.

The adjustment of the triangulation of King County, Wash., was in progress. This work is another instance of cooperation, the county paying the expense, and a Coast and Geodetic Survey officer supervising the field work. A large part of the adjustment has been completed.

The readjustment of that part of the Atlantic coast arc of triangulation which extends over the southern part of New York State and the northern part of New Jersey was completed. Additional bases, including one in New York City, were measured to control the lengths of the lines in the scheme. Laplace azimuths were also observed to control the directions. In the adjustment were included several inland arcs. The area covered by this triangulation is one of the most densely populated and richest in the country. The results of this adjustment not only furnish control for local surveys but connect those surveys to the Federal control survey.

Since the North American datum of 1927 was extended to southeast Alaska in 1928, all triangulation in that part of Alaska for which field observations have been made since 1907 has been adjusted on that datum. The plan has since been followed of adjusting all new field observations in this area as soon as they are completed.

With the completion of the adjustment of the triangulation of the Coast and Geodetic Survey and that of the Mississippi River Commission along the Mississippi River from Vicksburg, Miss., to New Orleans, La., all the triangulation along this river from the headwaters in Minnesota to the delta in Louisiana has been adjusted. This work has been done in cooperation with the Corps of Engineers, United States Army, which office has detailed mathematicians to the Coast and Geodetic Survey for the computations.

The results of the adjustments are being printed at the engineer reproduction plant of the Corps of Engineers and will appear in five volumes. The first volume, containing the results from Cairo, Ill., to Headwaters, Minn., appeared in 1934. The second and third volumes, containing results from Cairo, Ill., to Memphis, Tenn., and Memphis, Tenn., to Vicksburg, Miss., respectively, appeared in 1935. The fifth volume, containing the results from New Orleans to the delta, La., appeared in 1936. The fourth volume, which will be published in two parts and which will contain the results from Vicksburg, Miss., to New Orleans, La., will appear in 1939.

The computation and adjustment of the first-order traverse, Tamiami Trail, Fla., and the second-order traverse, Huntington Beach, Calif., and the readjustment, on the North American datum of 1927, of the first-order traverse, Savannah, Ga., to Norfolk, Va., were completed.

Several schemes of triangulation have been executed in various States in conjunction with the Soil Conservation Service. Practically all this triangulation has been adjusted to the North American datum of 1927.

Advice was given to the officials of the city of Minneapolis, Minn., regarding the least-squares adjustment of the control survey of that city and a review of the computations was made after the formation of condition equations.

The computations and adjustments of triangulation have been materially advanced by cooperation with the geodetic surveys of several States, particularly Massachusetts, Connecticut, Georgia, Florida, and Oklahoma. In all these States, with the exception of Massachusetts, a Coast and Geodetic Survey official has been assigned to the work in the role of technical adviser. In most cases excellent results have been obtained.

The practice, started in 1934, of computing the plane coordinates of all adjusted triangulation stations has progressed as far as possible with the much depleted force of mathematicians. In 1927, at the time of the adoption of the North American datum of 1927, the geographic positions of all triangulation stations in the United States except Meades Ranch, the initial of the new datum, were superseded. The readjustment of all the previously adjusted triangulation and the adjustment of other triangulation for which the field observations were completed were then started. At the end of December 1938, the geographic positions of 65,000 stations had been computed on the new datum and the plane coordinates of 28,000 of these stations had been derived.

In 1935 the plan was adopted of including in the publications containing the final results of the adjustment of triangulation, both the geodetic positions and the plane coordinates of the triangulation stations. The first publication to contain both sets of coordinates was the one containing the final results of first- and second-order triangulation in the State of Tennessee. During the period covered by this report, publications containing the final results of triangulation in the States of California, Minnesota, Utah, and Wyoming were issued containing both sets of coordinates.

The computing office sponsored by the Works Progress Administration, which was opened in New York City in December 1936 was still in operation at the close of December 1938. To this office are sent most of the computations for which little experience is necessary. The number of employees in this office engaged in triangulation computations varied from 10 to 40.

Numerous requests have been received from the National Aeronautic Association for the computation of lengths of courses over which planes fly, these distances being used for speed trial courses and commercial purposes. In areas covered by triangulation it is possible to use positions of marked triangulation stations to determine the distances; otherwises, it is necessary to use positions scaled from maps.

The expanded program of field work during recent years has caused an increased demand from engineers and corporations engaged in survey work for the geographic positions and plane coordinates of the triangulation stations. It is necessary to assign a large proportion of those usually engaged on triangulation computations to prepare data to meet this demand, which in turn causes a decrease in the force engaged in the actual computations. However, the continuance of the plan started in 1933 of furnishing photolithographic prints of the geographic positions and plane coordinates has helped meet the demand for final results.

MAP PROJECTIONS

By O. S. ADAMS, *senior mathematician, United States Coast and Geodetic Survey*

In the solution of a special problem in map projection which was presented to the Bureau, elliptic functions were applied to the development of formulas that map the world within a square. A table for the construction of such a map was computed and an outline map was constructed by use of the table. The illustration given in figure 3 shows the result of mapping the world on such a projection with the meridian of 10° west longitude as the central meridian of the map. (See Bull. Géodésique No. 52, p. 461.)

A table for the construction of a map of the State of Texas on the Lambert conformal conic projection with two standard parallels was computed by the United States Coast and Geodetic Survey for a general map of the State.

PLANE COORDINATES

In the last report an account was given of the establishment of plane coordinate systems in all of the 48 States of the Union. During the past 3 years, the work of the computation of the plane coordinates on the grids in the various States has been in progress. At the present time this work is practically completed in 23 of the States and in the other 25 States the work is about one-half completed. Publications of the triangulation in 5 States with the plane coordinates of the stations included have been issued by the United States Coast and Geodetic Survey.

In five States legislation has been adopted approving the use of the State coordinate systems for land surveys, while advances towards similar legislation is being made in several other States. As stated on page 12, the use of the State plane-coordinate systems is growing rapidly, not only in defining land boundaries, but also in surveying and mapping operations required in many engineering projects. To engineers and surveyors who understand and appreciate the usefulness of geodetic control for giving permanency and accuracy to detail surveys, the State systems furnish a means of utilizing the data provided by the national triangulation survey without requiring a personnel trained in geodetic processes.

CONTROL SURVEY ACTIVITIES OF THE WORKS PROGRESS ADMINISTRATION

By H. W. HEMPLE, *Assistant Chief, Division of Geodesy, United States Coast and Geodetic Survey*

This report supplements the information given on page 18 of Geodetic Operations of the United States, 1933–35, submitted to the last meeting of the International Geodetic Association.

As a measure for the relief of unemployment among engineers during the current recession, the Works Progress Administration has continued in 15 States the control survey projects which were initiated by the Coast and Geodetic Survey in November 1933 as a part of the Civil Works Administration program.

These projects are sponsored by local organizations in each State. Each sponsor contributes a certain percentage of the costs of operation, which are usually apportioned to the expenses of supervision and purchases of material. Wages of personnel selected from relief rolls are paid from the appropriations available to the Works Progress Administration.

The work accomplished under this program consists principally of traverse surveys of an order of accuracy of 1 part in 10,000, and leveling over the same marks for which the accuracy obtained is $0.05\ \text{foot}\sqrt{\text{distance in miles}}$. The traverses begin and end on triangulation stations

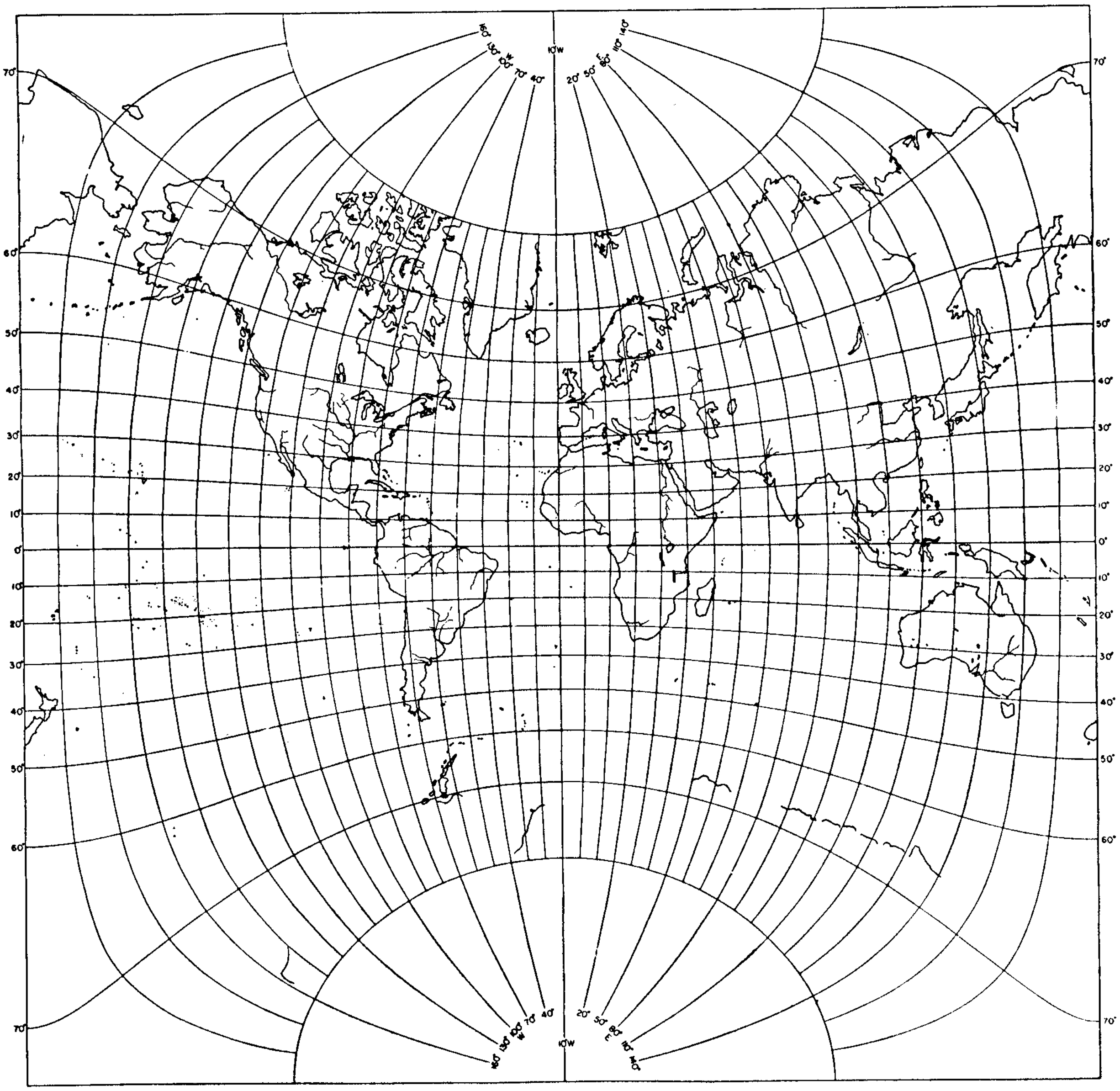

FIGURE 3.—Conformal map of the world in a square.

and are computed on the respective State plane-coordinate systems. The accuracy prescribed is obtained without difficulty, using the types of instruments ordinarily available for surveying operations in the United States.

Triangulation surveys have not generally been conducted under this program because of the expensive equipment needed to conduct such surveys. Triangulation has been carried on in only three States, where it has been possible because of the cooperation extended by the Coast and Geodetic Survey in loaning theodolites, portable steel towers, and furnishing supervision.

The data obtained on these surveys, if of the required standards, are included in the national net of control. Publications giving positions and elevations, together with descriptions of stations, have been issued in several of the States and it is hoped that, for the other States where work of this nature is being conducted, provision will also be made for the publication of the resulting data.

Under the unemployment relief program the Coast and Geodetic Survey has also sponsored and supervised a computing office in New York City and one in Philadelphia, Pa. Most of the employees in these two offices are selected from the relief rolls and are paid relief wages. In New York City the work being done consists of adjustment of triangulation and leveling. It has been possible to do this computation work with relief labor only because of the detailed supervision extended by permanent personnel from the Coast and Geodetic Survey who have been transferred to duty in this office. In Philadelphia the work done is of a nature intended to place our data in such shape as to be more readily available for distribution.

The Works Progress Administration is also conducting local control survey projects in a number of cities throughout the country. The data obtained on these surveys will be used for control of maps for planning purposes, for property-assessment purposes, and for indicating the locations of the various public utilities throughout the cities. Work of this nature, as conducted in the cities, is usually placed on the State plane-coordinate system and is therefore a part of the national net of control surveys.

THE UNITED STATES NAVAL OBSERVATORY, TIME SERVICE AND VARIATION OF LATITUDE WORK

By PAUL SOLLENBERGER, *principal astronomer, United States Naval Observatory*

[Communicated by the Superintendent, United States Naval Observatory]

During the past 3 years the photographic zenith tube at the Naval Observatory has continued in use for the determination both of time and of the variation of latitude. That instrument has now been used for time determinations for 4 years and has been found to be considerably more accurate for that purpose than the meridian transit instrument which was used previously. The zenith tube is only capable of observing objects which are very near to the zenith. The light from the star passes through the lens, and is reflected from a mercury surface which is placed about 8½ feet below the lens. Since the focal length of the lens is about twice that distance, the light comes to a focus just under the lens. A photographic plate is placed in the focal plane. The lens is so designed that its optical center lies below it, in the plane of the plate. In consequence of this fact, the lens and plate may be tilted together through a small angle without appreciably displacing the image of the star on the plate. The flexure of the telescope tube therefore has no effect on the accuracy of the observations. The level error is eliminated by the reflection from the mercury surface, and the collimation error is eliminated by rotating the lens and plate holder together through an angle of 180° about a vertical axis. Four exposures are taken on each star, the first and third in one position of the lens and plate and the second and fourth in the rotated position. During all the exposures, the plate holder is driven along a track at such a speed as to compensate for the apparent motion of the star due to the rotation of the earth. The track is rigidly attached to the lens cell, and the drive is by means of a synchronous motor, controlled by an oscillating quartz crystal. During all four exposures the plate carriage moves over the same portion of the track, and electric signals are automatically produced as the carriage passes certain points. By measurement of the four images produced by each star, the scale value and orientation of the plate may be determined, as well as the zenith distance in declination and time of meridian passage of the star.

During the past 3 years the instrument has been improved in several ways. These include an automatic device for rotating the lens and plate holder during exposures. Previously, that operation had been performed by hand and was attended by some danger of jarring the plate in its holder. Also, a new chronograph circuit has been developed. The need for this circuit arose from the fact that the direction of the motion of the plate holder with respect to the track is reversed when the lens and track are rotated. The direction of motion with respect to the sky remains the same. The point at which the chronograph control circuit is closed when the carriage is moving in one direction is the same as the point at which it is opened when the movement is in the opposite direction. The new circuit makes it possible to measure on the same basis the times of opening and of closing of the circuit.

The necessity of observing stars which culminate very near the zenith restricts the choice of stars. While this is in some respects inconvenient, it is an advantage in that a series of comparative observations of the same stars are obtained every year, with high precision. The study of these results furnishes an opportunity for study of astronomical constants. Such a study, entitled "Lunar Effects on Clock Corrections," by Paul Sollenberger and G. M. Clemence, will appear shortly in the Astronomical Journal.[1]

On March 31, 1938, the hours at which time signals are sent out were increased from 20 to 24 daily. Naval Observatory time signals are therefore now available on some frequency every hour of the day. Effective June 1, 1939, it is expected that the low-frequency Annapolis transmitter (17.8 kc.) will be put back into service on 1 hour daily. This frequency is preferred for reception in Europe, and its restoration has been much desired by persons interested in the study of trans-Atlantic radio time transmission.

The complete schedule of time transmissions via Arlington, Annapolis, and Mare Island, effective July 1, 1939, is given below. The hours are in Greenwich time and designate the times of the final signals of the 5-minute series. Under the call letters of each station are listed the frequencies, in kilocycles, used in transmitting time via those stations. In addition to the stations listed below, second-order time signals are sent out from station NPM, Pearl Harbor, T. H., at 3, 16, and 20 hours daily, and from station NBA, Balboa, C. Z., at 5 and 17 hours daily.

Frequencies of radio time signals

Hour	NSS	NAA	NAA	NAA	NAA	NAA	NPG
0			113	9425			42.8
1			113				
2				*9425			
3		64	113	9250	4390		(2)
4				*9425			
5			113	9425			
6			113	9425			
7			113	9425			
8			113	9425			42.8
9			113	9425			
10			113				
11			113				
12			113				
13			113	9425			
14			113	*9425			
15		64	113	9250	4390	(1)	(2)
16				*9425			
17	17.8		113	9425			42.8
18			113				
19			113	9425			
20			113				(3)
21			113	9425			
22			113				
23			113	9425			

NSS—Naval radio station, Annapolis, Md.
NAA—Naval radio station, Arlington, Va.
NPG—Naval radio station, Mare Island, Calif.
*May be sent via NSS instead of NAA.
[1] 12630 and 17370 kc.
[2] 42.8, 113, 9090, and 12540 kc.
[3] 113 and 42.8 kc.

Volume XIV of the publications of the Naval Observatory has been printed and will be ready for distribution soon. Among other things the volume contains a report of the world longitude determination work which was done at San Diego and Washington in 1933.

[1] Under the title "Variation of Latitude Observations at the U. S. Naval Observatory, ——," Mr. Sollenberger each year has reported the results of studies made with the photographic zenith tube. These have been published in the Astronomical Journal, as follows: Vol. 45, July 7, 1936, No. 1048; vol. 46, August 4, 1937, No. 1068; and vol. 47, July 13, 1938, No. 1087. Publication of results for 1938 may be expected soon.

GRAVITY AND GEODETIC ASTRONOMY

By C. H. Swick, *Chief, Section of Gravity and Astronomy, United States Coast and Geodetic Survey*

GRAVITY SURVEYS AND REDUCTIONS

The use of the Brown gravity apparatus has been continued by the Coast and Geodetic Survey during the 3 years covered by this report. The principal change in method has been to make independent determinations with two sets of apparatus instead of one at each station, to insure the integrity of the results. This has tended to increase the cost of the work slightly and to slow down the progress to a small extent, but the advantages of an adequate check on each station more than offset these disadvantages.

The total number of new stations in the 3 years is 313. In addition, about 30 old stations have been reoccupied, some of them because of known or suspected inaccuracies in the original determinations and some because of the desirability of connections between the old and new work in various areas. Isostatic reductions by the Hayford-Bowie method have been made for all of the new stations and have been revised for a large number of the older stations. Recent developments of improved computational methods, such as the Bullard modification of the Hayford-Bowie method, and the availability of better detailed maps have made these recomputations necessary or desirable.

The results of the field determinations and of the office processing, including the isostatic reductions, have been issued from time to time in the form of photolithographed tables. Copies of these may be obtained by application to the Director, Coast and Geodetic Survey, Washington, D. C. Copies of various computational tables and other aids are also available. The present distribution of gravity stations in the United States is shown in figure 4.

Besides the gravity work on land, a very important gravity-at-sea expedition to the West Indies was carried out during the winter of 1936–37 by the cooperation of the United States Navy, the American Geophysical Union, and other interested organizations. An observer of the Coast and Geodetic Survey assisted in making the gravity observations, which consisted of 60 determinations in the Carribean Sea and Atlantic Ocean near the Lesser Antilles and in various ports. The isostatic reductions for these stations and also for seven sea stations in the same region, which were determined by Dr. F. A. Vening Meinesz in 1938, were computed by the Coast and Geodetic Survey. Discussions of various aspects of the American expedition will be found in Transactions of the American Geophysical Union for 1937. The final report of the expedition has not as yet been published.

A very important innovation on this expedition was the use of a new type of crystal chronometer developed by the Bell Telephone Laboratories of New York. This chronometer gave such precise time control that it could have been used for the entire expedition without check against radio time signals and still without causing any appreciable inaccuracies in the gravity results due to the timepiece.

At the conclusion of the expedition, arrangements were made through the American Geophysical Union for the loan of the crystal chronometer to the Coast and Geodetic Survey. It was first used in testing the Meinesz gravity apparatus as a land instrument and was later used for deriving more precise constants for the Brown gravity apparatus. It not only gave greatly increased accuracy in deriving the constants, but made it possible to complete the work in a fraction of the time that would have otherwise been required. It is hoped that it will soon be possible to use a crystal chronometer of this type for routine field gravity work.

ASTRONOMICAL OBSERVATIONS AND COMPUTATIONS

The main purpose of the astronomical work of the Coast and Geodetic Survey is to provide the necessary Laplace-azimuth control for the adjustment of the triangulation of the country. It is anticipated that the results will be used also in further investigations of the figure of the earth and isostasy whenever the necessary time can be devoted to this scientific research. For this reason it has been the practice to make latitude as well as longitude and azimuth determinations at nearly all of the Laplace stations.

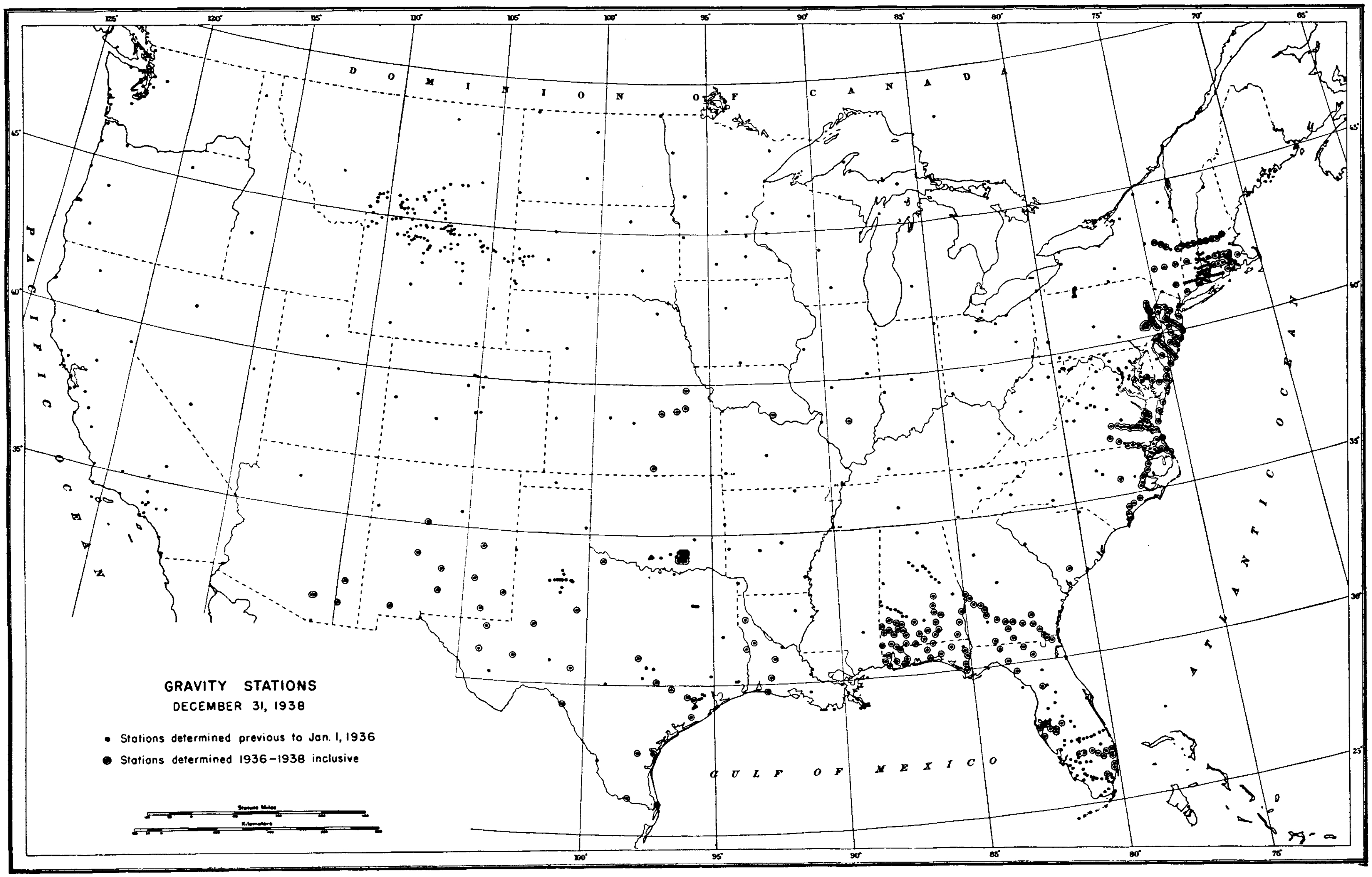

FIGURE 4.—Gravity stations in the United States.

The triangulation net of the country had been so far advanced by the end of 1935 that the new arcs observed during the interval covered by this report have required only a small number of Laplace stations to provide the needed rigidity in azimuth. The drastic curtailment of geodetic appropriations has also limited the work accomplished. During the 3 years, 27 longitudes, 26 azimuths, and 8 latitudes have been observed. The office processing of these observations and of 25 longitudes, 26 azimuths, and 62 latitudes which were in arrears at the end of 1935 has been completed. In addition the deflections of the vertical referred to the North American datum of 1927 have been derived for all stations not previously computed on the new datum, for which geodetic values are available. The Laplace stations which have been employed so far in the new adjustment of the triangulation net of the country are shown in figure 1.

In 1937 and 1938 cooperation was extended to two Central American countries, Guatemala and El Salvador, in providing Laplace control for the survey of the boundary between the two countries and for control of the interior triangulation in each. Precise measurements of the astronomical latitude, longitude, and azimuth were made at each of five stations. The observer and instrumental equipment were furnished by the Coast and Geodetic Survey for this work.

The two international latitude-variation observatories which are maintained by international agreement by the Coast and Geodetic Survey have been kept in continuous operation. The records obtained at these stations have been forwarded directly to Prof. L. Carnera, Director of the Royal Observatory of Capodimonte, Naples, Italy, who is in charge of the Central Office of the International Latitude Service.

SEA-LEVEL DATUM

By Paul Schureman, *senior mathematician, United States Coast and Geodetic Survey*

The sea-level datum to which the level net of this country is referred has been commonly called "mean sea level" since in its establishment the purpose has been to secure as close an approximation as possible to the mean level of the sea. The surface of the sea is ever in motion, the most obvious disturbances being due to tides, winds, and barometric changes. Numerous other causes, however, may also affect the level of the sea, such as temperature changes, rainfall, evaporation, melting of polar ice caps, submarine springs, absorption of water by earth, deposit of sediment carried into the sea by rivers, deflections arising from oceanic circulation, and changes in the position of the earth's axis. The relative elevation of land and sea may also be materially changed by crustal movements in the earth, which may be either slow or violent as in the case of an earthquake.

Although mean sea level is frequently defined as the surface the sea would assume if all disturbing factors were eliminated, it is practically impossible to attain a perfect elimination of all these factors, so we must be satisfied with a close approximation. Tide observations carried on continuously for a great many years at a number of tide stations along both coasts of the United States show annual variations in sea level amounting to several tenths of a foot, and even when a number of years are grouped together the means obtained for different groups may differ by several hundredths of a foot. Although it is desirable that the sea-level datum should be in approximate agreement with the theoretical true mean sea level, it is of much more importance from the standpoint of the engineer that the datum should remain fixed and not be subject to frequent changes in order to attain closer and closer approximations to a theoretical conception.

In past years there have been several adjustments of the level net to a sea-level datum. The latest, known as the "1929 General Adjustment," was based upon available sea-level determinations at more than a score of tide stations along the coasts of the United States and Canada, and the datum to which this adjustment is referred is officially known as the "sea-level datum of 1929," the year referring to the date of the adjustment and not to the time of the tide observations which covered various years at different tide stations. Excepting any appreciable change which may occur in the elevation of individual bench marks, it is now proposed to hold this adjustment regardless of small differences which may develop between the datum and theoretical mean sea level.

As a matter of interest there are given below the differences between the adopted datum and the mean sea level as determined from all the observations up to and including the year 1938 at a number of our primary tide stations. For stations along the Atlantic coast, reductions have been made by comparison with the sea level at the New York tide station, where observations are available for 46 years; and for stations on the Pacific coast, reductions have been made by comparison with the San Francisco tide stations, where observations are available for 41 years.

Elevation of mean sea level above sea-level datum of 1929

Location	Number of years	Years	Foot	Location	Number of years	Years	Foot
Portland, Maine	27	1912–38	−0.06	Norfolk, Va.	11	1928–38	+0.03
Boston, Mass.	17	1922–38	−0.04	Pensacola, Fla.	15	1924–38	0.00
New York, N. Y.	46	1893–1938	+0.11	Galveston, Tex.	30	1909–38	−0.05
Atlantic City, N. J.	25	1912–20; 1923–38	+0.05	Los Angeles, Calif.	15	1924–38	−0.06
				San Francisco, Calif.	41	1898–1938	−0.02
Baltimore, Md.	36	1903–38	+0.03	Seattle, Wash.	40	1899–1938	0.00
Annapolis, Md.	10	1929–38	+0.02				

The plus sign signifies that the mean sea level is above the datum and a minus sign that it is below the datum.

The sea-level datum held in the 1929 General Adjustment for the vicinity of New York was originally derived from 6 years of tide observations at Sandy Hook, N. J., covering the years 1876–81, inclusive, and since that time has been used as a standard reference plane for the area around New York. It is often called the "Sandy Hook datum" and it was used as the reference plane for the comprehensive system of levels covering the several boroughs of Greater New York, which were run in 1909–12 under the direction of Frederick W. Koop, of the board of estimate and apportionment. It differs by 0.11 foot from the mean sea level as determined from 46 years of observations in New York Harbor. Differences for all the other stations listed above are somewhat less.

As additional years of tide observations become available for these stations, it is reasonable to expect small changes in the above differences, but whether they become greater or less is somewhat a matter of conjecture as there are many factors involved. In either case there are sound reasons for maintaining the present sea-level datum unchanged.

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