GEODETIC OPERATIONS IN THE UNITED STATES AND IN OTHER AREAS THROUGH INTERNATIONAL COOPERATION

1954–1956

Publication 60–1

CHARLES PIERCE

U. S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

UNITED STATES DEPARTMENT OF COMMERCE
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January 1, 1954, to December 31, 1956

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

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FOREWORD

This publication has been prepared in accordance with a directive from the Central Bureau of the International Association of Geodesy. It will be distributed at the Eleventh General Assembly of the International Union of Geodesy and Geophysics at Toronto, Canada, September 1957. This report contains information describing geodetic operations of various agencies in the United States for a 3-year period from January 1, 1954, to December 31, 1956.

The format of this publication differs slightly from the previous publications of this series. The material has been arranged in five major sections corresponding to the five Sections of the International Association of Geodesy. These sections will be separated and compiled in individual reports of the five Sections. These section reports will be distributed at a later date by the Central Bureau of the International Geodetic Association.

Since the date of the previous report Mr. Hugh C. Mitchell passed from this life on November 20, 1956. He had made outstanding contributions to the geodetic literature of the United States. Among those who retired from active duty in the Geodesy Division, Coast and Geodetic Survey, are Walter D. Sutcliffe, Chief of the Field Records Branch, on October 31, 1954; Captain Albert J. Hoskinson, Chief, Geodesy Division, on July 1, 1955; and Captain P. C. Doran, Chief, Geodesy Division, on February 1, 1956. Captain Doran had succeeded Captain Hoskinson as Chief of the Geodesy Division, and upon Captain Doran's retirement, Captain Charles Pierce was appointed Chief of the Geodesy Division.

CONTENTS

	Page
Foreword	iii
Triangulation	1
United States Coast and Geodetic Survey	1
United States Geological Survey	6
United States Army Map Service	7
United States Air Force	7
United States Lake Survey	7
Precise leveling	10
United States Coast and Geodetic Survey	10
United States Geological Survey	13
United States Lake Survey	13
Geodetic astronomy	14
United States Coast and Geodetic Survey	14
Field observations	14
Variation of latitude	14
United States Army Map Service	14
United States Air Force	18
Eclipse observations	18
Gravity observations and reductions	19
United States Coast and Geodetic Survey	19
United States Air Force field gravity program	19
United States Geological Survey	23
Other organizations	23
Geoid investigations	24
United States Coast and Geodetic Survey	24
United States Air Force	24

ILLUSTRATIONS

Figure 1. Triangulation net of the United States	2
2. Extension of the triangulation net of the United States	3
3. Triangulation net of Alaska	4
4. Extension of the triangulation net of Alaska	5
5. Trilateration scheme, Florida to Trinidad	8
6. Trilateration scheme, Canada to Scotland	9
7. Level net of the United States	11
8. Extension of the level net of the United States	12
9. Astronomic-geodetic stations in the United States	15
10. Progress in astronomic observations in the United States	16
11. Astronomic-geodetic stations in Alaska	17
12. Gravity network of the Coast and Geodetic Survey	20
13. Extension of gravimetric observations by the Coast and Geodetic Survey	21
14. Coast and Geodetic Survey gravity base stations in Alaska	22

GEODETIC OPERATIONS IN THE UNITED STATES AND IN OTHER AREAS THROUGH INTERNATIONAL COOPERATION, JANUARY 1, 1954, TO DECEMBER 31, 1956

By Charles Pierce, *Chief, Geodesy Division, United States Coast and Geodetic Survey*

TRIANGULATION

United States Coast and Geodetic Survey

Geodetic control surveys form the basic framework for all mapping and charting activities of the Nation and are also a basic requirement in the planning and development of natural resources and of large engineering projects. The horizontal network of the country has been developed and is being extended by triangulation, traverse, and trilateration. Generally, the density of permanently marked horizontal control points is in direct ratio to land values. In metropolitan areas and along interstate highway systems, a spacing of 1- or 2-mile intervals may be required, and in rural areas of high land values a spacing of 3 to 4 miles may be desirable. Although wider spacing may suffice for Federal topographic mapping, closer spacing may be needed for property surveys, highway programs, transmission lines, reclamation projects, and numerous other engineering activities. The more closely spaced stations are so situated that they are readily available to local engineers.

During this 3-year period, the basic framework of arcs in Alaska was completed and considerable progress was made in the United States toward the filling-in of the area networks within the loops of the first-order arcs. Most of the area nets, which have been completed, are in regions where large-scale mapping is being carried on by the Geological Survey, or special engineering projects of the Bureau of Reclamation. Special high-precision surveys were made at several military installations to be used for control in the testing of various types of equipment.

A special-purpose triangulation project was accomplished along the coast of Louisiana in cooperation with several oil companies engaged in offshore drilling operations. The purpose of the project was two-fold: First, to replace lost triangulation stations along the coast and second, to locate accurately the drilling platforms off the coast. This was of considerable interest to the oil companies, as the possible locations of their wells are tied up with leasing rights and royalties and represent investments totaling millions of dollars. Two large triangulation parties were engaged for the project for about 5 months. Portable Bilby steel towers up to 90 feet in height were erected on a number of offshore platforms. The farthest platform located was about 28 miles from shore.

Most of the work completed in Alaska consisted of the extension of arcs across the Brooks Range, connecting the arcs in the interior of Alaska to the arc along the Arctic Coast. This work was accomplished during the summers of 1954 and 1955. Several Laplace azimuths are needed within this framework, but because of the difficulties of transportation and the short season for observing, several seasons will be needed to complete this phase of the work.

In this 3-year period there was an increasing demand for horizontal control along the axis of superhighways. Even before the enactment of the Interstate Highway legislation some of the states had requested assistance in placing control points along the routes of superhighways. Following the passage of the Interstate Highway Bill, several additional States have requested that these surveys be made. In some instances, these surveys are being made within the area networks previously established, but in some

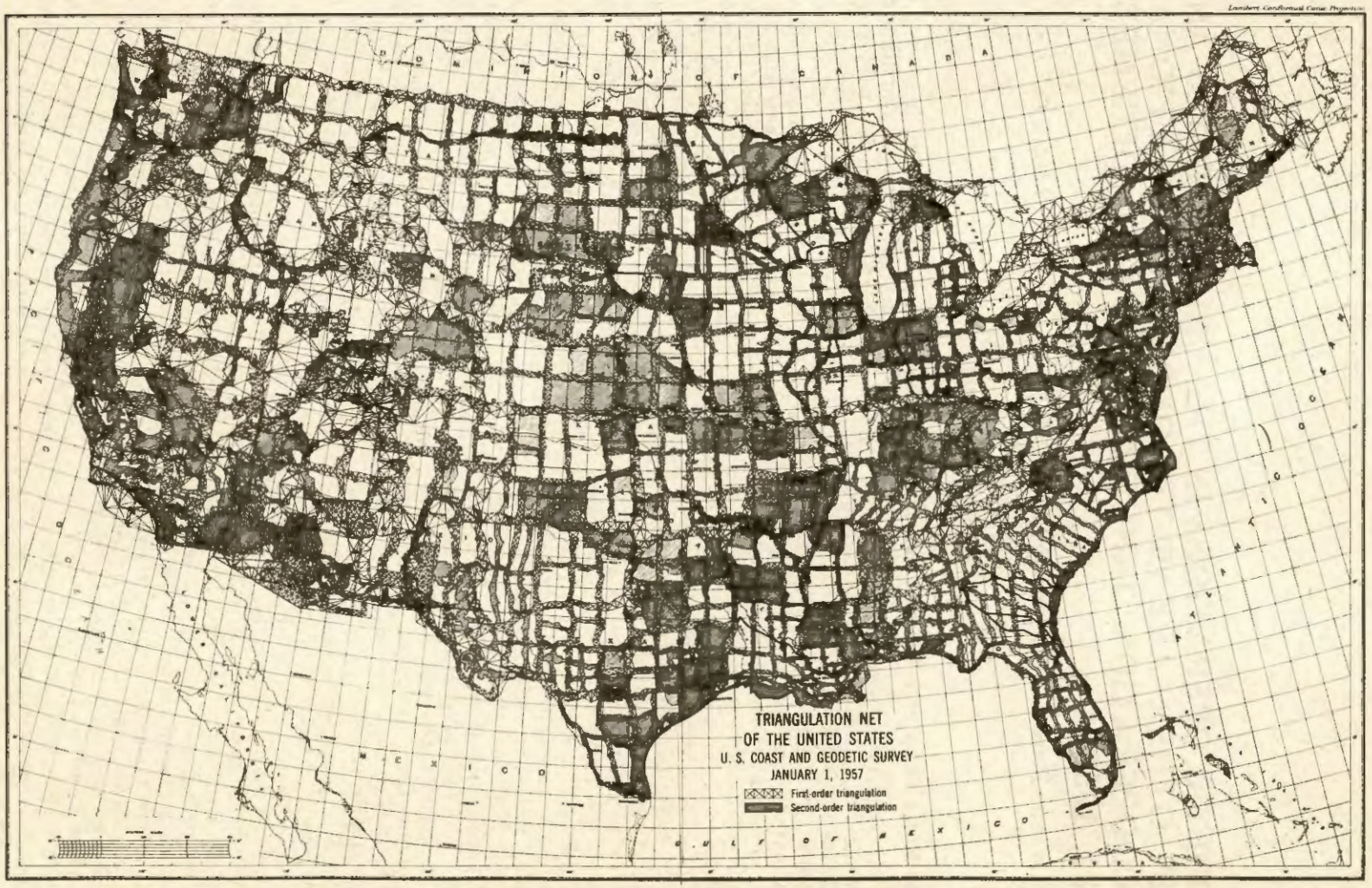

FIGURE 1.—Triangulation net of the United States.

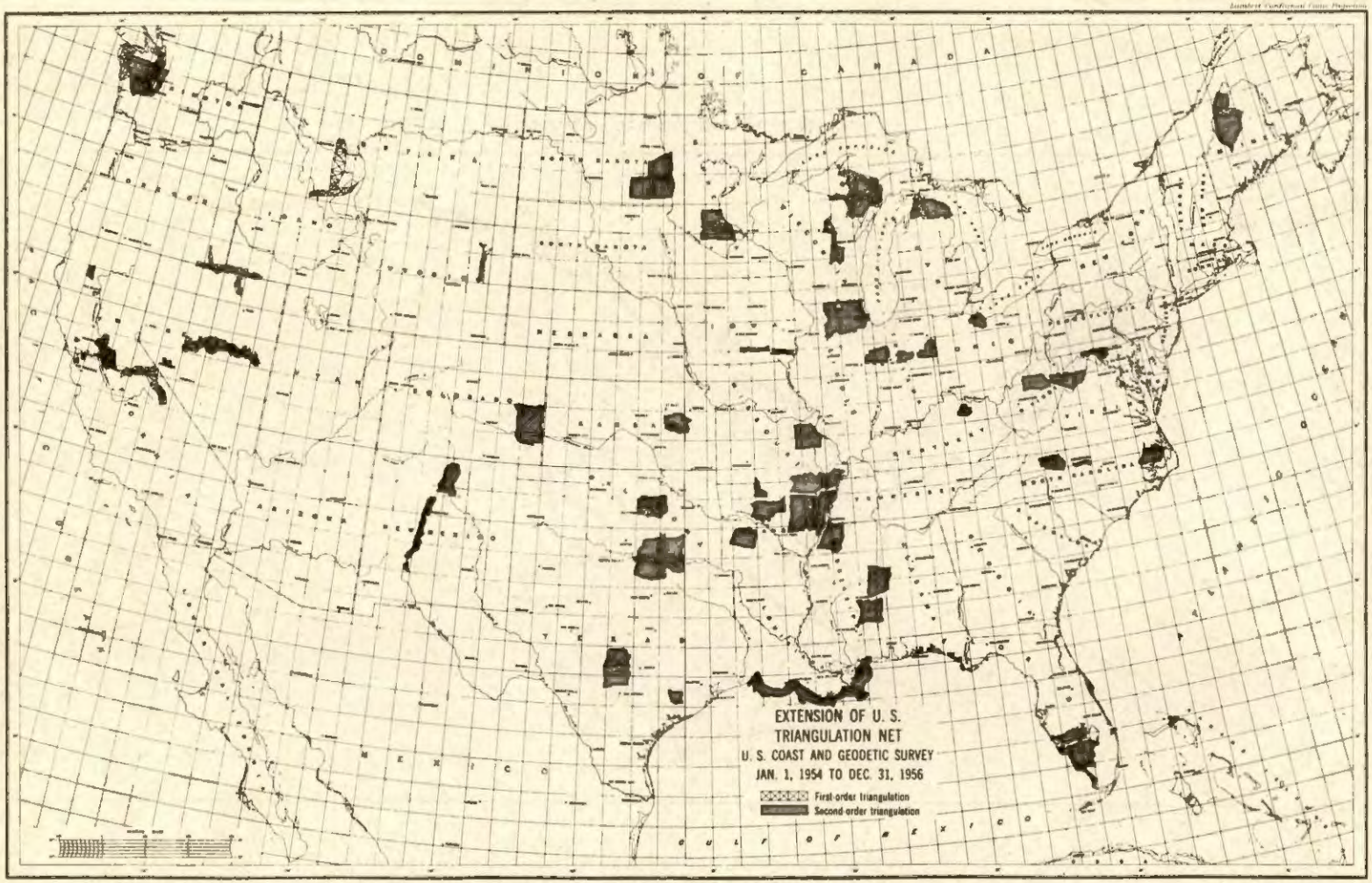

FIGURE 2.—Extension of the triangulation net of the United States.

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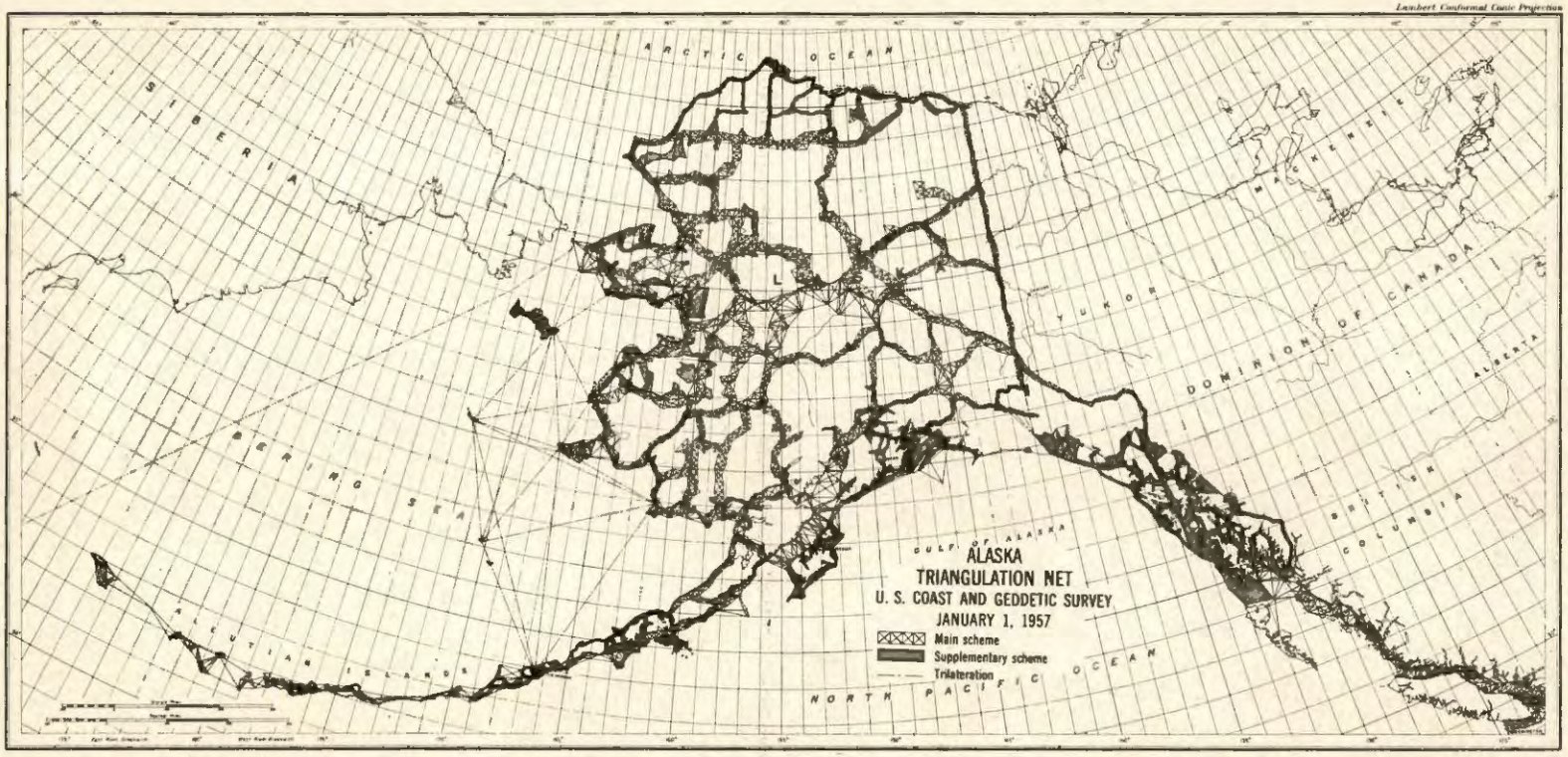

FIGURE 3.—Triangulation net of Alaska.

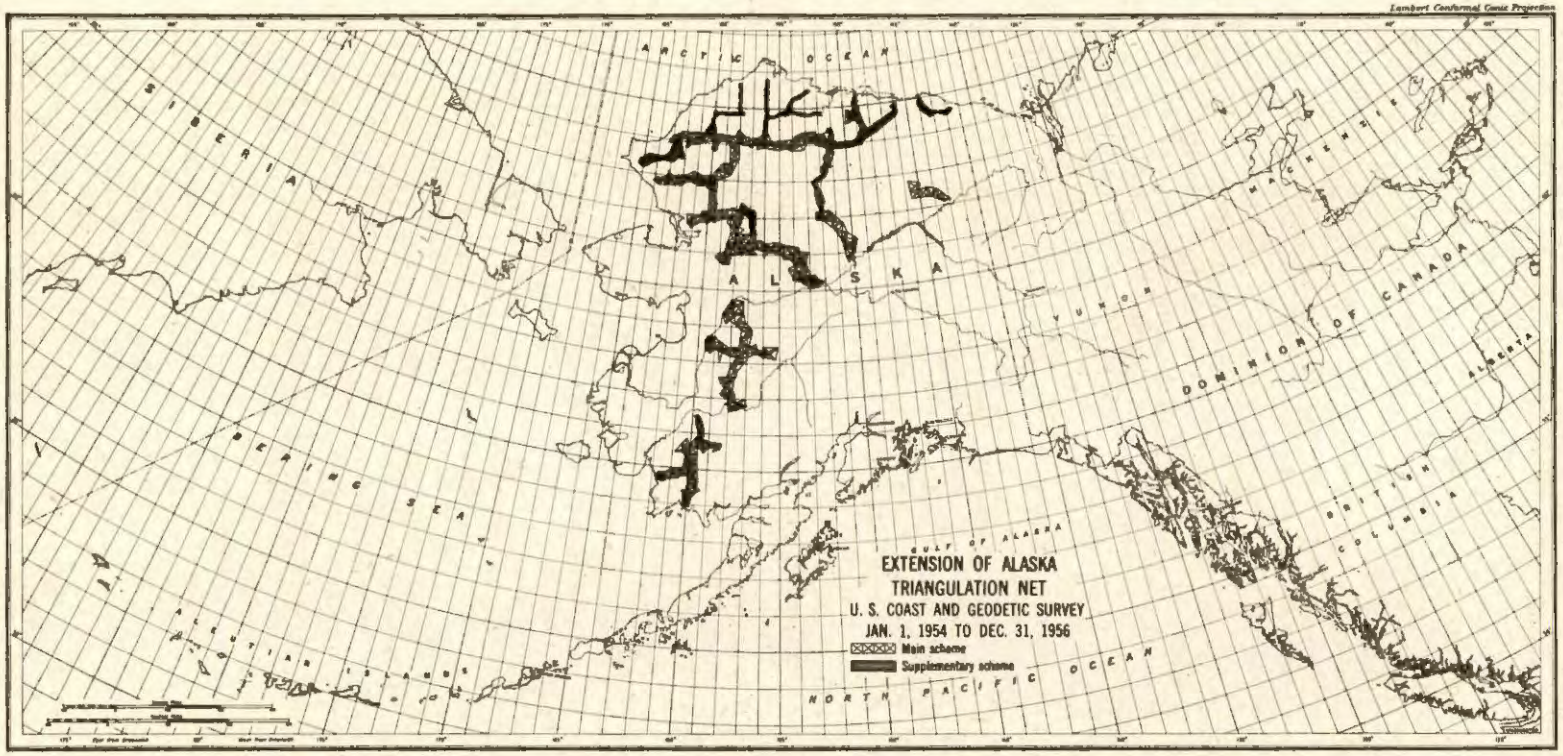

FIGURE 4.—Extension of the triangulation net of Alaska.

cases it is necessary to extend major arcs of triangulation between existing arcs. This type of work will continue for many years inasmuch as there are 40,000 miles of highways to be built within this interstate system, and the specifications for the construction of the highways are such that surveys of geodetic accuracy will be needed.

The geodimeter was used throughout the 3-year period for the measurement of baselines in areas where it was not practical to use invar tapes. A second geodimeter was obtained in 1956 and it, too, is being used for the same purpose. Whenever there is an opportunity to compare a geodimeter measurement with a taped measurement, this is done. Our experience has shown that these checks are of the order of 1:500,000. Late in 1956, a Tellurometer was ordered and it will be used for the measurement of baselines and traverses.

The adjustment of horizontal control surveys into the Federal network proceeded almost as rapidly as the field work itself was completed. The Bureau continued to use high-speed computing equipment with most of the work being accomplished on two Type 604 electronic calculators. One of the largest adjustments ever undertaken was that for the arcs of northern Alaska. There were over 1,100 points in this net, and by the use of the method of variation of coordinates a network of almost 3,400 equations was developed.

In 1956 an order was placed for a Type 650 Magnetic Drum Calculator. Several members of the Survey were sent to an IBM school for special instruction in the application of mathematical processes to this machine and an additional course of instruction was given to a larger group of employees within the Bureau with special emphasis on Bureau problems. A group of programers was organized late in 1956 with instructions to prepare programs for the adjustment of triangulation and related problems.

The Bureau continued its cooperative work with the Army Map Service in the adjustment of surveys in foreign countries. The network of triangulation around the eastern end of the Mediterranean Sea was adjusted. The arcs of triangulation extending southward from the United States through Mexico and Central America to South America were also adjusted. Assistance was given in the processing of horizontal control data in Thailand. This involved the adjustment of the major and minor triangulation networks as well as the computation of thousands of miles of traverse.

United States Geological Survey

The Geological Survey, a Bureau of the United States Department of the Interior, is charged with the responsibility for the topographic mapping of the continental United States, Alaska, the Hawaiian Islands, Puerto Rico, and the Virgin Islands. When necessary as a foundation for this mapping, it conducts geodetic surveys which consist of triangulation, transit traverse, and leveling.

All of these control surveys are tied to the basic network of first- and second-order control covering the country. The basic network is now sufficiently dense that it is seldom necessary for the Geological Survey to extend surveys of higher than third-order accuracy. In addition to providing a framework of control for the mapping, the control surveys of the Geological Survey are used extensively by other organizations (Federal, State, and local) and by engineers and others wherever third-order control satisfies the needs of local projects.

Permanent monuments are established at the primary triangulation stations and at intervals of from 2 to 3 miles along the lines of transit traverse. Positions and elevations for these monuments and for other identifiable intermediate points are published in separate lists which cover 15-minute quadrangles and are available to the public, upon request.

Accomplishments during the period covered by this report include about 5,000 new third-order triangulation stations, about 100 miles of second-order traverse, and 19,663 miles of third-order transit traverse.

Research and development on new ideas and techniques, the adoption of improved instruments, and the use of faster transportation have all affected the field operations and later processing of control surveys. Optical-reading theodolites were used almost exclusively. Helicopters were increasingly used to transport men and equipment to triangulation stations in remote areas. This greatly expedited progress and, in a few instances, enabled triangulators to establish stations on points never before visited by man. The Tellurometer, an electronic distance-measuring device developed in South Africa, is on order and will be tested. High hopes are held that it will revolutionize control-survey methods and reduce costs.

Plotting of projection corners and control points on the mapping base sheets by coordinatograph plotters has become standard practice. Since these plotters require the use of grid coordinates, it has also become standard procedure to convert the geographic

positions of the new horizontal control to the State plane coordinate systems. With respect to transit traverse, this innovation has been carried a step farther and the former practice of computing geographic positions abandoned entirely, in favor of computation directly on the State grid systems.

Availability of a high-speed electronic computer has opened the possibility of a feasible and reasonably inexpensive means of converting the enormous volume of older control stations to State plane coordinates and the problem of programing the computations is well along. Most of the networks of transit traverse were adjusted on the Electronic Survey Net Adjuster with results identical to those yielded by least squares and at considerable savings in time and man-hours.

United States Army Map Service

During the period of this report the Army Map Service measured 13 baselines in Thailand. Four were measured between February and May 1955, and nine between December 1955 and May 1956. These were all measured by geodimeter with a resulting average probable error for the 13 bases of 1 part in 3,000,000. For further details, reference is made to the report submitted by the Survey Department of Thailand.

Three links in geodetic surveying by United States agencies (on the 30th Meridian, by the Army Map Service; from Crete to Egypt, by the United States Air Force; the Central and South American arc, by the Inter-American Geodetic Survey, adjusted to 1927 North American Datum by Army Map Service) provided a system of astrogeodetic deflections along a 100° meridional arc in either hemisphere. This material was used for a tentative determination of the size of the earth by the arc method in a study at the Army Map Service (B. Chovitz and I. Fischer, A New Determination of the Figure of the Earth from Arcs, Transactions, American Geophysical Union, Vol. 37, No. 5, October 1956). The results derived for the major semiaxis of the ellipsoid of revolution best fitting these arcs are: 6,378,240±100 m. for free-air, and 6,378,285±100 m. with isostatic reductions, both for a given flattening of $\frac{1}{297\pm1}$. A mean value of 6,378,270 m. with flattening $\frac{1}{297}$ is named the *Hough ellipsoid* in honor of Floyd W. Hough who is credited with the conception and general direction of this project.

United States Air Force

The United States Air Force continued its successful employment of high-precision Shoran (HIRAN) techniques for carrying geodetic surveys across very great distances. During the summer seasons of 1954, 1955, and 1956, the tie connecting North America with Europe was completed. This trilateration network included the Scotland-Norway net (completed during the summer of 1953) and extended from that network through the Faeroes to the east coast of Iceland, and from the west coast of Iceland to Greenland, across the Greenland Icecap, and terminated on Baffin Island with ties to Canadian geodetic stations.

In 1954, a HIRAN trilateration net connecting Puerto Rico, the Lesser Antilles, and Trinidad was completed. This project, tieing into and adjusted with the previously completed network from Florida to Puerto Rico, connects the triangulation of the United States Coast and Geodetic Survey in Florida with that of the Inter-American Geodetic Survey in Trinidad.

United States Lake Survey

The geodetic work of the Lake Survey for the calendar years 1954–1956 consists of approximately 12 miles of second-order triangulation and three first-order level lines.

In 1954, second-order triangulation was carried along the St. Lawrence River from Massena Point to Louisville Landing, N. Y., establishing the geodetic positions of 14 stations on the North American 1927 datum.

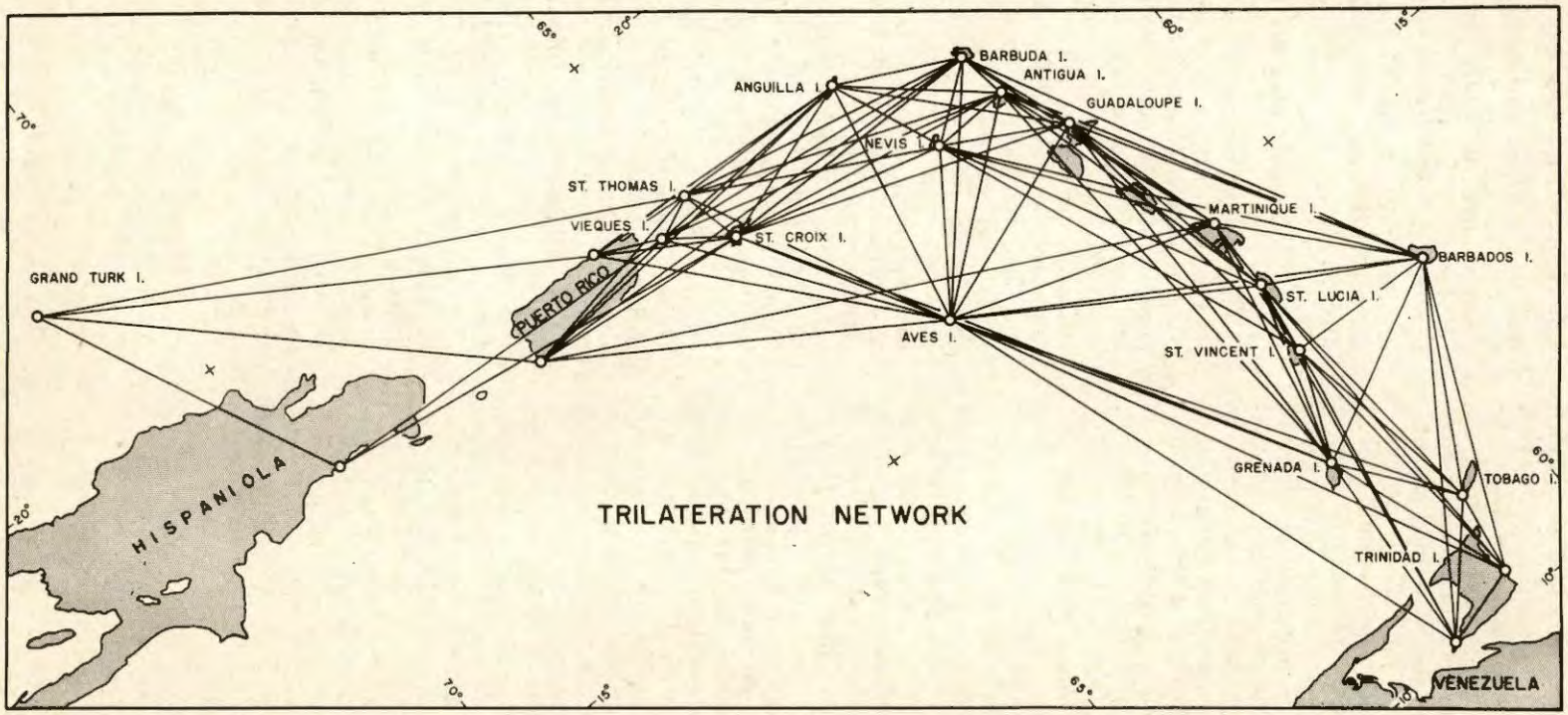

FIGURE 5.—Trilateration scheme, Florida to Trinidad.

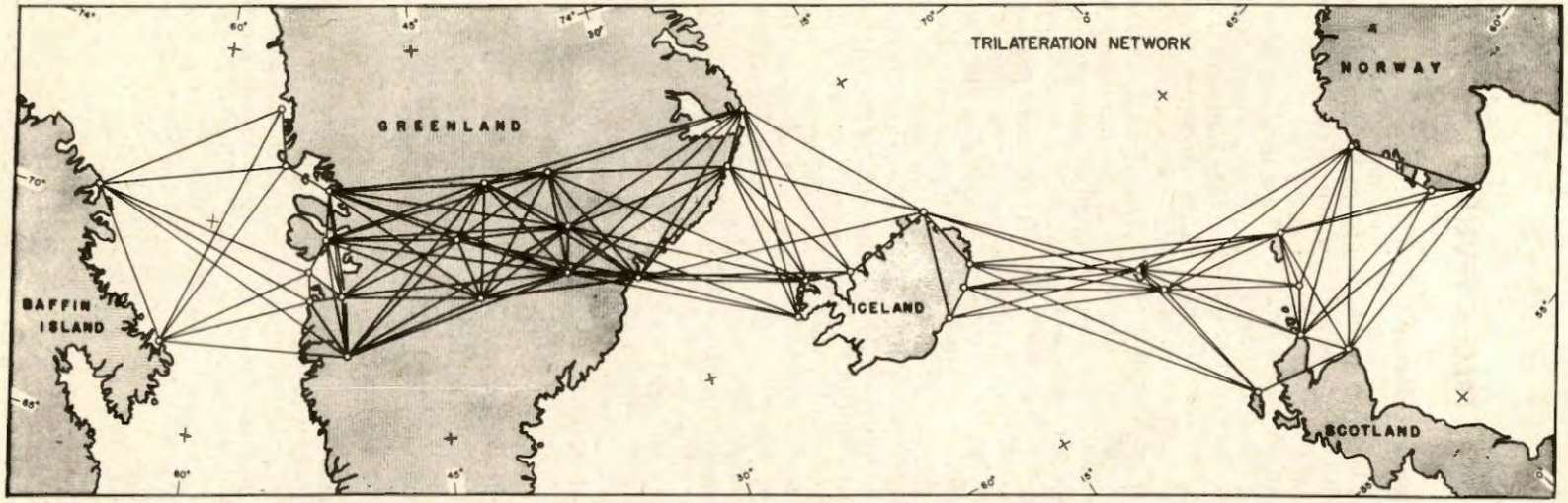

FIGURE 6.—Trilateration scheme, Canada to Scotland.

PRECISE LEVELING

United States Coast and Geodetic Survey

The total length of lines of leveling in the geodetic level net of the United States as of December 31, 1953, was 153,000 miles of first-order and 247,000 miles of second-order leveling. During the period from January 1, 1954, to December 31, 1956, the Coast and Geodetic Survey undertook leveling along 12,826 miles of first-order and 5,157 miles of second-order lines. The total leveling in the net as of December 31, 1956, is 166,000 miles of first-order and 252,000 miles of second-order which total 418,000 miles of first- and second-order leveling along which 339,000 benchmarks have been leveled over.

The instrument employed by the Coast and Geodetic Survey in leveling of first- and second-order accuracy is the Fischer level (known as the Coast Survey level), equipped with a level vial which has a sensitivity of 2 seconds of arc per 2 millimeters graduation. The leveling rod consists of an invar strip graduated in centimeters with a coefficient of expansion of 0.0000005 to 0.0000025 per degree centigrade.

The method of observing consists of direct rod readings to the nearest millimeter for three cross hairs on both the backsight and foresight, for which a mean is computed to four decimal places in meters. First-order level lines are run in both directions until forward and backward runnings are obtained which agree within the limit of 4.0 mm. $\sqrt{K}$, where K is the length of section in kilometers. Second-order leveling is run with the same equipment in only one direction with loop closures within the criterion 8.4 mm. $\sqrt{K}$, where K is the distance in kilometers around the loop.

Elevations of benchmarks in the geodetic level net are based on the "Sea Level Datum of 1929." In 1929, a simultaneous adjustment of the first-order leveling of Canada and the United States was undertaken in which mean sea level was held at zero at 26 tide stations along the Atlantic and Pacific Oceans and the Gulf of Mexico.

First-order lines are spaced at approximately 100-mile intervals with second-order lines at 25-mile intervals. Within the 25-mile loops, "area" leveling has been established for about 15 percent of the United States consisting of second-order lines spaced from 5 to 10 miles apart. Releveling has been undertaken for practically all of the first-order lines established prior to 1916 which is the date the invar rods came into use.

New leveling is adjusted to the basic net. However, where extensive releveling or new leveling indicates changes in elevation, it is often necessary to readjust portions of the basic net.

Descriptions and elevations in meters and feet are published by lines or areas by a photo-lithography process. Publication by bulletin form has been discontinued.

Three main parties have been leveling continuously during this period, one on the east coast, one in the Central States, and one on the west coast. Each of these field parties had two units during the winter months and usually three units during the summer months. One additional unit was assigned to leveling on Long Island, N. Y., and in New Jersey for 5 months during 1956 for the purpose of connecting tidal benchmarks to the geodetic level net. For the 3-year period, there was a total of 268 unit-months of leveling accomplished.

In the Galveston-Houston, Tex., area releveling was started in 1953 and continued in 1954 to determine the magnitude and extent of settlement. The maximum settlement measured was 2.85 feet at Texas City from 1936 to 1954. Releveling of this net of lines is scheduled at 5-year intervals, therefore the next releveling will be during the winter of 1958–59.

In the San Joaquin Valley of California, a releveling of certain portions has been scheduled at 2-year intervals. The maximum rate of settlement is 1¾ feet per year and some areas have settled a total of 16 feet. In planning releveling in the San Joaquin Valley, the geology of the region is studied to ascertain where bedrock anchors are available. Lines are extended to provide as many anchors in granite as possible.

In the Santa Clara Valley, the San Jose, Calif., net was releveled from April to June 1954. The maximum settlement is 7.75 feet from 1912 to 1954 at benchmark P 7 located in The Hall of Records building at San Jose. A composite lithographed list was published in 1956 showing elevations resulting from the 16 different levelings in the

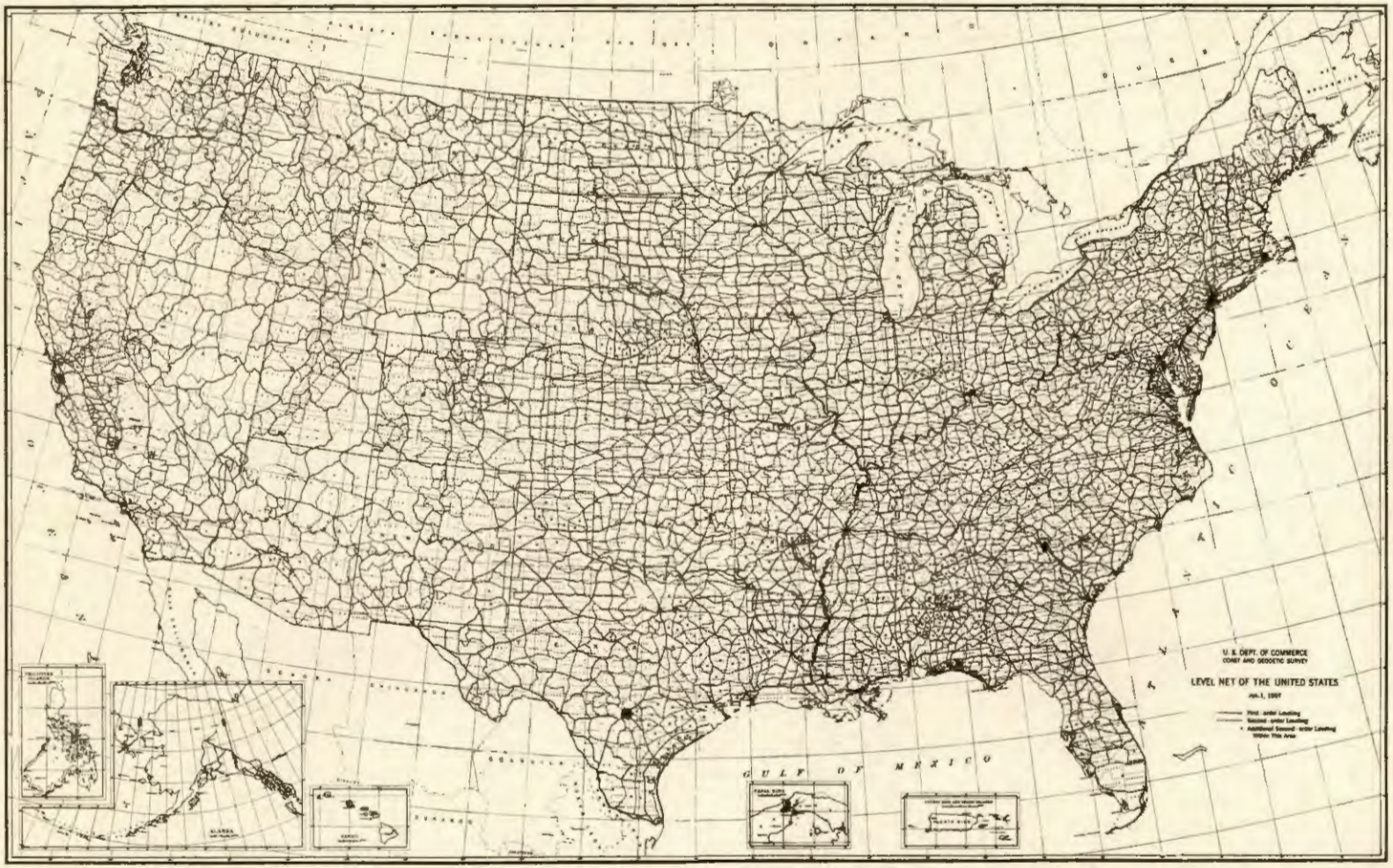

FIGURE 7.—Level net of the United States.

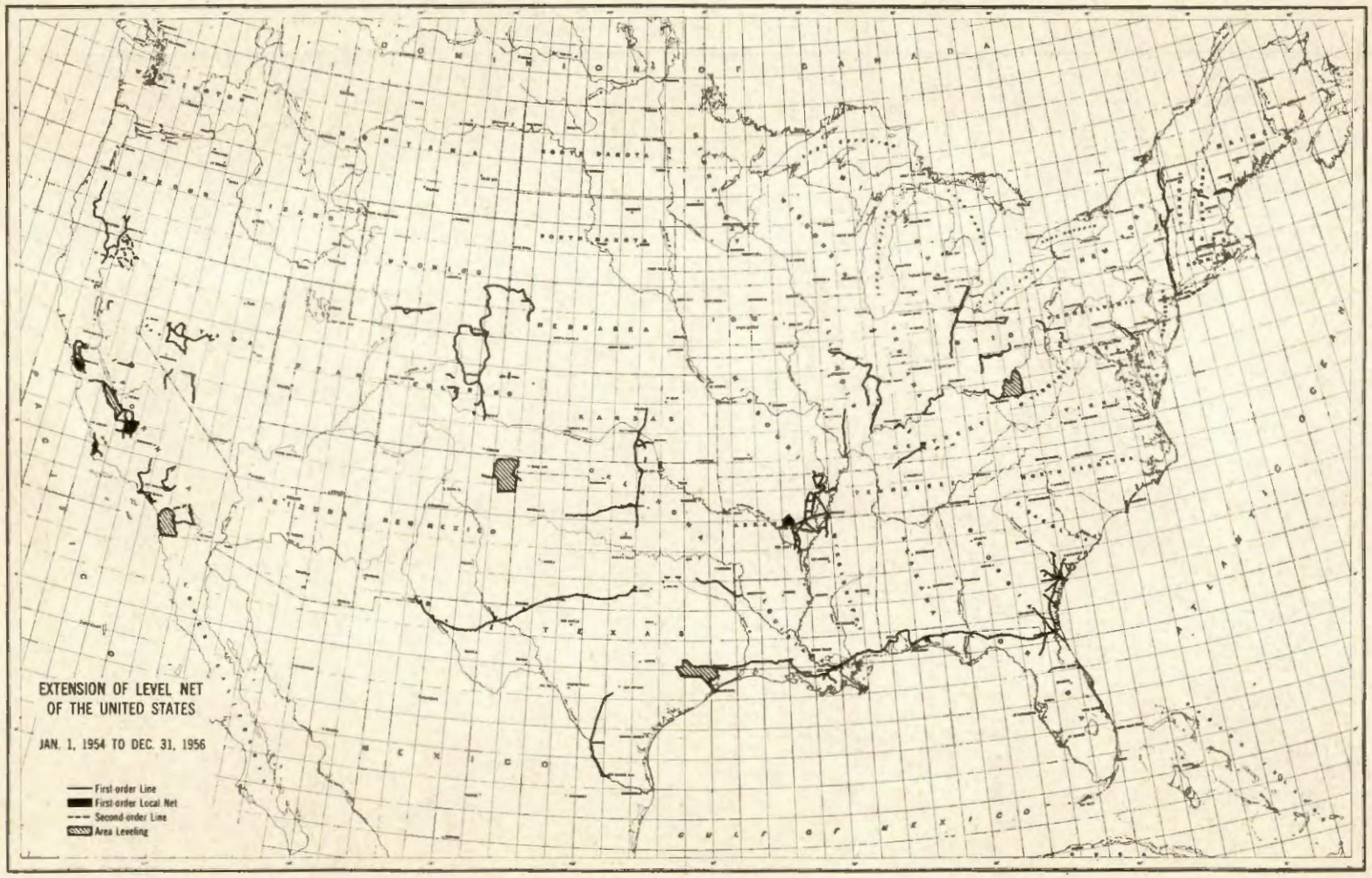

FIGURE 8.—Extension of the level net of the United States.

San Jose area. Very good stability has been shown on bedrock marks set as an anchor in jurassic ultrabasic intrusives south of San Jose, Calif. Of course, it is possible that tectonic action such as earthquakes could change these anchors but so far there is good agreement between levelings from tidal benchmarks at the Presidio, San Francisco, and these rock marks.

Over the years, the type of benchmark most frequently established has been the concrete post which is about 4 feet in length, about a foot in diameter, and weighing about 600 pounds. Since one of the very important items in leveling is the establishment of marks that will remain stable, it was considered advisable to install at 5-mile intervals a basic benchmark which consists of copper-coated steel rods driven to considerable depth.

During 1955 and 1956, each of the level parties was supplied with a gasoline hammer for driving these rods which are ½ inch in diameter and 5 feet long. The 5-foot sections are coupled with a brass coupler and the rods driven to refusal. After reaching refusal the rods are cut off at the ground level and a disk compressed to the rod. Usually if refusal has not been reached at 50 feet, driving is sufficiently difficult to furnish a stable mark; however, some rods have been driven to depths of 80 feet.

Due to changes that are often necessary in the elevations of benchmarks, the practice of stamping elevations on benchmark disks has been discontinued. A new benchmark disk will be used by our level parties when the supply of the present disks is exhausted. The new disk will be the same as that used for tidal benchmarks, except it will not have the circle at the center.

United States Geological Survey

During the period covered by this report the Geological Survey ran 40,324 miles of third-order leveling. Permanent marks were established at intervals of from 2 to 3 miles along the lines of leveling. Elevations for these monuments are published in separate lists which cover 15-minute quadrangles and are available to the public, upon request.

About a third of the leveling was done with automatic, pendulum-type levels which give satisfactory third-order results while increasing the rate of progress. Most of the networks of leveling and vertical-angle elevations were adjusted on the Electronic Survey Net Adjuster, giving results identical to least-squares adjustments at considerable savings in time and man-hours.

United States Lake Survey

The Lake Survey ran level lines in the following areas.

In 1954, first-order levels were run along the St. Lawrence River in various sections between Ogdensburg, N. Y., and St. Regis, Quebec, Canada. The level lines covered 27 miles and established elevations for 47 benchmarks.

In 1955, first-order levels were carried up the St. Marys River from Detour to Sault Ste. Marie, Mich., a total distance of 60 miles establishing elevations for 69 benchmarks. Also, first-order levels were run in various sections of the St. Lawrence River from Ogdensburg to Massena, N. Y. These level lines covered 16 miles and established elevations for 37 benchmarks.

In 1956, first-order levels were carried up the St. Marys River from Sault Ste. Marie to Point Iroquois, Mich., on Lake Superior, a total distance of 20 miles establishing elevations for 31 benchmarks. Also first-order levels were carried down the St. Clair River from Algonac, Mich., to Harsens Island in the St. Clair Flats, a total distance of 12 miles, establishing elevations for 22 benchmarks.

GEODETIC ASTRONOMY

United States Coast and Geodetic Survey

FIELD OBSERVATIONS

Astronomic latitudes and longitudes are employed in converting astronomic azimuths to geodetic azimuths and in investigating the size and shape of the earth. Especially, in certain applications the characteristics of the earth's gravity field are effectively revealed by comparison of astronomic and geodetic coordinates at selected points on the earth's surface. Astronomic azimuths are observed at regular intervals to control the orientation of triangulation arcs and for certain special purposes such as detection of crustal movement in earthquake regions.

During the period 1954–56 first-order latitudes and longitudes were observed at 29 stations. These included 5 stations on the Alaska mainland during the summer of 1955, 7 stations on the 35th parallel geoid profile between the Atlantic coast and the 85th meridian, and 17 stations observed in other areas of the United States. Fifteen first-order Laplace stations were observed in the United States and Alaska for control of triangulation and for earthquake investigations.

Conventional meridian transits of the Bamberg and Wild T–4 types are employed in first-order position determination. Latitudes are based on 15 to 20 Horrebow-Talcott star pairs. Longitudes are based on 5 to 7 sets of about 6 stars each, with WWV time signals recorded on drum chronographs and compared with chronometers at approximate 1-hour intervals. First-order azimuths are usually observed with Wild T–3 theodolites in the United States and with the Wild T–4 in Alaska. Close circumpolar stars at any hour angle were used exclusively in the azimuth observations.

A considerable number of second-order latitudes and longitudes have been observed during the past 3 years. These included 62 stations on the island arc between Puerto Rico and Trinidad, and 34 stations on the 35th parallel between the Atlantic coast and the 85th meridian, at an average station spacing of 18 miles. Wild T–3 theodolites were employed, observing four east-west star pairs for longitude, and Polaris with a matching south star for latitude. Personal equations for the longitude observations were evaluated by reoccupation of first-order points at approximate 5-station intervals. A new method of timing has been adopted for second-order astronomic position determinations whereby the observer estimates times of star pointings directly from the continuous WWV 1-second time signal pulses. Experimental observations have shown this method to be simpler and more accurate than was previously obtainable by the use of an intermediate chronometer. Average probable errors of about 0.4 second of arc in each component are obtained with the simplified second-order procedure.

VARIATION OF LATITUDE

Two of the five northern-hemisphere International Latitude Service observatories have been maintained in continuous operation by the Coast and Geodetic Survey. These are located at Gaithersburg, Md., and Ukiah, Calif. A new and expanded observing program was adopted by the IUGG in September 1954 at Rome. The new program, put into effect in January 1955, increases from 4 to 6 hours the nightly observing period and increases from 12 to 18 the number of star pairs per night. This permits more accurate determination of both the day-to-day and secular variations of the pole. In view of the expanded program an assistant observer was assigned to each of the United States observatories early in 1955. Observing records from Gaithersburg and Ukiah are forwarded to the Central Bureau of the International Latitude Service at Torino, Italy.

United States Army Map Service

Ten stations in Thailand were occupied, between December 1955 and March 1956, by an Army Map Service Party for observation of latitude, longitude, and azimuth. The average probable errors for the ten stations are: latitude, $\pm 0''.07$; longitude, $\pm 0''.08$; azimuth, $\pm 0''.23$. For further details, reference is made to the report submitted by the Survey Department of Thailand.

During the period December 1954 through December 1956 the Army Map Service has been cooperating with various other army and government units in obtaining Pacific Island positions which are independent of the deflection of the vertical. These positions were obtained by occultation survey procedures involving the lunar parallax.

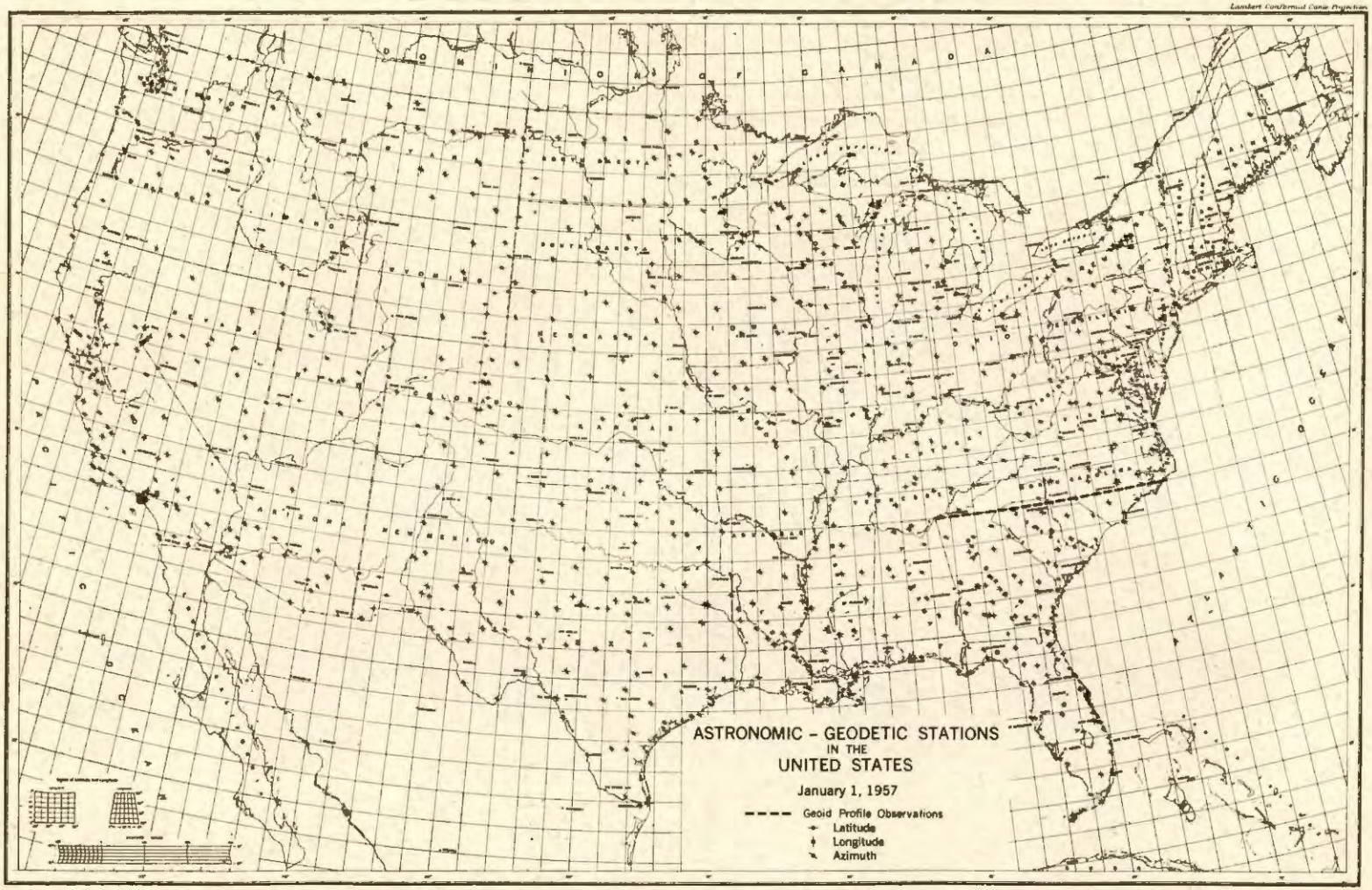

FIGURE 9.—Astronomic-geodetic stations in the United States

Lambert Zenithal Equal Area Projection

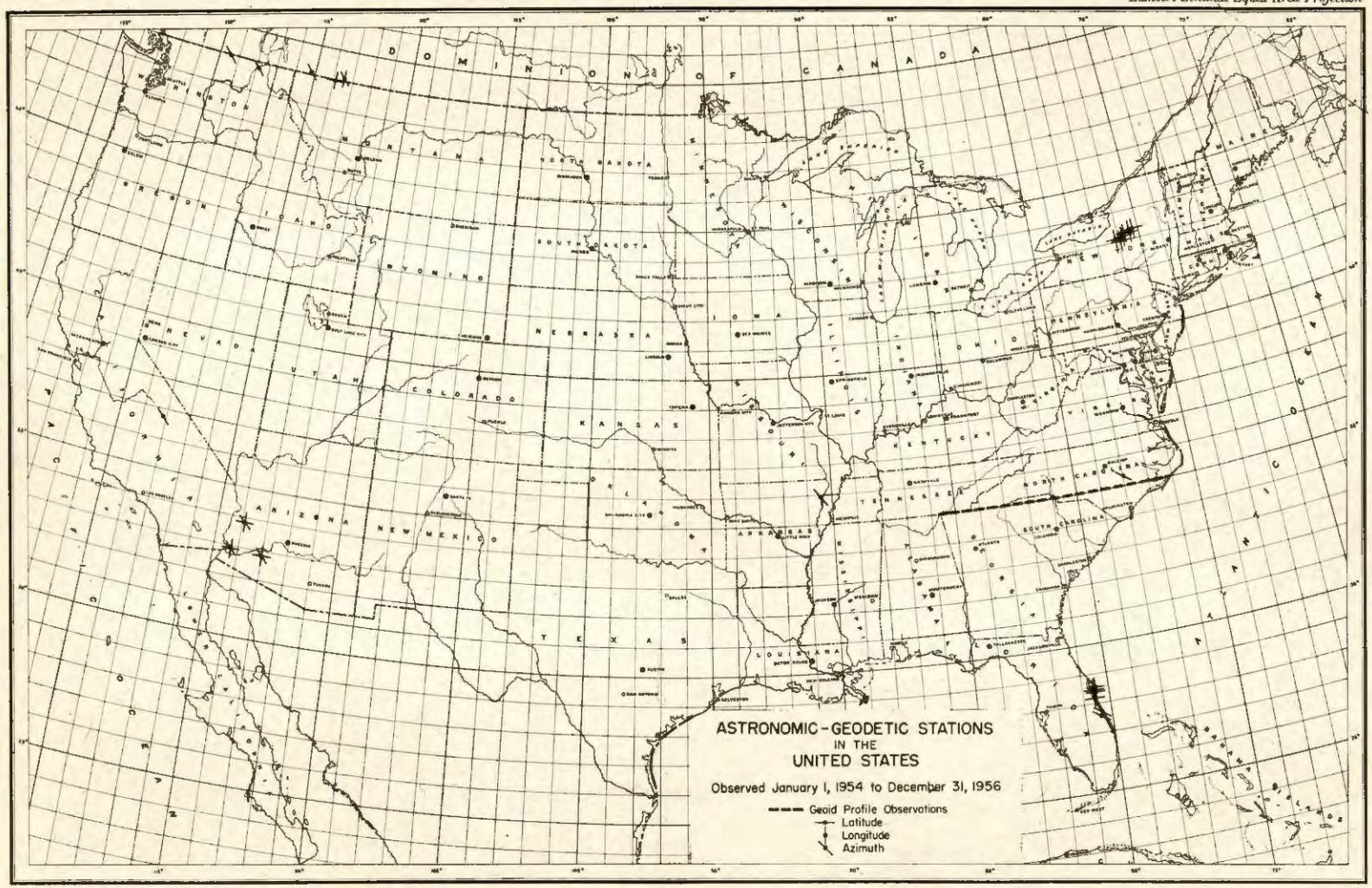

FIGURE 10.—Progress in astronomic observations in the United States.

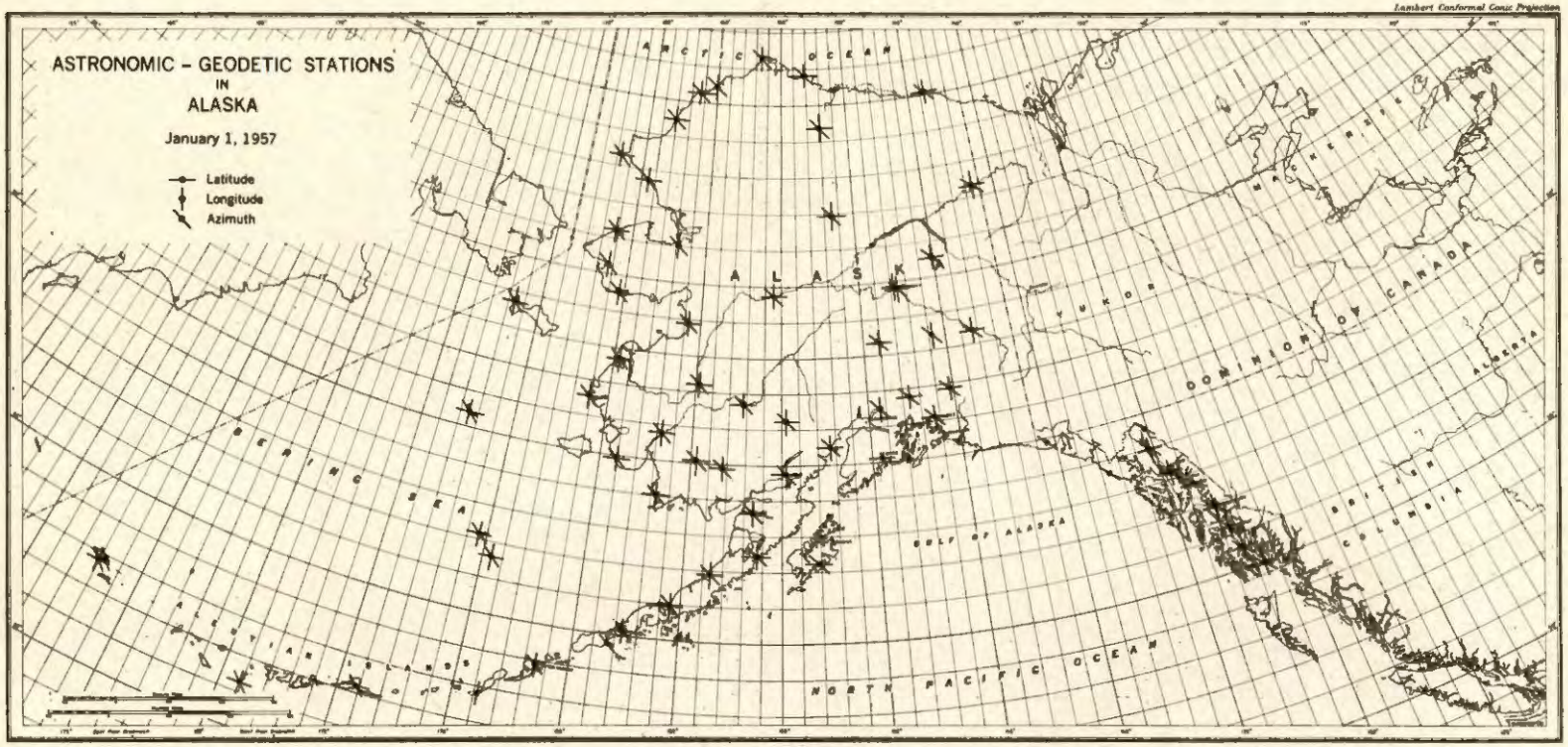

FIGURE 11.—Astronomic-geodetic stations in Alaska.

As part of a project designed to determine the positions of Saipan, Guam, Ulithi, and Palau in relation to one another, the position of Palau with respect to the datum of the Philippine triangulation was determined in cooperation with the 30th Engineer Group (Topo Svy), United States Coast Guard, and the Army Map Service, Far East.

Partial measurements have been made on several other island connections both by the Army Map Service in cooperation with the 30th Engineer Group, and the Army Map Service, Far East, in cooperation with the 29th Engineer Group.

United States Air Force

ECLIPSE OBSERVATIONS

During this period two solar eclipses were observed: The June 1954 total eclipse and the December 1955 annular eclipse. The 1954 eclipse extended from North Central United States, eastern Canada, across the North Atlantic to Norway and Sweden, across eastern Russia, into Iran and Afghanistan and was observed at sixteen (16) sites. The December 1955 eclipse was observed at eleven (11) sites from Khartoum in Anglo-Egyptian Sudan to Tainan, Formosa. The data obtained from these two eclipses and also the eclipses of 1947, 1948, and 1952 are now in the process of being reduced at Georgetown University. This reduction process is long and tedious (to obtain the required accuracy even the smallest correction must be considered). It is planned to use high-speed computers in those phases of the reduction process where such computers are applicable. It is expected that the data reduction for the 1947, 1952, and 1954 eclipses will be completed by mid-1957.

GRAVITY OBSERVATIONS AND REDUCTIONS

United States Coast and Geodetic Survey

All gravimetric observations by the Coast and Geodetic Survey during the reporting period were accomplished with gravity meters. The operations have consisted mainly of area surveys and development of the national gravity control network, as well as some contribution to the international network now being developed.

The recent area surveys have been extended east and north of existing continuous coverage in the south-central United States so as to increase the amount of data suitable for geodetic studies. These areas included the major portion of the State of Georgia, and several additional elements centered on Iowa and Minnesota. Area surveys are normally based on an average station spacing of 6 miles. Using all data now available the present continuous coverage provides bands several degrees in width extending from Mexico nearly to the Canadian boundary and from New Mexico eastward to the Atlantic coast.

Free-air and simple Bouguer anomalies are determined for area coverage stations, employing IBM equipment for computing and listing. Isostatic anomalies according to the Hayford-Bowie hypothesis are determined for all pendulum stations and for certain gravity-meter and sea stations where applicable. Through the cooperation of the Heiskanen group at Ohio State University, Pratt-Hayford isostatic anomalies for the 1,200 United States pendulum stations have been converted to the Airy-Heiskanen (30 km) system.

Isostatic anomalies associated with the Puerto Rico trench and the adjacent island arc are illustrated in a contour map recently compiled. The anomalies were reduced on the Pratt-Hayford system (D=113.7 km) and are contoured at a 25-milligal interval.

Accuracy of the United States gravity control network is gradually being improved by reoccupation of pendulum stations established prior to 1951. Gravity meter calibration standards are derived from the gravity traverse extending from southern Texas to the Canadian boundary. The traverse is controlled by precise pendulum observations at six primary stations. Gravity at these stations has been measured by the Coast and Geodetic Survey (Brown invar apparatus), Dominion Observatory of Canada (Cambridge invar apparatus) and the University of Wisconsin (Gulf-Woollard quartz apparatus). The calibration base has been effectively transferred to the east coast region by air-transport gravity-meter connections between Washington, D. C., and Grand Island, Nebr., and between Orlando, Fla., and Houston, Tex.

As a contribution to the international program for comparison of gravity calibration bases, the Coast and Geodetic Survey cooperated with the Geophysical Observatory of Trieste, Italy, in measuring the gravity difference between New York and Rome by means of three round-trip shipments of four Worden meters. With addition of similar connections later completed between Montreal and Geneva, and between Paris and Gander, by the Dominion Observatory of Canada and the Geophysical Observatory, a highly precise network is now available for comparison of European and American values over wide gravity differences. Following the New York-Rome connection in 1954, one of the Worden meters of the Geophysical Observatory of Trieste was operated over the midcontinent gravity base to provide a direct comparison between European and American standards. Both the above modes of calibration comparison indicate that the European and American bases are in substantial agreement. A precise gravity-meter traverse between the national reference stations at Washington, D. C., and Ottawa, Canada, has been measured jointly with the Dominion Observatory of Canada in order to improve this connection and to compare calibration standards of the two countries.

United States Air Force Field Gravity Program

In addition to the Eclipse Program and the Gravity Reduction Program, the Air Force also sponsors a Field Gravity Program. This Program is directed toward the calibration and expanded use of new improved geodetic gravity meters, and to effect the improvement of the operation and standardization of pendulum gravity measurements. The

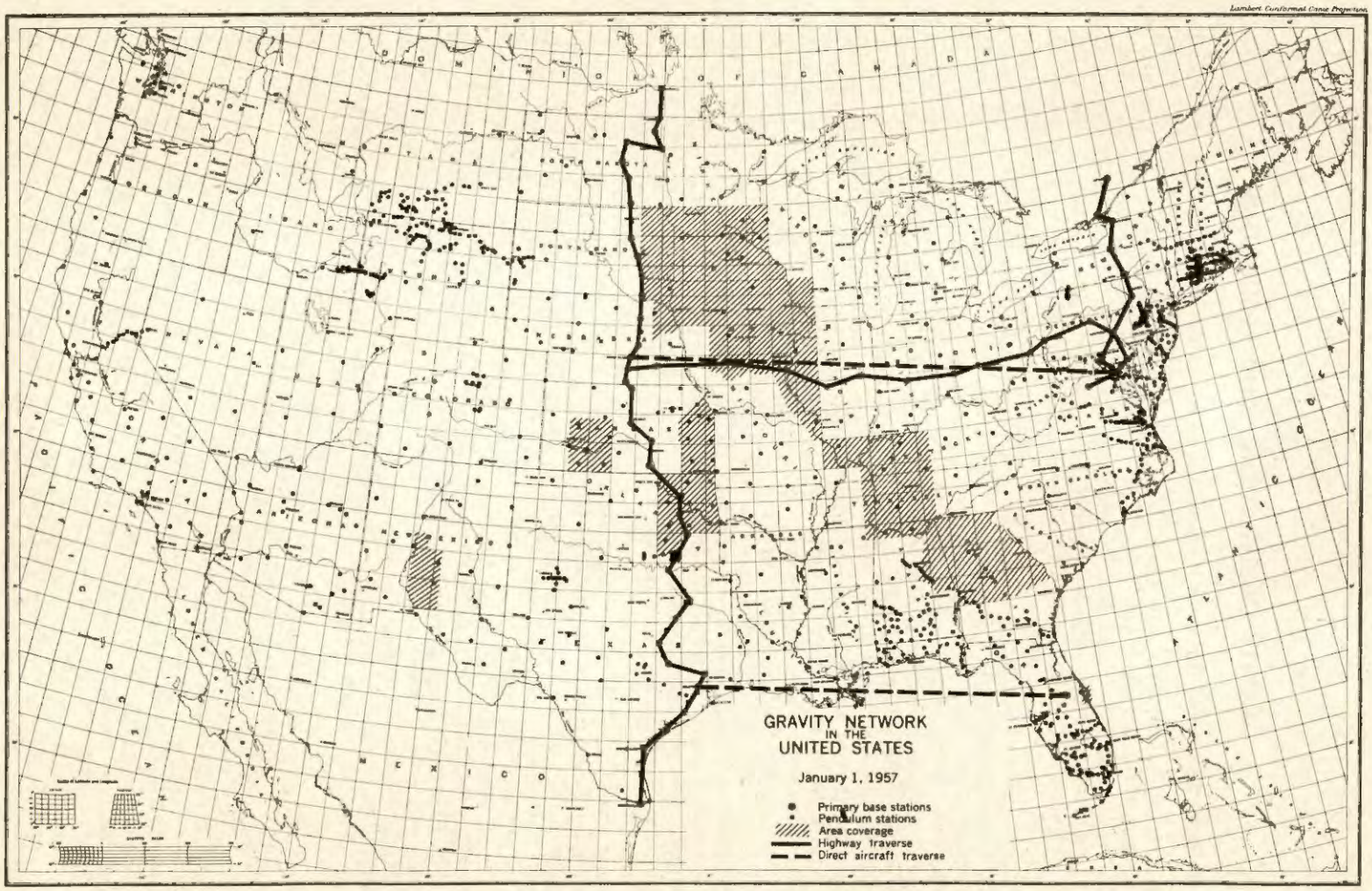

FIGURE 12.—Gravity network of the Coast and Geodetic Survey.

Lambert Zenithal Equal Area Projection

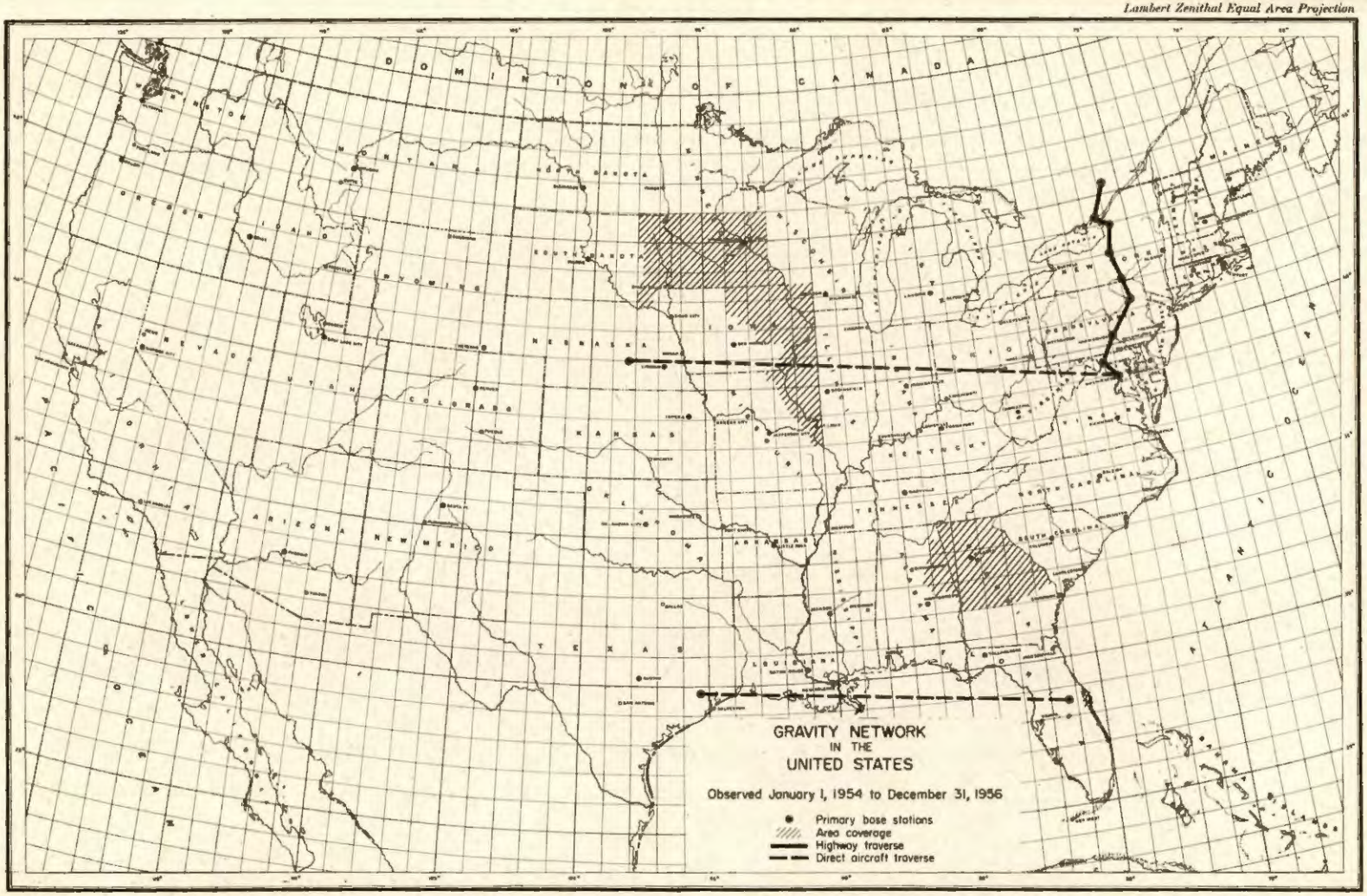

FIGURE 13.—Extension of gravimetric observations by the Coast and Geodetic Survey.

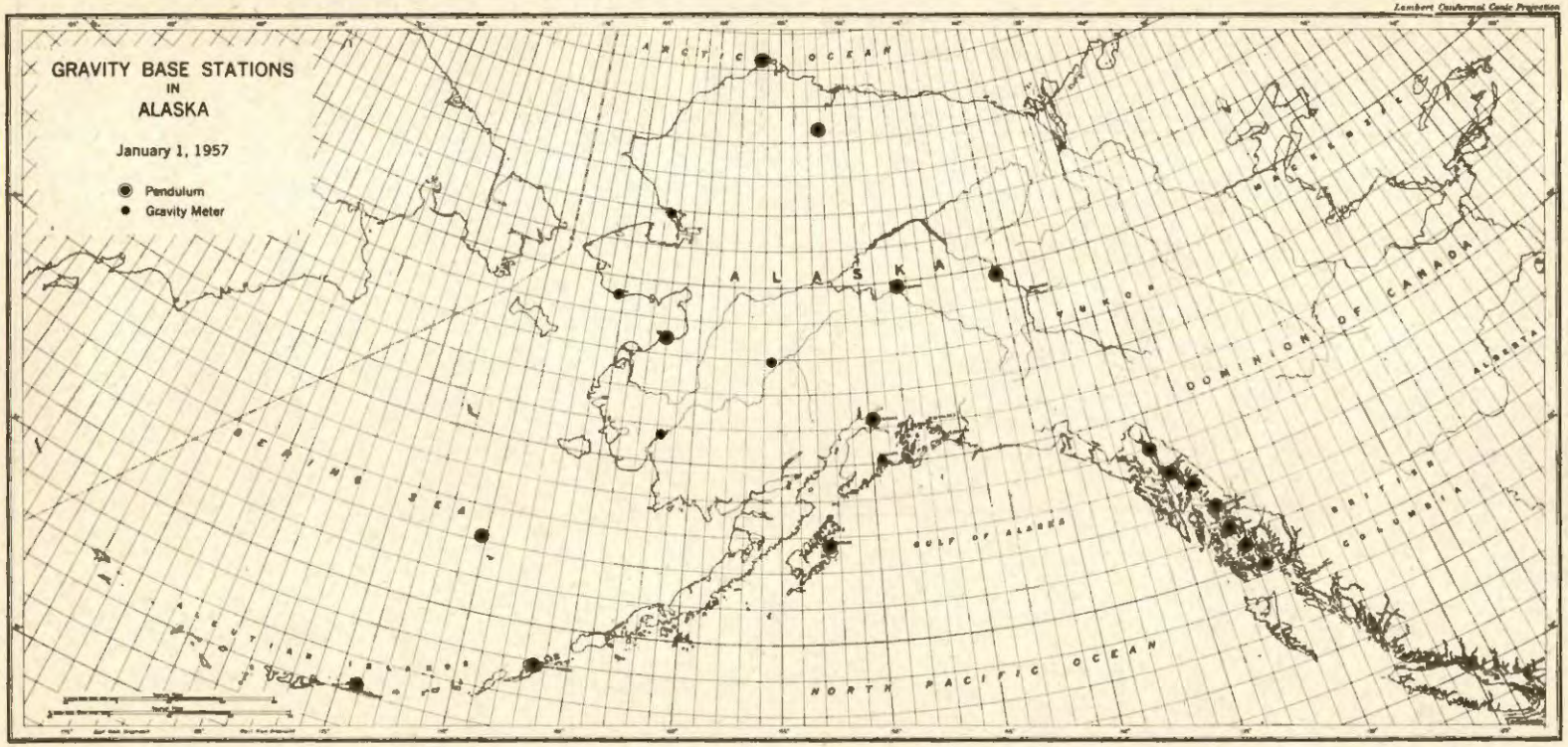

FIGURE 14.—Coast and Geodetic Survey gravity base stations in Alaska.

net result will be the establishment of a standard gravity base for the world gravity systems.

To this goal, a pendulum gravity baseline was completed from Alaska to Mexico City and a series of circumequatorial pendulum gravity bases were established. A baseline along the 30th Meridian Triangulation Network in Africa was also established. Many gravimeter ties between pendulum bases and local gravity surveys were made concurrently.

In the United States, only the area between the Rocky Mountains and the Pacific Coast remains before a reference framework of gravity control bases will have been completed.

United States Geological Survey

Regional gravity surveys in parts of the western states have been conducted by the Geological Survey in connection with geologic investigations. Various areas totaling about 50,000 square miles have been wholly or partly completed in northern Utah, western Washington, southern California, and the Colorado Plateau. In this work gravity stations were observed at intervals of 1 to 3 miles along roads, and additional detail was obtained to outline significant gravity anomalies. These data were used primarily to locate and trace geologic structures and obtain information on major structural units.

Detailed gravity surveys were made in Camaguey Province, Cuba, as part of a systematic exploration program conducted by the Geological Survey to locate deposits of refractory-grade chromite. Approximately 41,920 gravity stations were established over 20 x 40 and 30 x 60 meter grids in nine areas, embracing about 12 square miles in the Camaguey chromite district. Gravity meters with low scale constants were used in making measurements sufficiently accurate to delimit anomalies as small as 0.05 milligal. The results were used to guide exploratory drilling which found five deposits containing a total of about 250,000 long tons of chromite.

Other Organizations

Gravity traverses along level lines throughout the United States have been established by parties working under Dr. G. P. Woollard of the University of Wisconsin. These data are processed to include free-air and simple Bouguer anomalies. Most of the data are now being computed on IBM punchcards. As a contribution to the gravity control, Woollard has established about 150 stations at principal airports distributed around the United States. The Woollard group has also made some progress in regional gravity surveys in Alaska.

A regional gravity survey of the State of Ohio was completed in 1956 by the Ohio State University group under Dr. W. A. Heiskanen. The survey comprises about 2,000 evenly spaced gravity stations and is contoured at a 5-milligal interval. Free-air, Bouguer, and Airy-Heiskanen (T=30 km) anomalies have been computed.

A gravity survey of Puerto Rico has been carried out by the Lamont Geological Observatory, Columbia University. This survey comprises 600 stations and is displayed by modified Bouguer anomaly contours at a 5-milligal interval. Progress of the submarine gravity program of the Lamont Geological Observatory was outlined in two recent reports (Trans. Amer. Geophys. Union, vol. 36, No. 2, pp. 326–338, 1955). This group observed a total of 2,057 stations during the 1947–53 period. Free-air and Bouguer anomalies for several of the cruises have been compiled. Gravity measurements in the Pacific Ocean have also been carried out with the Vening-Meinesz apparatus by the group under Professor Louis Schlicter of the University of California at Los Angeles.

GEOID INVESTIGATIONS

United States Coast and Geodetic Survey

In cooperation with the United States Air Force a study was made of relative geoidal undulations in a rectangular area of about 200 x 1,100 miles between Cape Canaveral, Fla., and Puerto Rico. Deflections of the vertical were calculated directly by the Stokes formula at several hundred points on a regular mesh in the area. Probable error of the calculated deflections was approximately 3.0 seconds of arc in each component, as determined from 78 astrogeodetic test stations. The computed deflections were integrated and the geoid height differences adjusted by least squares to produce a geoid contour map with a 1-meter interval. An interesting feature of this map is the drop of about 35 meters in the geoid between Cape Canaveral and a point about 100 miles north of Puerto Rico. Major geoid height differences are associated with the Puerto Rico trench.

During 1956 work was begun on an astrogeodetic profile of the geoid on the 35th parallel across the United States. Stations are observed at an average interval of 18 miles. By the end of 1956 this chain had progressed as far west as Chattanooga, Tenn., a distance of about 600 miles.

United States Air Force

During the period 1954–56, efforts were directed toward the collection and cataloging of gravity data from sources all over the world. Studies of gravity reduction methods were made, and the use of high-speed computers for gravity calculations was investigated. Theoretical studies of the earth's gravitational field were also made. Templates were designed for convenient computations of the undulations of the geoid and deflection of the vertical components for different latitudes at intervals of 5 degrees.

The tangible results of much of the above work has been incorporated in two maps which were just recently completed. One of these maps shows the free-air gravity anomalies in 5° x 5° squares for the entire world where gravity data are available; the other is the corresponding map showing the undulations of the geoid for the Northern Hemisphere.

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