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COAST AND GEODETIC SURVEY
ROBERT F. A. STUDDS, Director

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

## January 1, 1939, to December 31, 1953

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

Special Publication No. 320

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## PREFACE

This publication is one of a series which have been prepared for distribution at the General Assemblies of the International Association of Geodesy. In addition to supplying the information required for the National Reports assembled by the Association, these publications have a historical value for geodesists in the United States. They provide a means of tracing the development of surveying methods and the extension of the control networks in this country. The first of these publications appeared as an Appendix to the Director's Report for 1889. In later years these reports on geodetic operations have been prepared as Special Publications of the Coast and Geodetic Survey.

This report contains information describing the operations for the 15-year period from January 1, 1939, to December 31, 1953. During that time there was an increasing interest in the use of geodetic control surveys with a corresponding acceleration in research and in the application of geodetic information to engineering projects. The technical advances made in all fields of science and engineering have required the use of the most modern instruments and methods for geodetic operations.

In this 15-year period the geodetic profession lost several outstanding leaders and colleagues by death. Dr. William Bowie, whose contributions to the International Association of Geodesy and the International Union of Geodesy and Geophysics are well known, passed from this life on August 28, 1940. Tribute is also given to the deceased colleagues of Dr. Bowie who served with him in the Coast and Geodetic Survey and whose contributions are known nationally and internationally. Comdr. George D. Cowie, who had served as Assistant Chief of the Geodesy Division, was killed during the bombing of Manila on December 24, 1941. Walter F. Reynolds, Chief of the Triangulation Branch for many years, died May 1, 1942. Henry G. Avers, Chief Mathematician of the Geodesy Division, died January 19, 1947. Charles J. Clifford, a mathematician in the Geodesy Division, who served as the American representative for assembling material for the bibliography of the International Association of Geodesy, died December 21, 1949.

Recognition is given those men who, because of age, have retired from active duty. Even though retired, many of them continue to take an active part in national scientific and engineering organizations. Oscar S. Adams, an international authority on projections and related mathematical developments, retired June 30, 1944. Capt. Clement L. Garner, who succeeded Dr. Bowie as Chief of the Geodesy Division, retired September 30, 1945. Hugh C. Mitchell, recognized as a leader in establishing precise city and urban surveys as well as a vigorous proponent for the use of State plane coordinates, retired November 30, 1945. Clarence H. Swick, who served for many years as Chief of the Gravity and Astronomy Branch and later as Chief of the Triangulation Branch, retired December 31, 1945. Frederic W. Darling, mathematician in the Gravity and Astronomy Branch, retired March 31, 1949.[1] Walter D. Lambert, internationally known and highly esteemed geodesist, retired June 30, 1950. Capt. Henry W. Hemple, who followed Captain Garner as Chief of the Geodesy Division, retired October 31, 1952. Howard S. Rappleye, Chief of the Leveling Branch, retired March 31, 1953. Much of the work described in this report was accomplished under the direction

[1] Deceased April 1954.

and leadership of these men. They have made outstanding contributions to the advances which have been made in the geodetic activities of this country.

This report was prepared with the general assistance of Lansing G. Simmons, Chief Mathematician; Charles A. Whitten, Chief, Triangulation Branch; James B. Small, Chief, Leveling Branch; Donald A. Rice, Chief, Gravity and Astronomy Branch; Walter D. Sutcliffe, Chief, Field Records Branch, and other members of the Geodesy Division. The editorial work of combining the reports of other agencies performing geodetic operations with the information describing the activities of the Coast and Geodetic Survey was assigned to Charles N. Claire. The Coast and Geodetic Survey diagrams were prepared by Cecil H. McLendon, Robert C. Moler, and Mrs. Patricia Battley.

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# GEODETIC OPERATIONS IN THE UNITED STATES AND IN OTHER AREAS THROUGH INTERNATIONAL COOPERATION, JANUARY 1, 1939, TO DECEMBER 31, 1953

By ALBERT J. HOSKINSON, *Chief, Geodesy Division, United States Coast and Geodetic Survey*

## GENERAL STATEMENT

The geodetic activities carried out by the various agencies in this country during this 15-year interval involve the prewar period, World War II, and the postwar period. In the prewar period and the early years of the war there were many requests for special surveys in strategic areas. The most outstanding of these operations was the extension of geodetic control into the interior of Alaska during the war. Since the end of the war, this work in Alaska has been continued using all available resources.

In the postwar years there has been an increasing demand for geodetic control, not only for mapping at larger scales but also for major engineering projects involving reclamation, conservation, or construction. The geodetic survey program is coordinated with the requirements of the Geological Survey for its topographic mapping, with the military agencies for their special needs, and with the Bureau of Reclamation, Forest Service, and many State and local agencies who use primary horizontal and vertical control surveys. There has also been an increased demand for precise geodetic surveys in areas of crustal movement, some of which are related to earthquakes and others to withdrawals of water and oil from the ground.

With this ever increasing geodetic activity there is an accumulation of a tremendous volume of survey data which requires the maintenance of a large office force for the processing of these records. Before the war, special computing groups were maintained in New York and Philadelphia in addition to the regular staff in the Washington office. The total number of personnel engaged in the processing of these records in these three offices exceeded 400 at the time of the peak employment.

After the war, the difficulty of obtaining adequately trained personnel presented a serious problem. Rapid advancement had been made during the war years in the development of high-speed computing equipment and such equipment could be obtained for work which contributed to our national defense. In 1948 a unit of International Business Machines was set up in the Coast and Geodetic Survey to assist in processing our geodetic data. Similar machines had been used for specialized work during the war by the Lake Survey and after the war by the Army Map Service, both of the Corps of Engineers, United States Army. The number of personnel presently engaged by the Coast and Geodetic Survey for the processing of geodetic data is about 100, supplemented with the unit of punched-card computing equipment. With the aid of these high-speed computing machines, this Bureau was able to cooperate with the Army Map Service in the adjustment of large blocs of triangulation in Europe. Details concerning these special activities have been published in other reports.

## TRIANGULATION

The basic framework of the Coast and Geodetic Survey triangulation net of the United States consists of first-order arcs which, in general, are north-south or east-west in direction.

This network of arcs is nearing completion with only a few areas remaining where arcs are needed to provide a final spacing of 50 to 60 miles. The present policy of the federal mapping and surveying agencies is to establish triangulation stations at a density of 1 per 50 square miles with stations being placed along principal highways at about 4-mile intervals, and in urban areas they may be as close as 2 miles. The areas within the loops formed by the arcs of first-order triangulation are covered with a network of area triangulation having an accuracy only slightly below that of first order. At the present time there are more than 150,000 points in the network.

During this 15-year period great emphasis has been placed on the extension of these area networks with the result that more than 25 percent of the nets have been completed.

Although most operations in Alaska are limited to a short summer season, excellent progress is being made in the extension of the basic triangulation network in that territory. Airplanes and helicopters have become standard equipment for the transportation of instruments and personnel to the triangulation stations. Caterpillar trains have been used along the northern coasts during mid-winter for the transportation of supplies and personnel to the working grounds. The diagram of the Alaskan triangulation network shows the surveys that have been completed along the coastline and into the interior. Several of the islands which are offshore and beyond the limit of visibility from the mainland have been connected to it by electronic distance measurements.

In the development of the area networks, careful consideration has been given to the selection of base sites. If the surveys covered an urban area, two or more bases were generally measured and greater care exercised in observing the horizontal directions so that primary control of very high first-order accuracy could be obtained for use in city surveys. These extra base lines give added strength to the adjustment of the nets. There are a few areas within the United States where the basic control determined by the successive subdivision of loops has presented serious difficulties in the adjustment of the area networks. An excessive amount of strain has been introduced by the adjustment, and the presence of base lines helps to evaluate the accuracy of the final adjusted data. In 1953 the Coast and Geodetic Survey secured a geodimeter (one of a group of five obtained by the Engineer Research and Development Laboratories, Fort Belvoir). To date this instrument has been used only for experimental work, but it is anticipated that it will be used to measure lines of triangulation in areas where it is not practical to measure a base with tapes.

The elevations of the triangulation stations have been determined by means of trigonometric leveling in most of the areas where new surveys have been established. The only exception to this general policy is in the case of surveys in the eastern part of the United States where steel towers are used and where there is sufficient density of precise leveling lines for vertical control. In such instances, vertical angles are not measured.

An increasing interest in the use of the State plane-coordinate systems has been clearly indicated by the fact that legislatures of twenty additional States have passed laws which recognize the use of these systems. The diagram (fig. 4) shows the States which have enacted plane-coordinate legislation.

As rapidly as the surveys are completed, the results are processed so that printed diagrams of the triangulation, and descriptions, geographic positions, and plane coordinates of the newly established points are available for engineering and mapping purposes. The amount of this material has become so great that it is necessary to maintain comprehensive indexes. These indexes are being prepared and maintained through the use of our punched-card equipment. Printed indexes can then be made available by means of photolithography.

# GRAVITY AND GEODETIC ASTRONOMY

## GRAVITY SURVEYS AND REDUCTIONS

Gravity activity of the Coast and Geodetic Survey during the 15-year period covered by this report reflects a gradual transition from the pendulum to the gravity meter in obtaining coverage for geodetic purposes. At the same time, accuracy standards of pendulum data have been materially increased to afford adequate datum and calibration control of gravity-meter determinations.

During the period 1939–41, 145 new pendulum stations were established in the United States, following the previous practice of gradually extending coverage and supplying more detailed information in areas of special geophysical interest. This work was suspended during the War. Pendulum operations were resumed in 1948, but by then they had taken on new importance with regard to gravity-meter control. Gravity-meter surveys included various areas in the southern and central portions of the United States, along with establishment of a gravity-traverse system extending from Texas to North Dakota and from Kansas to the national gravity base in Washington, D. C.

Establishment of a modern system of gravity bases in Alaska was begun in 1952, involving long-range gravity-meter measurements closely controlled by a series of five new pendulum stations extending throughout the mainland gravity range. Air transport was used exclusively in this project. The group of 10 new stations, in conjunction with 12 pendulum stations established in previous years, will provide the framework for future gravity surveys in Alaska.

During the 15-year period, the Coast and Geodetic Survey has established 39 pendulum gravity base stations in areas outside North America, including 1 in the Territory of Hawaii, 4 in the Southwest Pacific, and 34 in Central and South America.

Considerable experimental work was done to improve accuracy of results obtained from the Brown pendulum apparatus. New observing procedures were adopted to minimize thermal, magnetic, and flexure effects. Since the adoption of the gravity meter in 1948 as a standard instrument for geodetic work, many field tests have been made to evaluate and control performance of the meters with regard to constancy of calibration, linearity, and drift stability.

Isostatic reductions by the Hayford-Bowie method have been made for all stations established by pendulum observations and for certain gravity-meter stations where the spacing is appropriate to the isostatic method. In area coverage, where the gravity-meter station spacing is customarily 6 to 10 miles, free-air and simple Bouguer anomalies are computed and displayed by iso-anomaly curves.

Through the cooperation of the Dominion Observatory of Canada, which had obtained the Cambridge University multiple invar-pendulum apparatus on a 2-year loan, independently determined gravity values were furnished at five stations of the United States north-south base line in 1952. The Dominion Observatory also observed two stations in the Republic of Mexico as part of this project. In 1953, the Dominion Observatory established a series of stations extending through western Canada to Fairbanks, Alaska, thereby connecting to the new Alaskan gravity network established by the Coast and Geodetic Survey in 1952. As another phase of this cooperative undertaking, a group from the University of Wisconsin has obtained gravity values over the Mexico-Alaska base system using quartz pendulums developed by the Gulf Oil Co. Results obtained by these three independent systems appear to be in satisfactory agreement, and will be the nucleus of an improved base network for control of North American gravity surveys.

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## ASTRONOMIC OBSERVATIONS

Determination of astronomic longitudes and azimuths in the United States has kept pace with requirements for Laplace azimuth control of the triangulation net. Latitudes were also determined at most of the Laplace stations to enable computation of the total deflection of the vertical. In a few instances, astronomic positions were determined specifically for geoid investigations. During the period reported, 93 latitudes, 100 longitudes, and 97 Laplace azimuths were observed in the United States with first-order accuracy. A considerable number of second-order astronomic positions were also observed for special purposes, such as determination of approximate deflections of the vertical for correction of horizontal angles observed in areas of rugged topography.

The past 15 years has witnessed the extension of the North American 1927 datum throughout Alaska. As this network developed, Laplace azimuth control was provided at suitable intervals and, following previous practice in the United States, astronomic latitudes were observed at most of the stations occupied. At the end of the reported period, 47 latitudes, 53 longitudes, and 58 Laplace azimuths had been observed at Alaskan geodetic stations. Due to severe restrictions imposed by weather and the limited observing time available nightly during the summer months, long periods of occupation were sometimes required to complete a station. Such delays were minimized as much as possible by providing sufficient equipment for a party to observe two elements simultaneously during favorable breaks in the weather. In recent years, the Wild T–4 theodolite has superseded the Bamberg transit for determination of astronomic azimuths in these high latitudes. Transportation and living conditions presented unusually difficult problems, the relatively small astronomic parties often operating as independent units in regions of extreme isolation. Almost all transportation was by air, and it was frequently necessary to use combinations of large airplanes, small airplanes, and helicopters to deliver the personnel and equipment to station sites.

A number of astronomic stations were established outside the United States and Alaska, among these being four Laplace points in Canada for control of the Alcan Highway triangulation, and a considerable group established in conjunction with a Shoran triangulation survey in the West Indies.

Experimental astronomic work included observations for comparison of various systems of second-order position fixing, and determination of azimuth in extremely low and high latitudes.

## SPECIAL GEODETIC ACTIVITIES

Fundamental data applicable to various geodetic investigations were published in tabular form. These data included tables of the Cassinis type for calculation of topographic-isostatic deflections of the vertical, and tables for application of the Stokes formula in determining deflections of the vertical from gravity anomalies.

A practical test of the Stokes formula for gravimetric deflections was carried out over an extensive gravity field in the south-central United States, utilizing gravity data from several commercial geophysical sources supported by control data and additional area coverage obtained by the Coast and Geodetic Survey.

## VARIATION OF LATITUDE

Two of the observatories of the International Latitude Service, at Gaithersburg, Md., and Ukiah, Calif., have been maintained in continuous operation by the Coast and Geodetic Survey during the 15-year period. New and enlarged living quarters have been built at each observatory. The records obtained at these observatories are forwarded monthly to the Central Bureau of the International Latitude Service, now located at Torino, Italy.

## PRECISE LEVELING

During the period from January 1, 1939, to December 31, 1953, the Coast and Geodetic Survey had an average of about ten separate leveling units in the field under the supervision of three chiefs of party, during which time 42,000 miles of first-order and 84,000 miles of second-order leveling were run. As of December 31, 1953, the total miles of leveling in the net were about 153,000 miles of first-order and 247,000 miles of second-order, or a total of 400,000 miles of leveling. On these lines 311,000 benchmarks have been leveled over. The present practice is to establish marks at approximately 1-mile intervals; however, there are fewer marks than miles of leveling because on the earlier leveling marks were not established at this close interval.

In regard to instrumental equipment, the Coast and Geodetic Survey is continuing to use the Fischer level on the major portion of its field work but we have been experimenting with the Wild N III and the Zeiss Opton instruments.

The ultimate development for the level net of the United States is for lines spaced from 5 to 10 miles apart, depending on available routes. Originally, 100-mile spaced first-order lines were developed and then the circuits formed were divided by 25-mile spaced second-order lines. The second-order spacing has been completed except for small areas in the western portion of the United States. The 25-mile spaced lines are being filled in with "area" leveling, which is sometimes referred to as 7½ mile spacing since we endeavor to place the lines along the boundaries of 7½ minute quadrangle sheets as far as feasible.

Subsidence studies have been continued in the vicinity of San Jose, Calif., and a new first-order net of lines was established in the vicinity of Delano, Calif., for settlement study. San Jose has settled about 6 feet since 1912, and Delano has settled about 6 feet since 1931. Releveling in 1953 in the central valley of California near Firebaugh shows a subsidence of approximately 10 feet since 1935 and a subsidence of 6 feet since 1947. About 1,000 miles of first-order leveling was established in the central valley of California for the needs of the United States Bureau of Reclamation.

The development of several city level nets has been undertaken in cooperation with the local authorities to establish basic nets for local use. This has been done at San Antonio, Fort Worth, and Dallas, Tex.; Cincinnati, Ohio; New Orleans, La.; Norfolk, Va.; Charleston, S. C.; and New York City, N. Y. Since subsidence has been noticed in the vicinity of San Antonio, 21 marks were placed in monuments extending to a depth of 35 feet by the local authorities to perpetuate the leveling.

New lines of leveling are being established to fill requests for elevation data and additional releveling is undertaken when feasible in order to provide closer spacing of marks on the older lines.

Some progress has been made in the recovery and stamping of elevations on marks. We have had one man at each of our regional offices at Atlanta, Ga.; Fort Worth, Tex.; Kansas City, Mo.; and Portland, Oreg., undertaking recovery work.

In order that the users of our data may readily know where lines of leveling have been established, we have published State maps (usually 1–500,000 scale) on which are plotted the routes of the lines. The data can be ordered by line number for the particular area in which the user is interested. The descriptions and elevations of the benchmarks are now published by lines in lithograph form. Publication in bulletin form by States has been discontinued. The major portion of the descriptive data is reproduced lithographically by using the description cards as prepared by the field party. In this way, it is not necessary to retype the descriptions. Preliminary elevations based on the field computations are prepared immediately after completion of the field work and, after the office computation and adjustment are completed, the list of preliminary elevations is superseded by a list of adjusted elevations.

In 1935, eight short lines, each of approximately 10 miles in length, were established normal to earthquake fault lines in Southern California. Marks were spaced very closely on each side of the fault line and the spacing increased as the distance from the fault line increased. There were about 200 marks established on each of these eight cross lines. The original plan was to relevel these when feasible in order to determine what changes had taken place. During the period 1939 to 1953, these lines have been releveled as follows:

| Line title | Original leveling | Releveling |
|---|---|---|
| 1. Inglewood, Calif | 1935 | 1946 |
| 2. Brea, Calif | 1935 | 1946 and 1949 |
| 3. Cajon, Calif | 1935 | 1944 |
| 4. Palmdale, Calif | 1935 | 1938 and 1947 |
| 5. Moreno, Calif | 1935 | 1949 |
| 6. Gorman, Calif | 1935 | 1938 and 1953 |
| 7. Whitewater, Calif | 1935 | 1949 |
| 8. Maricopa, Calif | 1935 | 1938, 1948, and 1953 |

In addition to releveling these cross lines, we undertook releveling in 1953 after the Tehachapi earthquake in Southern California and found changes in elevation from approximately plus 2 feet to approximately minus 2 feet. First-order releveling was undertaken from Galveston via Houston to Port Isabel, Tex., in connection with subsidence studies. The maximum settlement found on this assignment was approximately 2½ feet near Texas City Junction from 1942 to 1951.

## GEODETIC OPERATIONS OF THE UNITED STATES GEOLOGICAL SURVEY

The Geological Survey, a Bureau of the United States Department of the Interior, conducts geodetic surveys including third-order spirit leveling, transit traverse, and triangulation. The fundamental purpose of this work is to establish the control survey framework for topographic mapping done by the Geological Survey. However, the control so established is used extensively by other organizations (Federal, State, and local) and by engineers and other individuals.

Usually the geodetic work of the Geological Survey is of third-order accuracy. During the 15-year period covered by this report, ties to first- or second-order surveys generally have been available within reasonable distance, so that it has not been necessary to run higher-order surveys in order to tie the mapping operations to the basic geodetic net. In the execution of its third-order work the Geological Survey established permanent marks which are available to define standard datum in any local engineering project for which this grade of control is sufficiently accurate.

During this 15-year period, the total amount of control accomplished was approximately 200 miles of second-order traverse, 6,248 third-order triangulation stations occupied with many more intersected points, 99,835 miles of third-order transit traverse, and 165,201 miles of third-order leveling. The average annual rate of accomplishing the control has grown during the period, as topographic mapping activity in general has been appreciably increased.

The former practice of publishing the results of control surveys in bulletins covering entire States has been superseded by the present method of publishing control lists for individual 15-minute quadrangle areas. Separate lists are published for leveling, transit traverse, and

triangulation. A large portion of the computing effort during the earlier years of the report period was devoted to readjusting much of the older work to the latest geodetic datums to bring it up to date for publication.

The geodetic activities of the Geological Survey during the period have been marked by an increased amount of research and development on new ideas and techniques in both field and office practice. Attention has been devoted to the possibilities of electronic methods of surveying, including Shoran and radar altimetry, especially as the framework for mapping in remote areas such as Alaska. Helicopters have replaced many of the older and slower methods of transportation in inaccessible country. New instruments have been introduced, such as optical-reading theodolites and pendulum levels. New field techniques include subtense-base traverse and increased use of slope-taping techniques. Improvements in office techniques include the replacement of logarithmic computation by machine methods, adjustment of survey nets electrically, and other time-saving devices.

An index map has been issued showing the extent of vertical control established in the United States by various Federal agencies. A similar index has been issued showing the existence of horizontal control. These maps are intended to serve governmental agencies and the general public in ascertaining the existence and availability of such data. Revised editions are published from time to time.

## GEODETIC OPERATIONS OF THE CORPS OF ENGINEERS, UNITED STATES ARMY

### ARMY MAP SERVICE

#### ARC OF THE 30TH MERIDIAN IN AFRICA

During the period December 1952 to January 1954 the Army Map Service, in cooperation with the Survey Departments of the Sudan, Uganda, and the Belgian Congo, carried out a first-order triangulation to close the gap in the Arc of the 30th Meridian in Africa.

As of 1952, there existed in this Arc a gap of 1,000 kilometers between Semliki Base at latitude 1° N. and Abu Qarn Base at latitude 10° N. The southern part of the gap is mountainous between Semliki Base and Juba at latitude 5° N. The section from Juba to Abu Qarn Base along the Nile Valley crosses the flat region of the Sudd and throughout the section steel towers 33 meters in height were required.

The angle observations were made by a field party of the Army Map Service, while the measurement of three base lines at Luluba, Kwidok, and Ayod, and the astronomic work were accomplished by the Sudan Survey Department.

For a detailed account of this cooperative project, reference is made to the report submitted by Great Britain.

#### HIRAN (HIGH-PRECISION SHORAN) PROJECTS

In 1952 the Army Map Service initiated a project for a geodetic connection by electronic trilateration (HIRAN) between North Africa and the Greek triangulation in the Aegean Sea. The purpose of this project was to obtain a better positioning of the triangulation around the Eastern Mediterranean, currently being readjusted, by a direct tie with the adjusted European Net across the Mediterranean Sea. The observations were carried out in the summer of 1953 by the United States Air Force in cooperation with the Greek Army Geographical Service and the Survey of Egypt.

In the same year, a similar HIRAN project across the North Sea was accomplished by the United States Air Force, at the request of the Army Map Service and in cooperation with the

Ordnance Survey of Great Britain and the Geografiske Oppmaling of Norway. The purpose was to establish a direct connection between the triangulation of the British Isles and that of Norway. This HIRAN connection now closes the loop of existing triangulation around the North Sea.

For further information on these HIRAN operations, reference is made to the report submitted by the United States Air Force.

## UNITED STATES LAKE SURVEY

Geodetic work of the Lake Survey from January 1, 1939, to December 31, 1953, has been mostly confined to first-order levels. A small amount of triangulation has been observed but this has been in the nature of third-order work for control of local surveys.

Level lines run by the Lake Survey are as follows:

(*a*) In 1941, a first-order level line was carried down the St. Lawrence River from Cape Vincent, N. Y., to Cornwall, Ontario, with a branch line from Alexandria Bay to Philadelphia, N. Y., a total distance of 170 miles, establishing elevations for 177 benchmarks.

(*b*) In 1946, a first-order level line was carried down the St. Clair River from Port Huron to Roberts Landing, Mich., a distance of 25 miles, establishing elevations for 31 benchmarks.

(*c*) In 1947, a first-order level line was carried along the south shore of Lake Huron, from Port Huron to Lakeport, Mich., a distance of 9 miles, establishing elevations for 18 benchmarks.

(*d*) In 1948, a first-order level line was carried down the St. Clair River from Port Huron to St. Clair, Mich., a distance of 14 miles, establishing elevations for 28 benchmarks.

(*e*) In 1949, a first-order level line was carried down the Detroit River from Grosse Pointe to Gibraltar, Mich., a distance of 40 miles, establishing elevations for 90 benchmarks.

(*f*) In 1953, a first-order level line was carried down the St. Lawrence River from Cape Vincent to Alexandria Bay, N. Y., a distance of 28 miles, establishing elevations for 20 benchmarks. In the same year another first-order line was carried from Fort Covington, N. Y., to Cornwall, Ontario, a distance of 18 miles, establishing elevations for 16 benchmarks.

## GEODETIC OPERATIONS OF THE UNITED STATES AIR FORCE

The United States Air Force entered the field of establishing geodetic control shortly after the beginning of World War II in 1942. The then Army Air Forces initiated field projects to establish lower-order astronomic stations in areas of interest in the world where usable geodetic control was sparse or nonexistent. Medium- and small-scale charts were being compiled from trimetrogon photography, and the AAF astronomic stations served to fill the geodetic control gaps. The astro stations were of third-order accuracy and were established with either a prismatic astrolabe, pendulum astrolabe, or zenith camera in China, Africa, South America, Mexico, Alaska, Canada, and the Near and Middle East.

In 1945 the AAF initiated a test project in the United States to determine whether Shoran bombing equipment could be used for establishing geodetic control. The test proved that ground control could be established successfully with certain modifications of equipment and techniques. As indicated in the accompanying diagrams, three successful high-precision Shoran (HIRAN) projects have been completed by the USAF. Those projects are: (1) the net which ties Florida with the Bahama Islands, Cuba, Haiti, Dominican Republic, and Puerto Rico; (2) the net of Crete-North Africa, which ties Crete and adjoining islands with Libya and Egypt; and (3) the Scotland-Norway net, which ties together Norway, Scotland, and the Shetland Islands.

In 1951 the Aeronautical Chart and Information Center, the charting organization of the USAF, established six first-order astronomic stations along the path of the projected 1952 Eclipse across Africa and Saudi Arabia. The control was later utilized to compare reduced eclipse distance data with computed distances between the astronomic stations.

In 1953 the Aeronautical Chart and Information Center of the USAF observed 13 third-order astro stations in the Bahama Islands. This control, which was established with the zenith camera, is now being utilized for charting purposes and gravity studies.

## GEODETIC OPERATIONS OF THE UNITED STATES NAVY HYDROGRAPHIC OFFICE

### GENERAL STATEMENT

The higher-order geodetic work done by the USN Hydrographic Office prior to 1939 was interrupted at the beginning of World War II. The wartime surveying was of necessity of lower order, sufficient only for hydrographic control, except in a few instances where greater accuracy was required. From 1945 on, the higher-order work was resumed as standard procedure.

### TRIANGULATION

Second-order triangulation in conjunction with hydrographic surveys was executed during the period 1939–53 in Mexico, North America; British Guiana, Colombia, Ecuador, Galapagos I., and Venezuela, South America; Guantanamo, Cuba; Jamaica and Little Exuma I., British West Indies; Cape Haitian, Dominican Republic; Guam Atoll and Saipan-Tinian, Marianas, South Pacific; Truk I., Carolines, South Pacific; and Okinawa Shima, South Pacific. Ships participating in these operations were the U. S. S. *Bowditch*, U. S. S. *Hannibal*, U. S. S. *Maury*, U. S. S. *Pathfinder*, U. S. S. *Sumner*, and U. S. S. *Tanner*.

### ASTRONOMIC OBSERVATIONS

In 1940 an astronomic party established 24 stations in the British West Indies; in 1943 an additional 23 stations were established.

During the period 1940–46, 15 astronomic stations, for the purpose of locating LORAN sites, were established on South Pacific Islands.

As a general practice, one astronomic station is taken each year as a survey progresses for the purpose of computing Laplace corrections for use in azimuth equations. Observations are made with a 60° prismatic astrolabe using chronograph and radio time signals.

### GRAVIMETRIC OBSERVATIONS

Gravimetric observations were conducted at nine positions on the north coast of Puerto Rico in December 1952. Seven of these points are new observations and the two end points at San Juan and Ramey AFB are recovered stations previously established by Dr. Woollard's organization.

## GRAVITY MEASUREMENTS BY OTHER ORGANIZATIONS

### GRAVITY AT SEA

Prior to World War II three gravity surveys at sea were made by United States submarines in the West Indies and the Caribbean Sea. These were the Navy-Carnegie Institution of Washington Gravity Expedition of 1928, the Navy-Princeton University Expedition to the West Indies of 1932, and the Navy-Geophysical Union Gravity Expedition of 1936–1937.

In 1947 the surveys were resumed through an Office of Naval Research contract with the Lamont Geological Observatory of Columbia University. One or more surveys have been made each year since then and a total of some 2,000 gravity observations have been made. These observations were taken in several crossings of the Pacific between the United States, Hawaii, Australia, and Japan, cruises off the west coasts of North and South America, cruises off the east coast of the United States, in the West Indies and Caribbean Sea, and two crossings of the North Atlantic.

In 1953 the Institute of Geophysics of the University of California began its program of marine gravity studies under contract with the Office of Naval Research. One survey off the California coast has been completed and others are being planned.

The gravity surveys participated in by the United States have been the result of cooperation between many scientists and scientific organizations both Government and private. Specific expression of appreciation is due Dr. F. A. Vening Meinesz, not only for his development of the gravity apparatus used on all the surveys reported here but for his continued interest and participation in our marine gravity program.

## WORLDWIDE GRAVITY MEASUREMENTS

During the period 1948–1953 a campaign of gravity-meter observations covering all the continents has been carried out by a group headed by Dr. George P. Woollard, of the University of Wisconsin. This group was sponsored and supported by the U. S. Air Force, U. S. Navy, and the Woods Hole Oceanographic Institution. The global network involves about 2,000 bases in 78 countries, and affords a direct comparison between national gravity bases to which the various existing surveys are referred. As previously mentioned, this group has also established pendulum stations along the North American gravity calibration traverse extending from Mexico City, Mexico, to Fairbanks, Alaska, in cooperation with the Coast and Geodetic Survey and the Dominion Observatory of Canada.

## REGIONAL GRAVITY SURVEYS

Good progress has been made during the past fifteen years in the development of regional gravity in the United States. Many gravity-meter operations, although intended primarily for geological purposes, have contributed a substantial amount of data which can be used in geodetic studies. In the main, these operations were carried out by State, educational, and commercial agencies and consisted of intensive geophysical area surveys, or traverses along highways where elevation control was readily available.

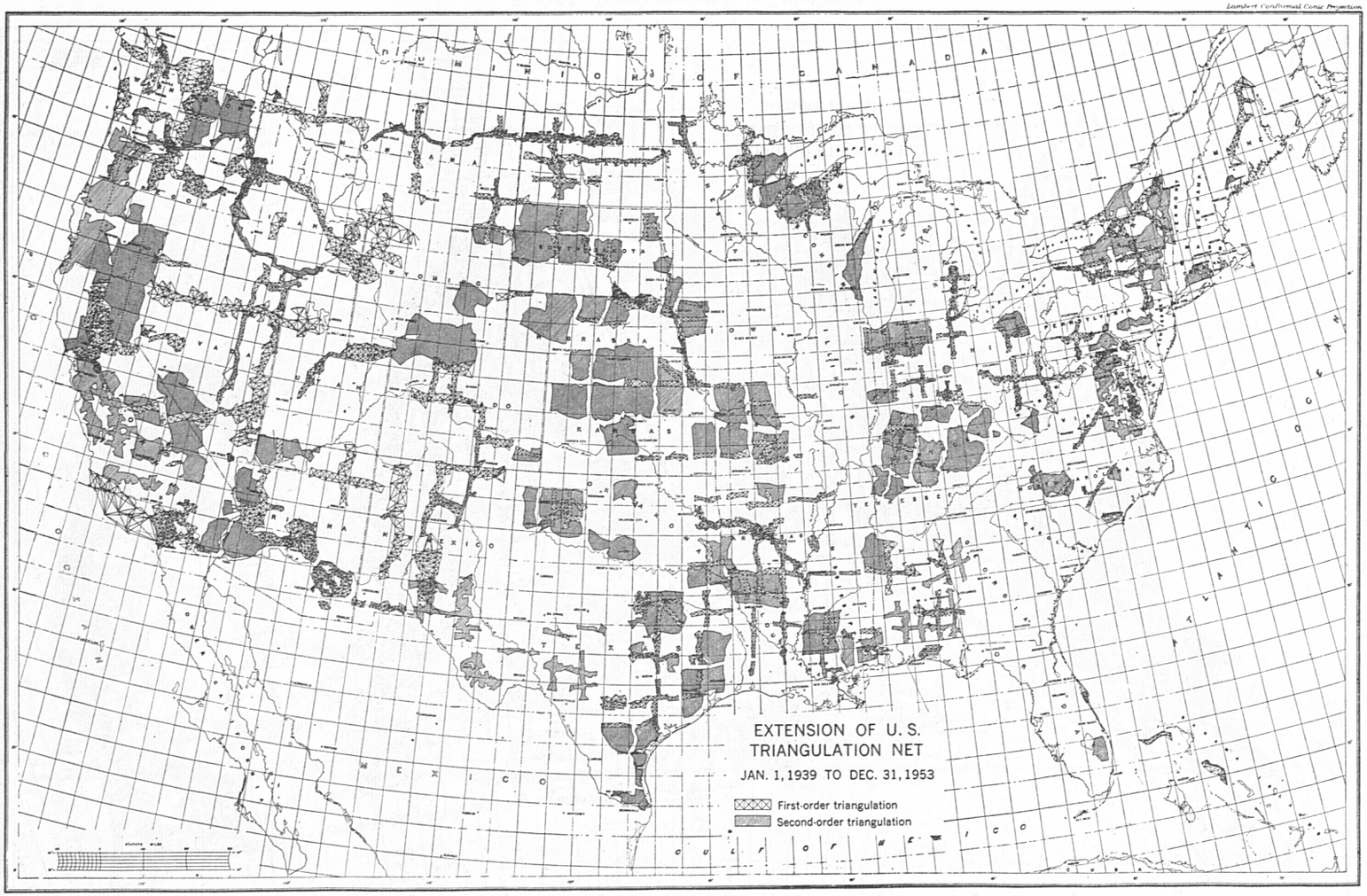


FIGURE 1.—Extension of the triangulation net of the United States.

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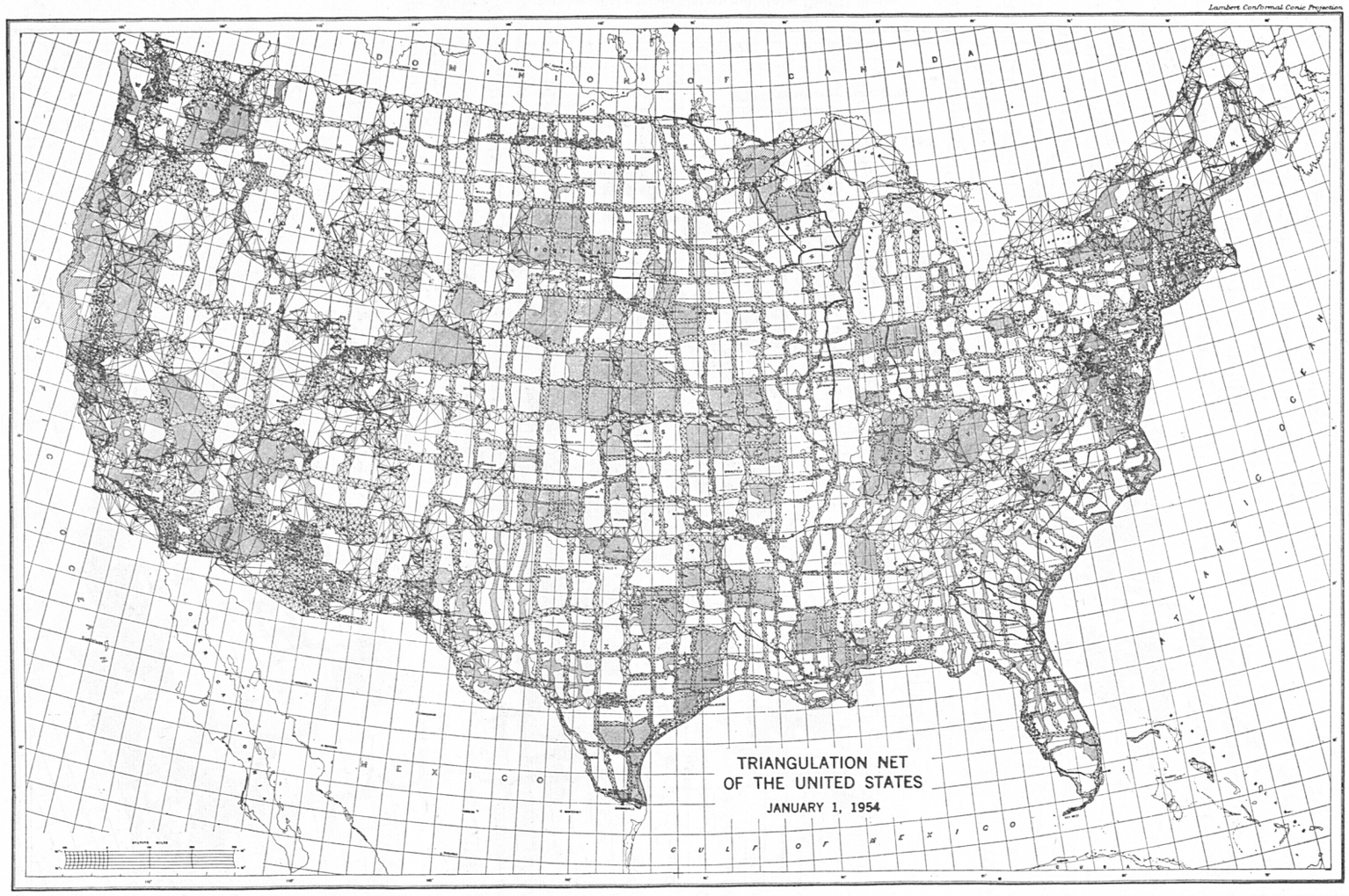


FIGURE 2.—Triangulation net of the United States.

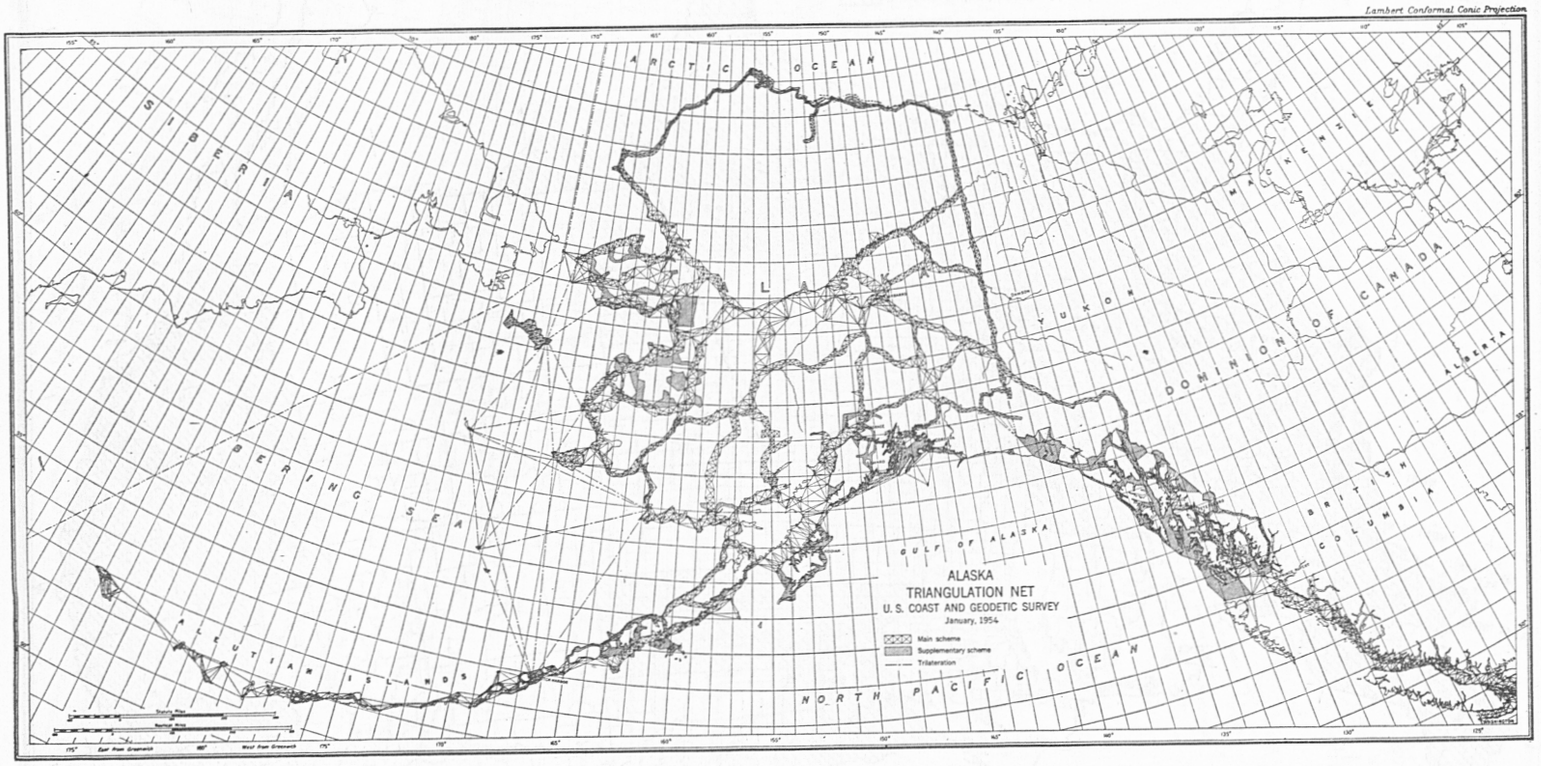


FIGURE 3.—Triangulation net of Alaska.

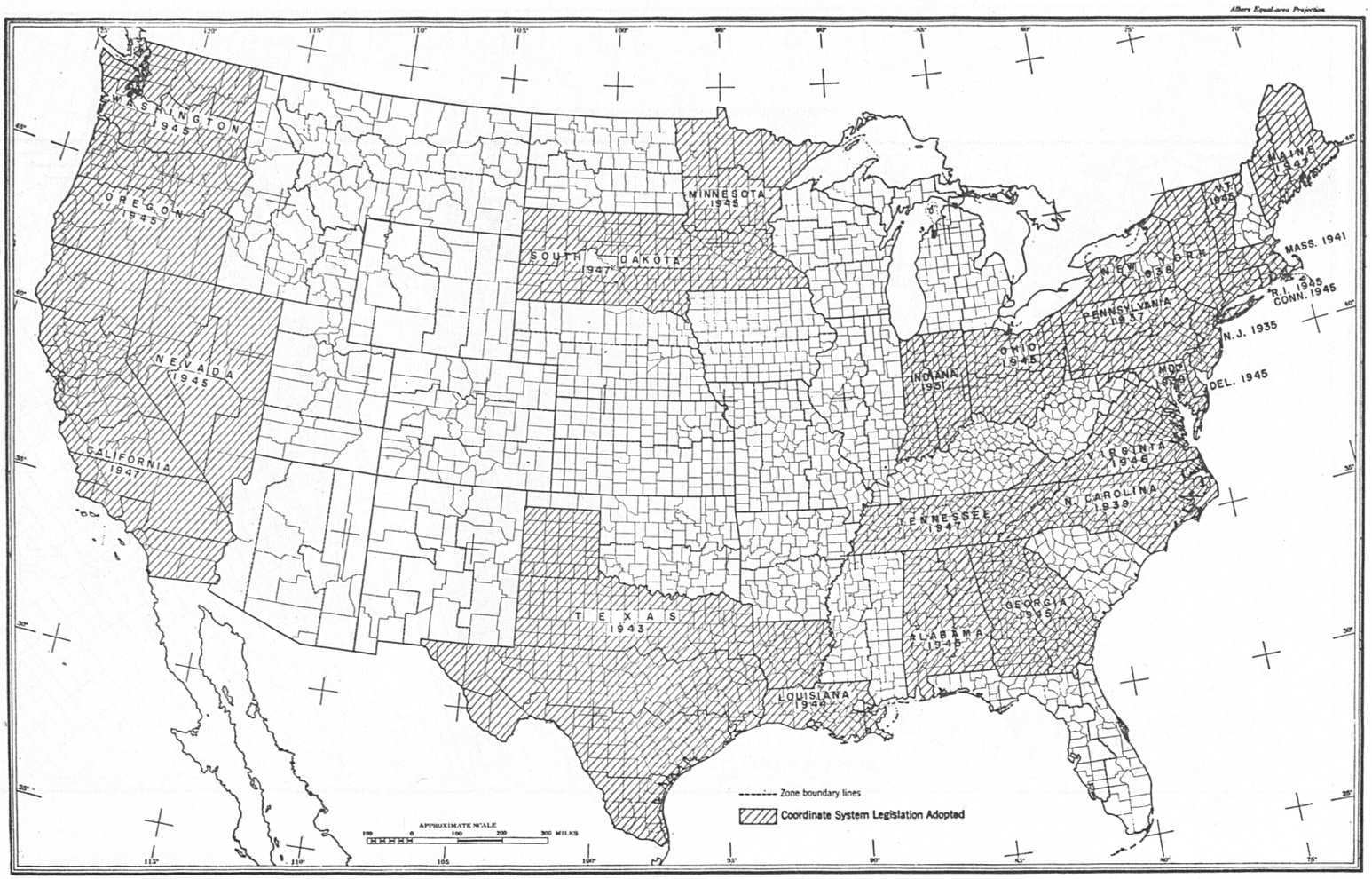


FIGURE 4.—States that have legally adopted the State plane-coordinate system

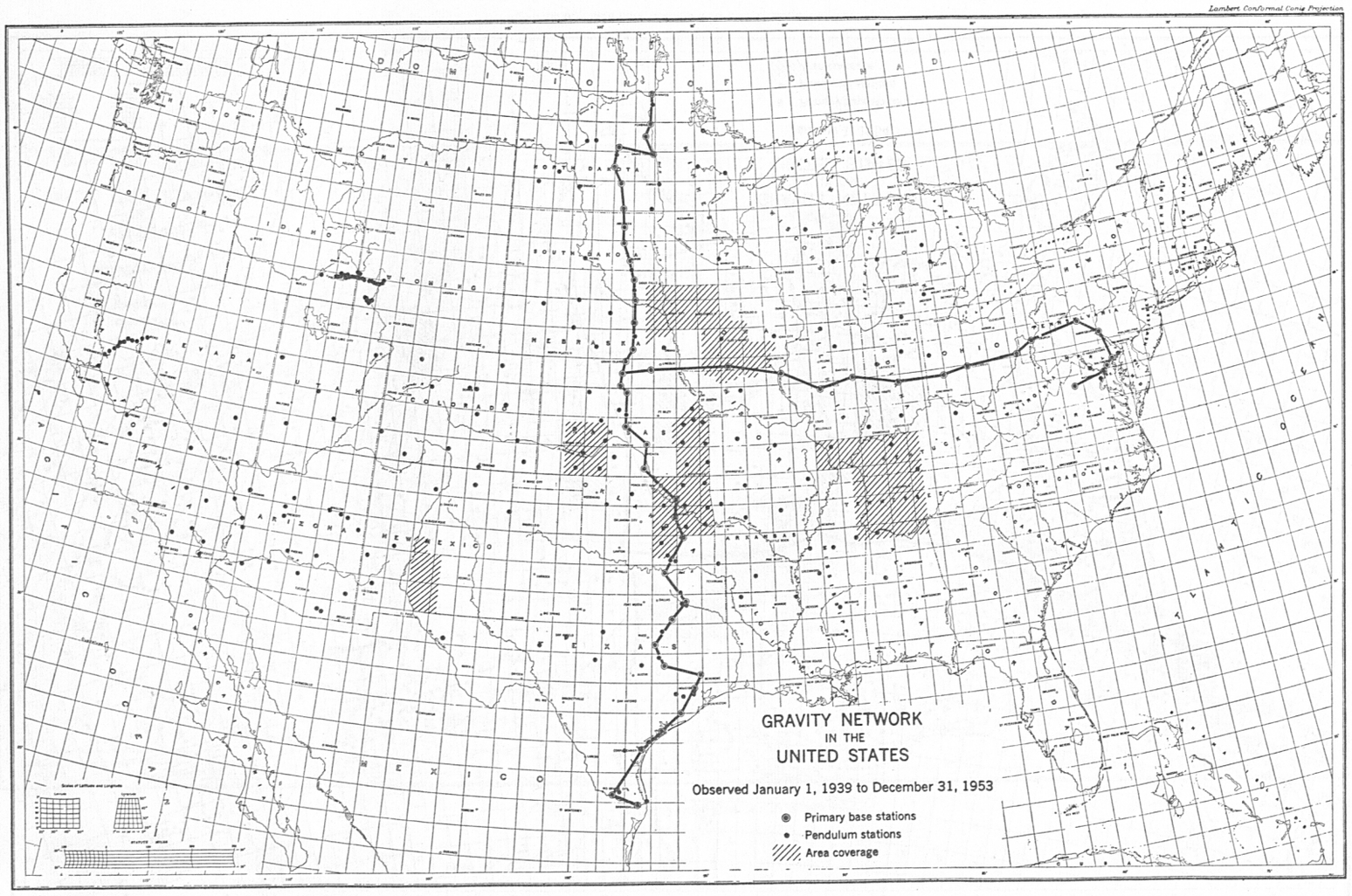


FIGURE 5.—Gravity network in the United States.

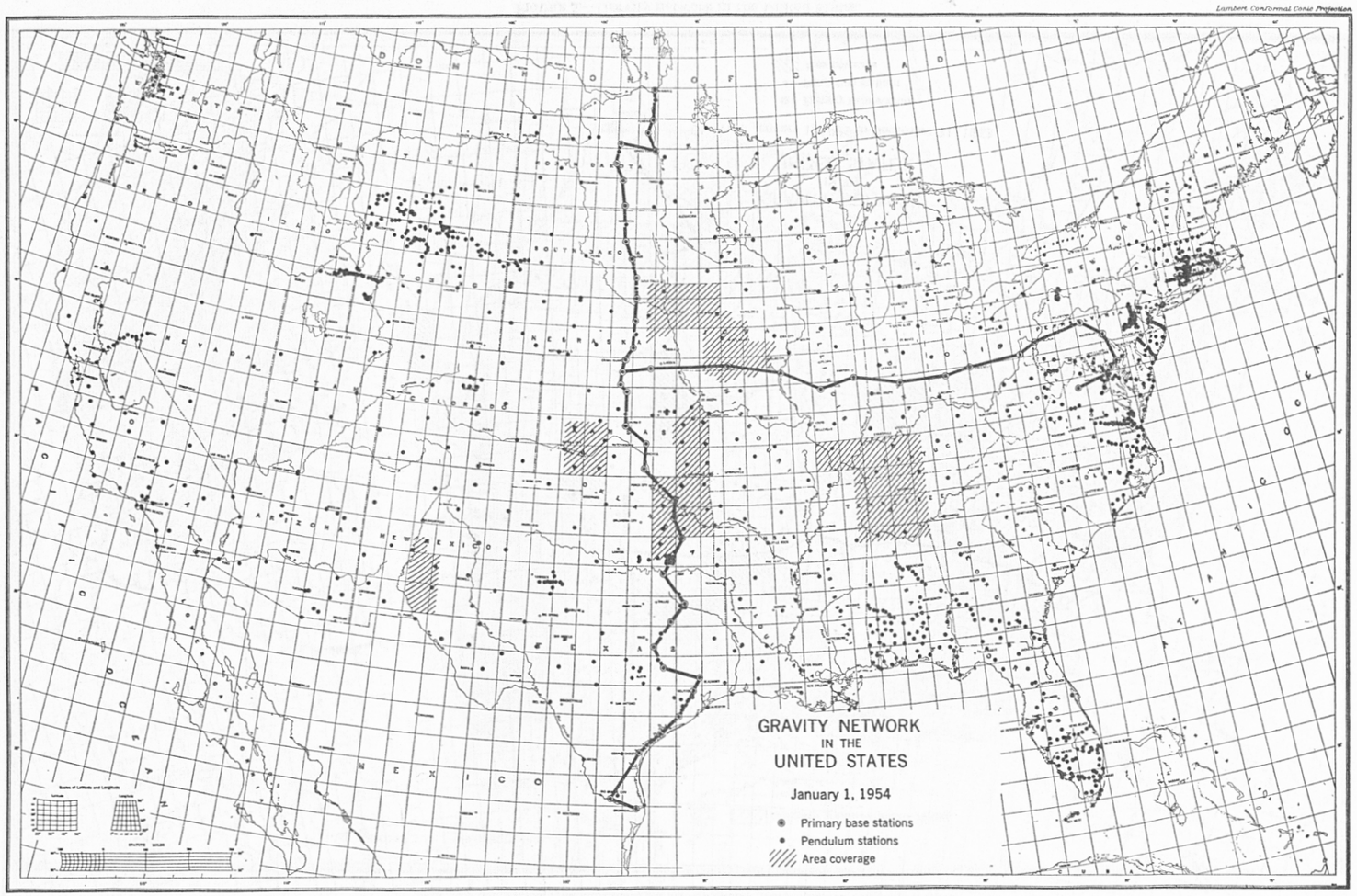


FIGURE 6.—Gravity network in the United States.

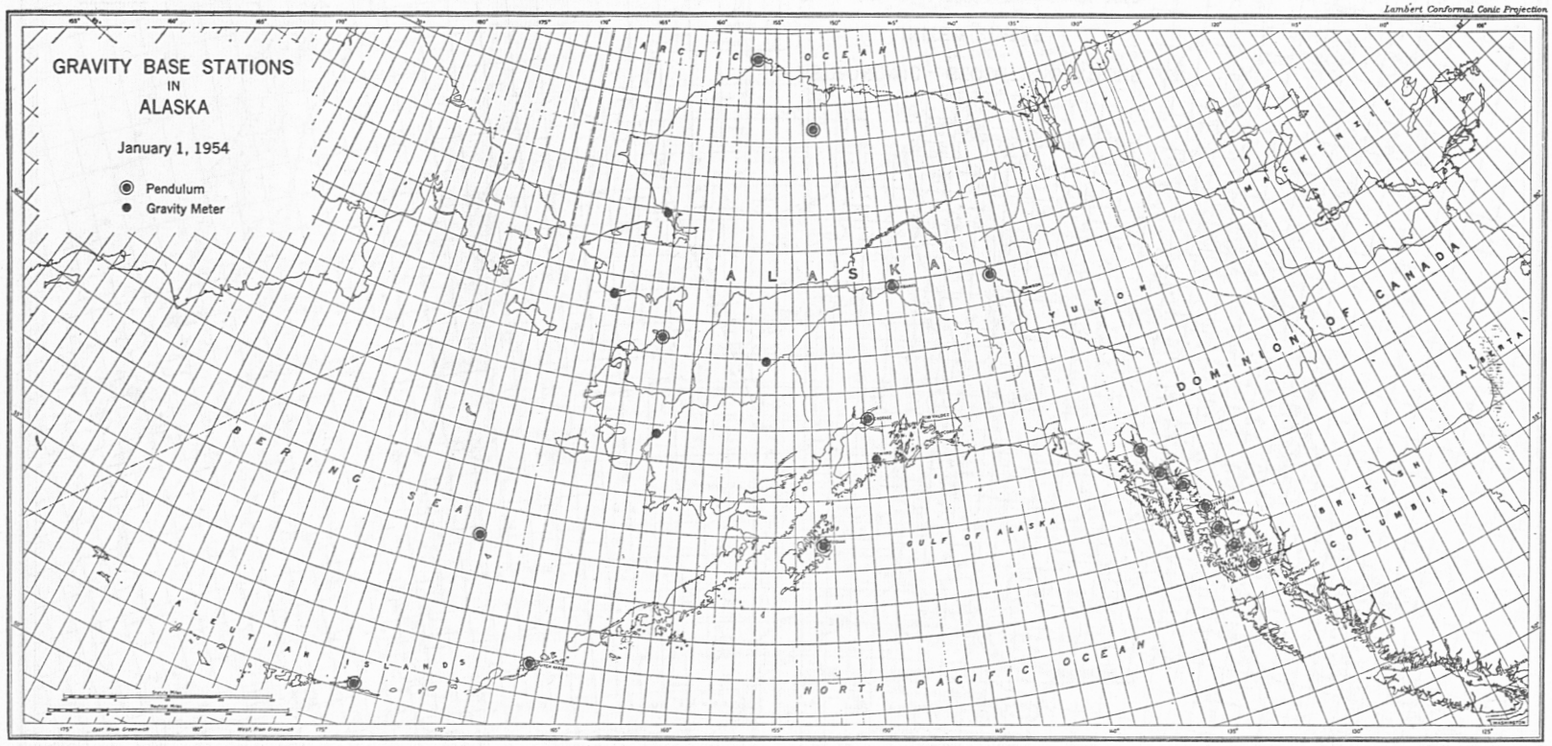


FIGURE 7.—Gravity base stations in Alaska.

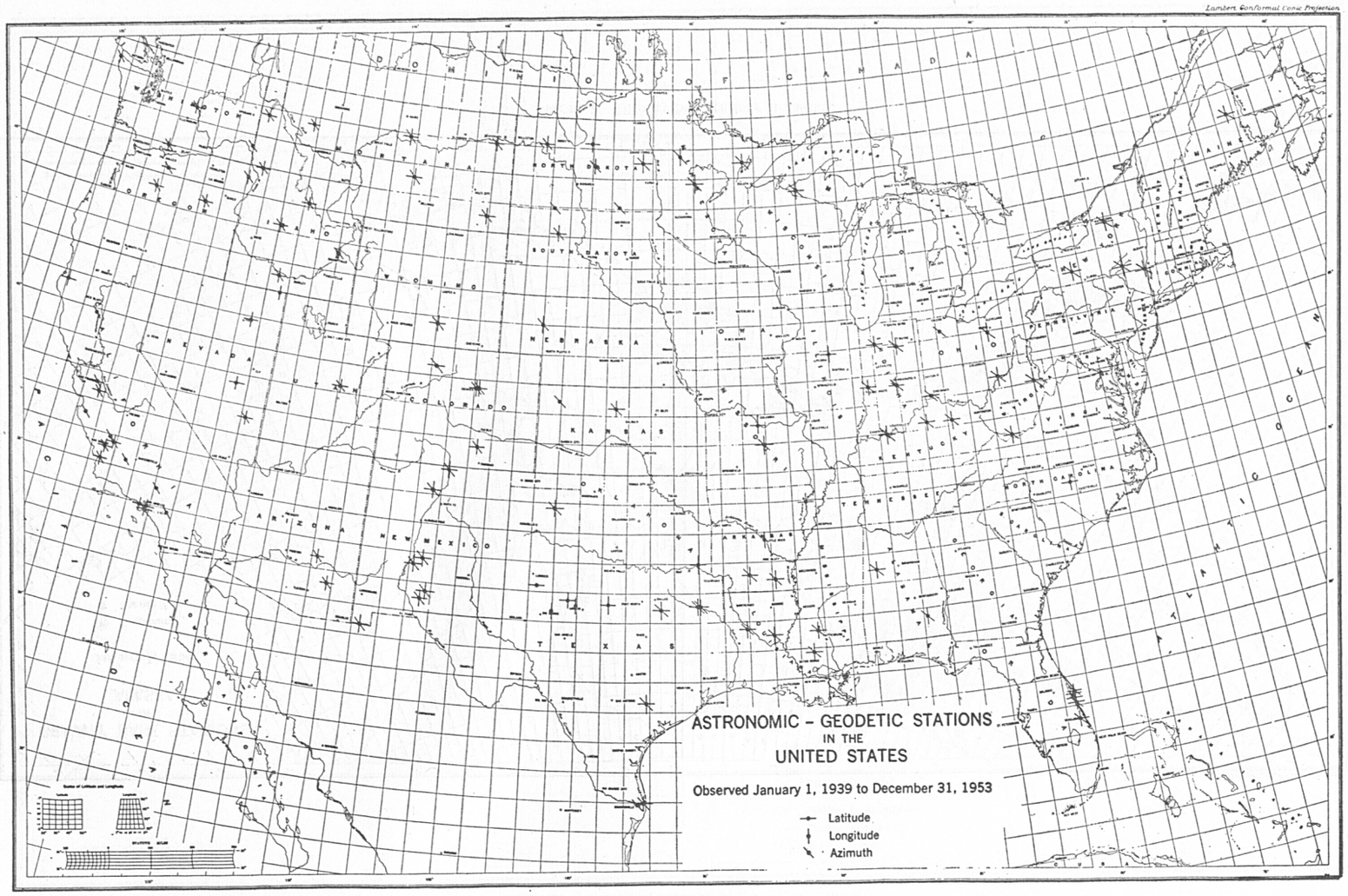


FIGURE 8.—Astronomic-geodetic stations in the United States.

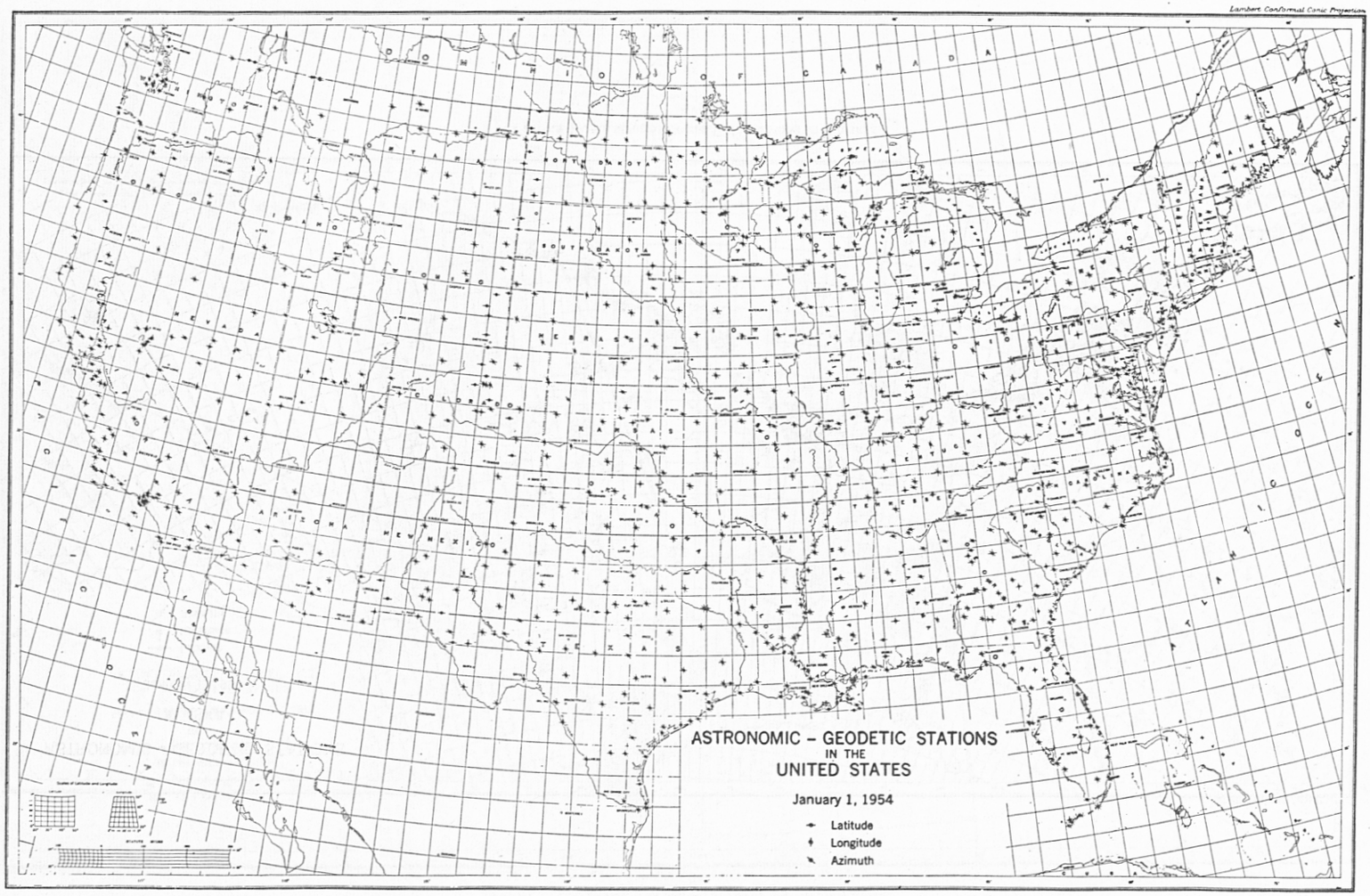


FIGURE 9.—Astronomic-geodetic stations in the United States.

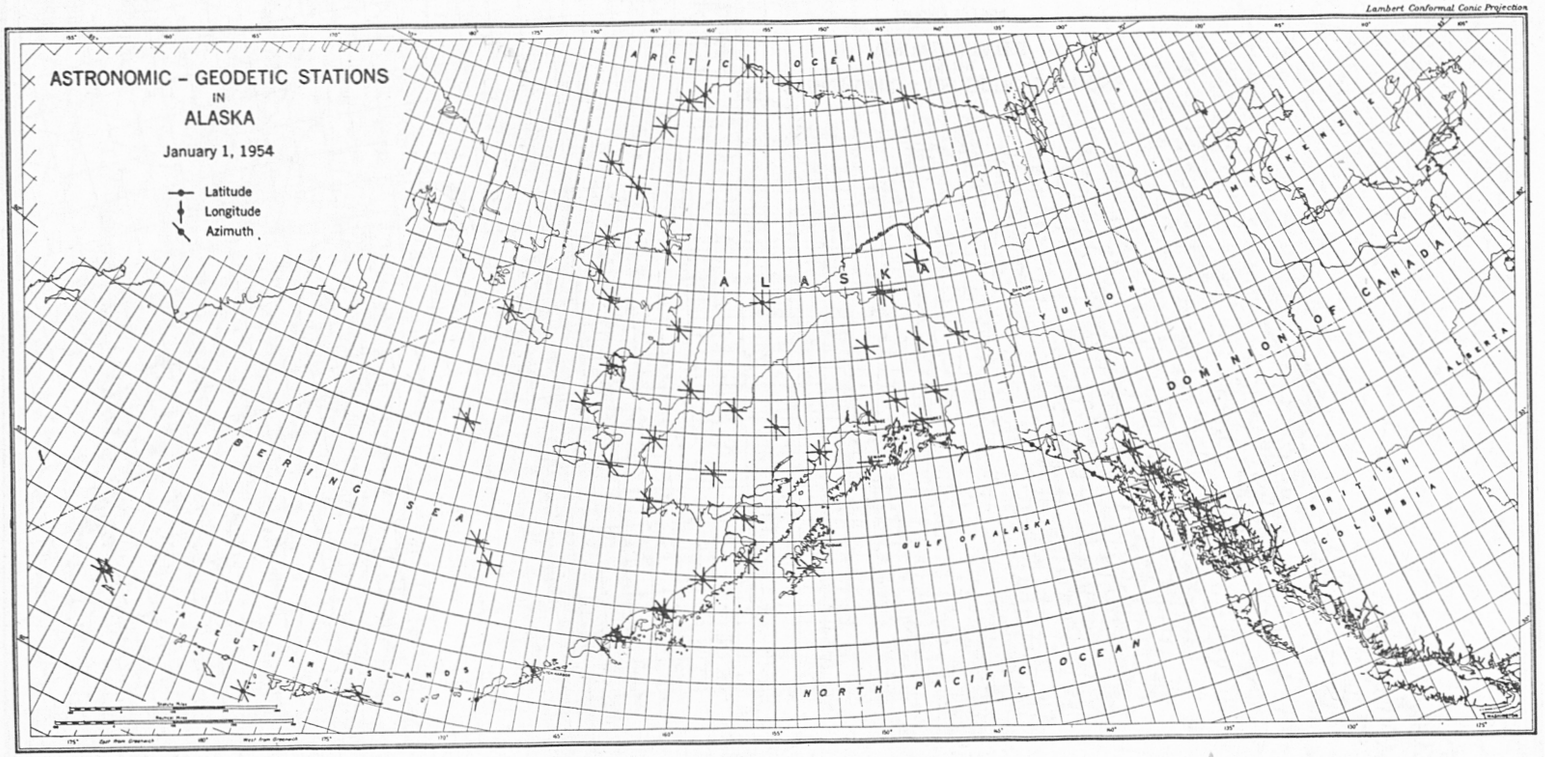


FIGURE 10.—Astronomic-geodetic stations in Alaska.

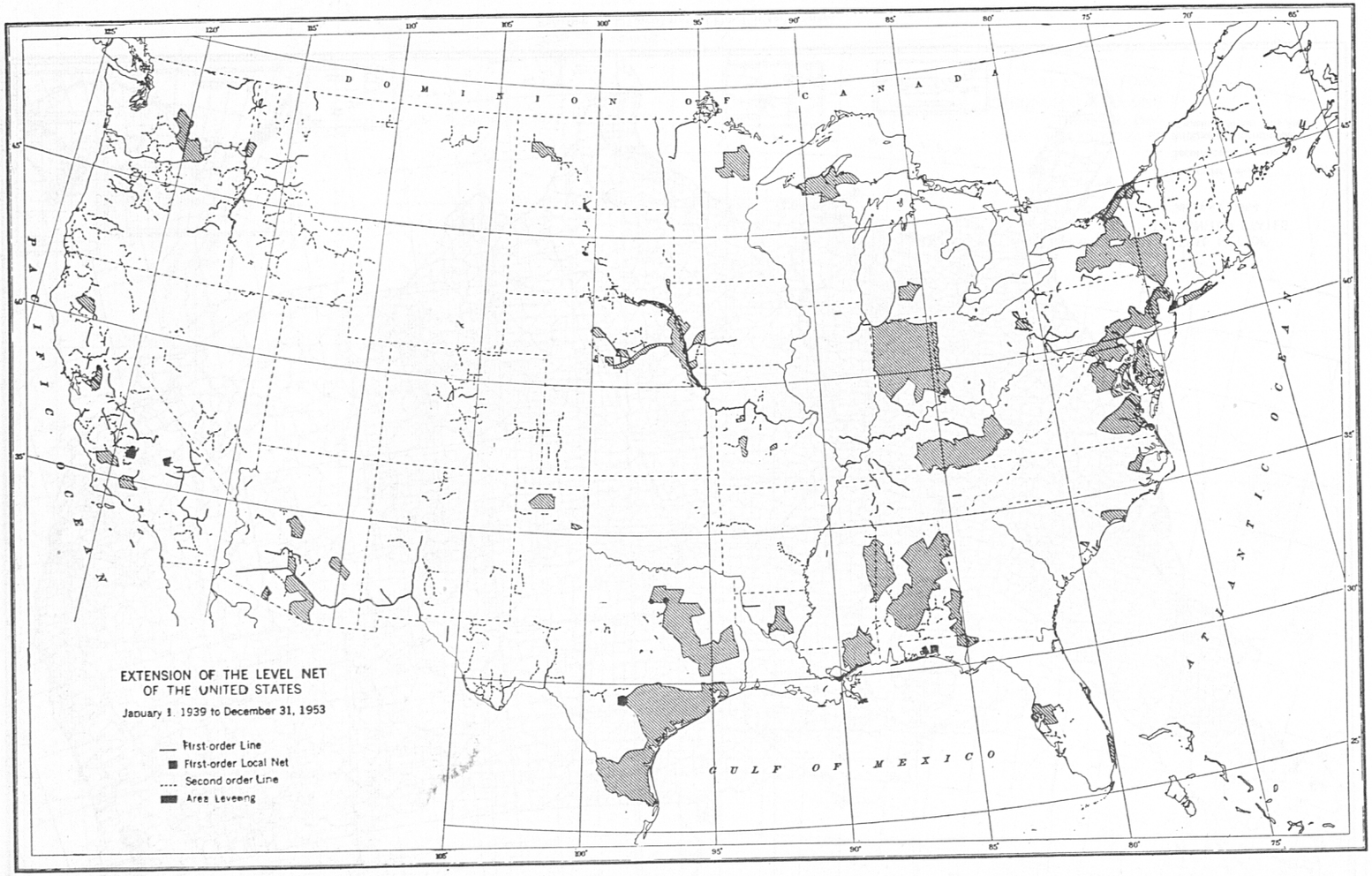


FIGURE 11.—Extension of the level net of the United States.

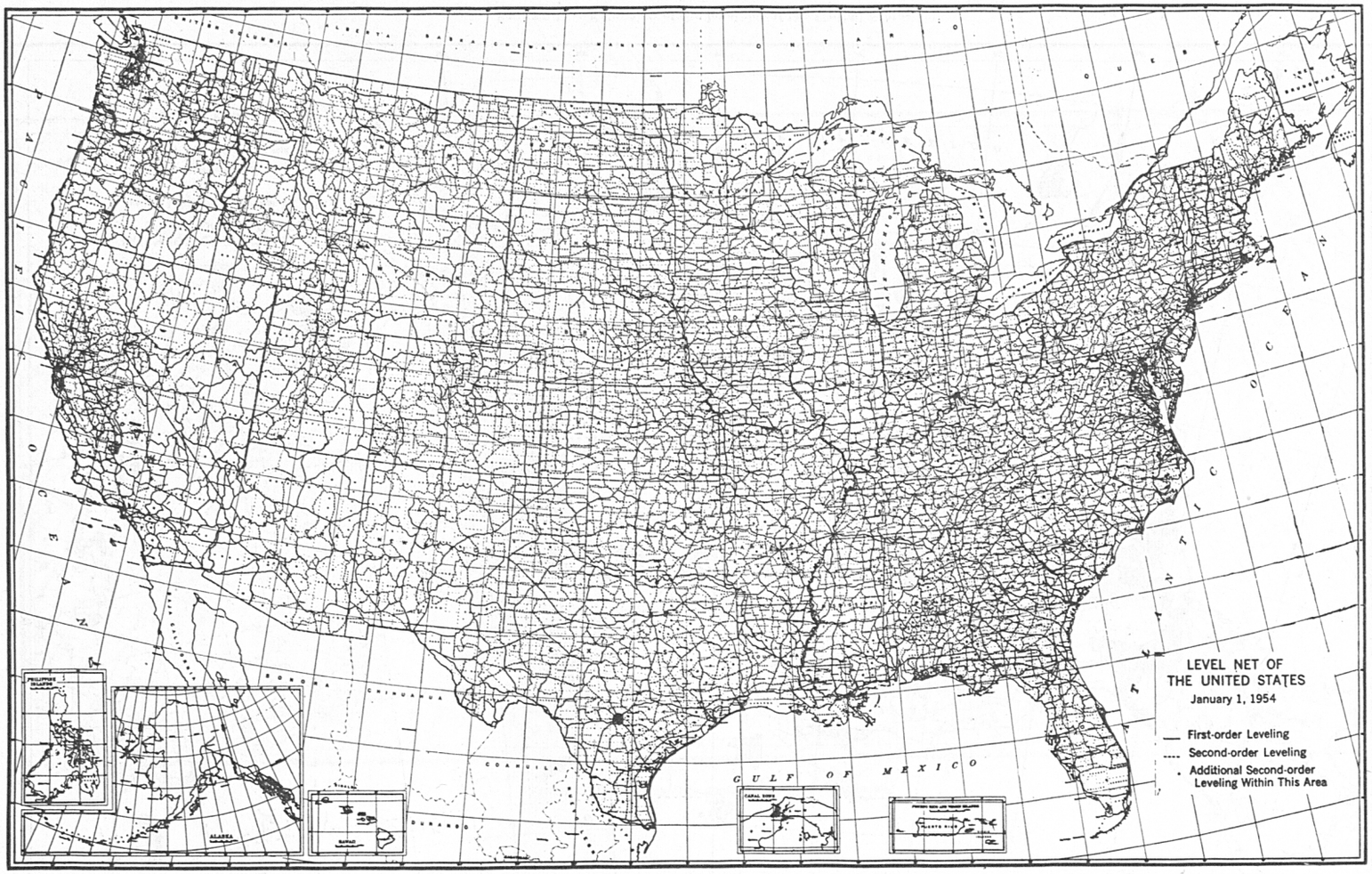


FIGURE 12.—Level net of the United States.

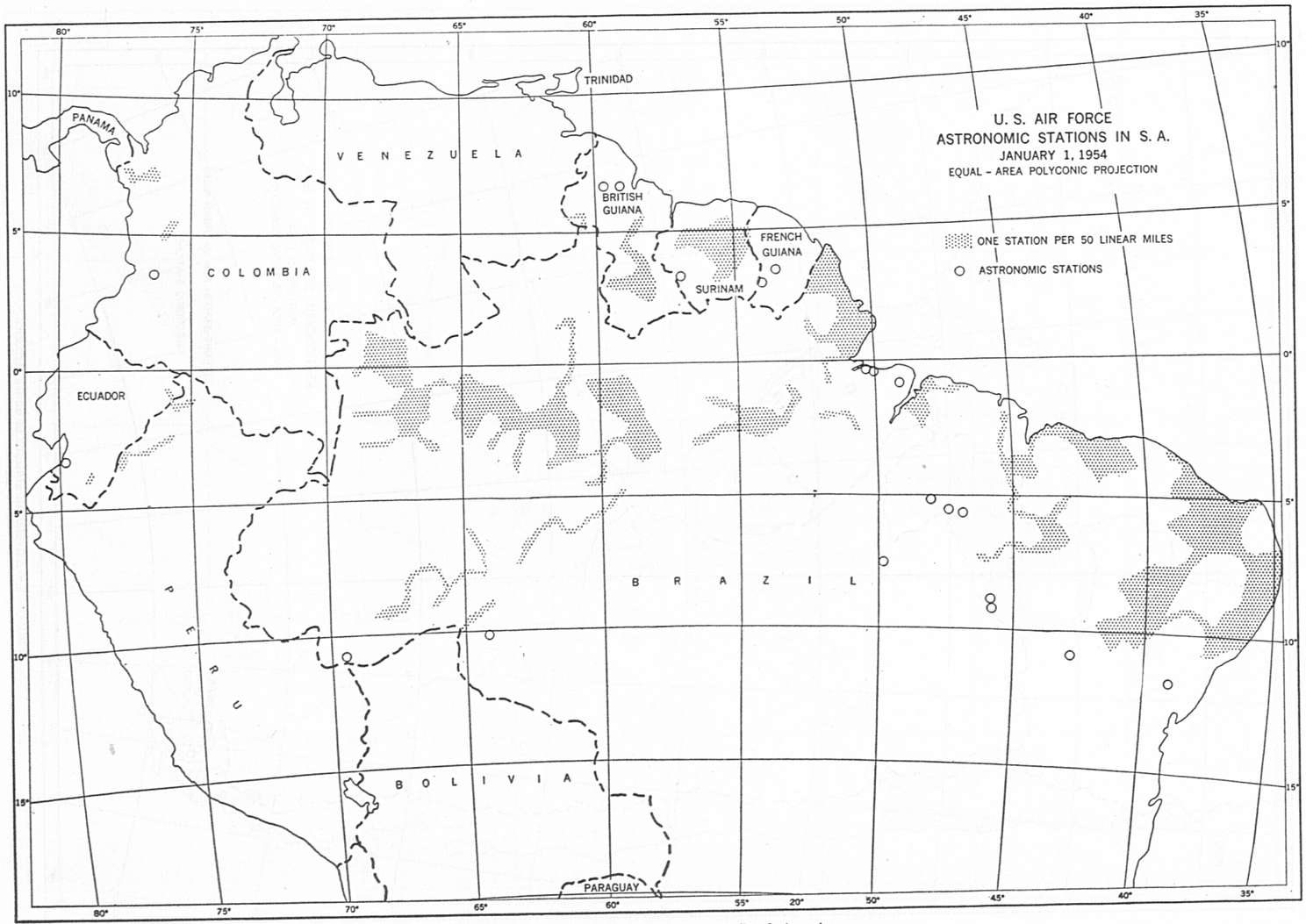


FIGURE 13.—Astronomic stations in South America.

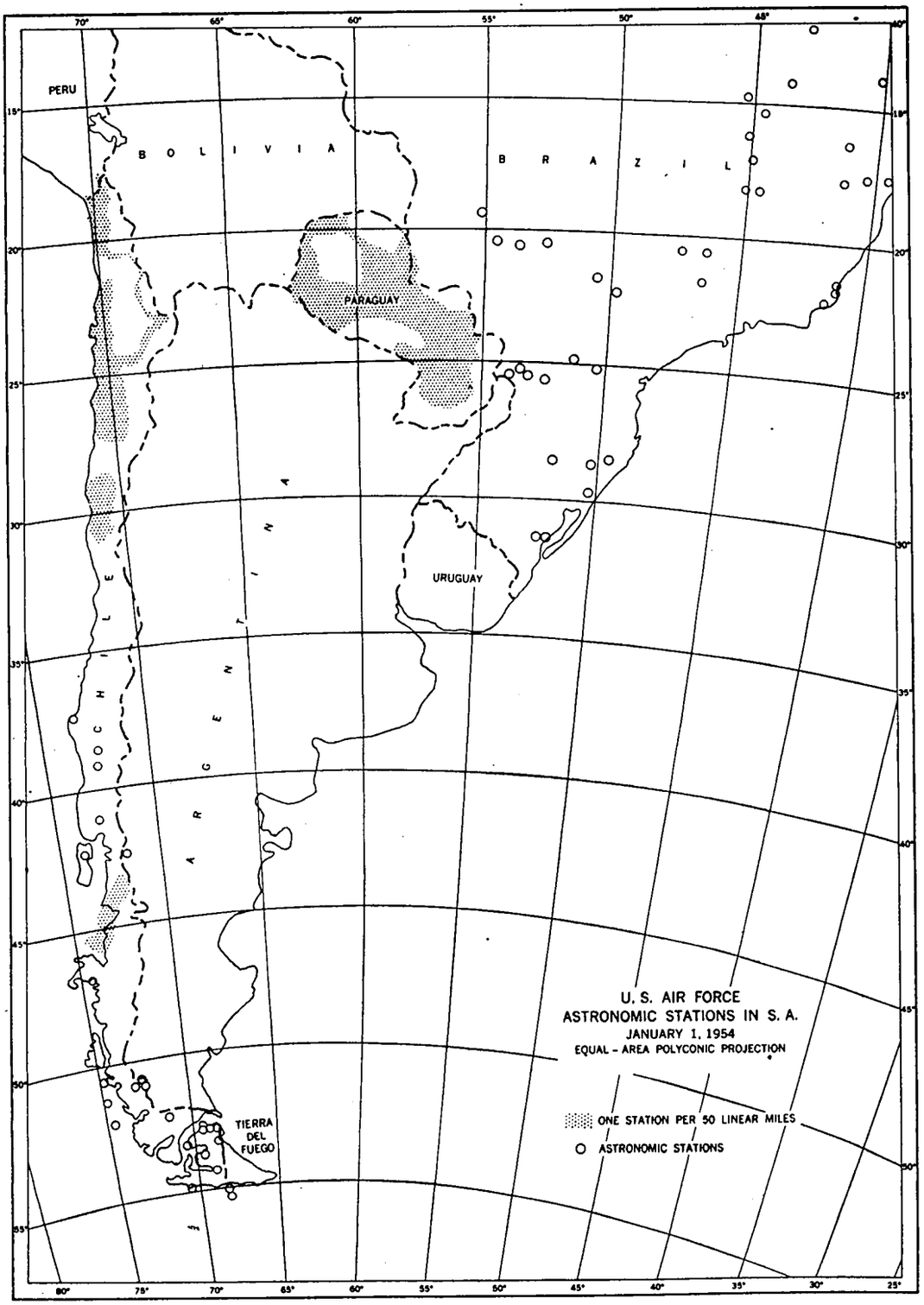


FIGURE 14.—Astronomic stations in South America.

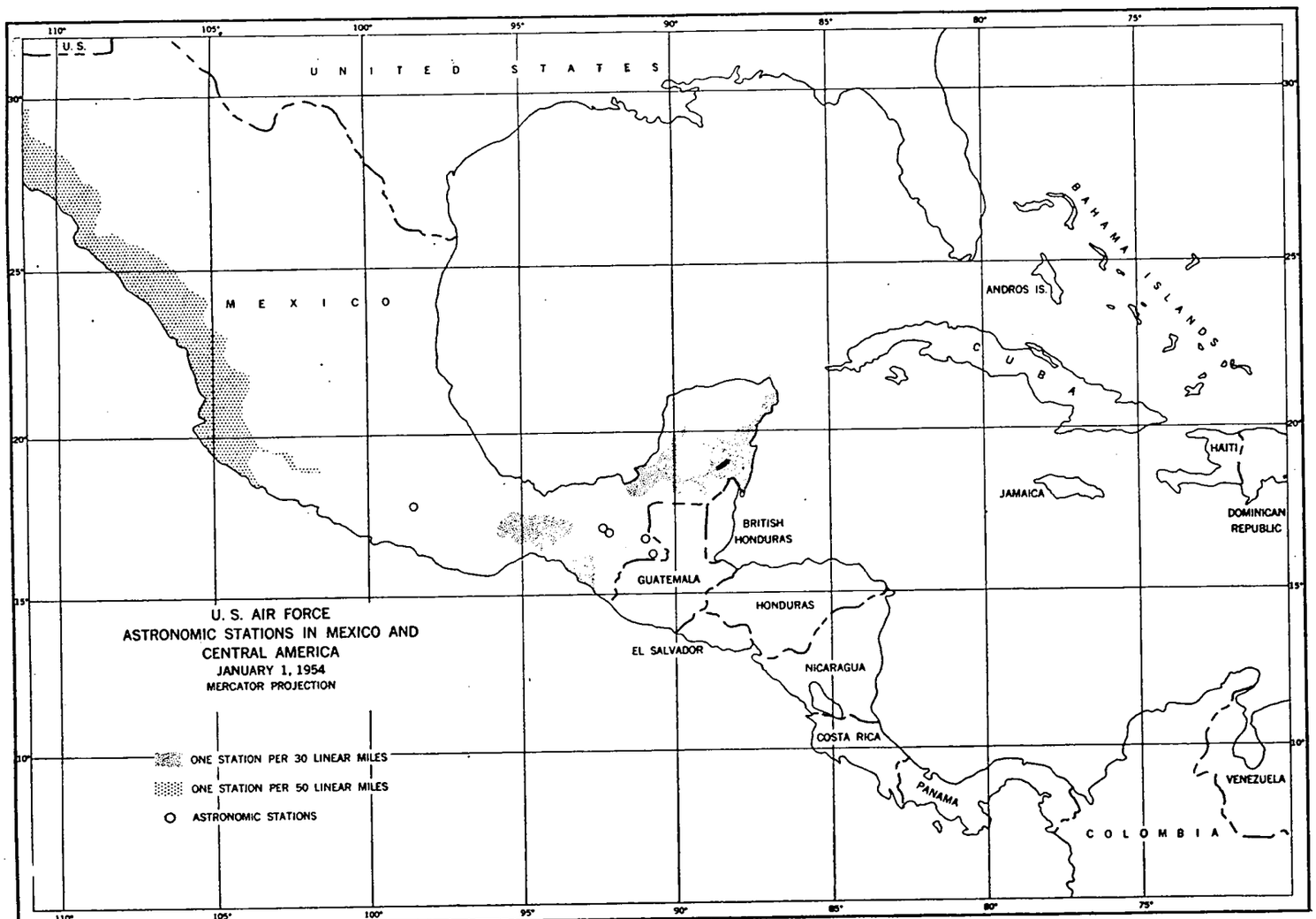


FIGURE 15.—Astronomic stations in Mexico and Central America.

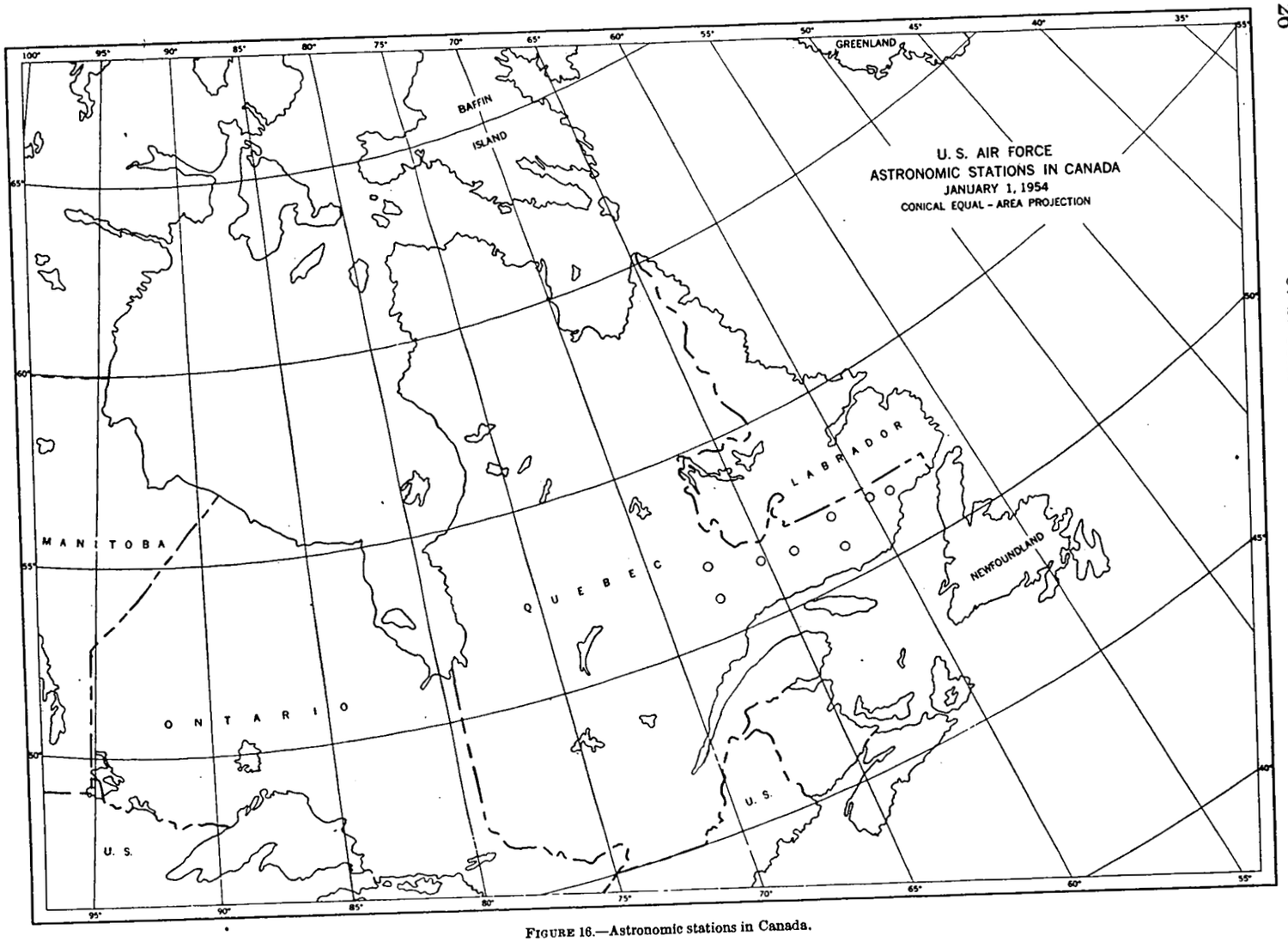


FIGURE 16.—Astronomic stations in Canada.

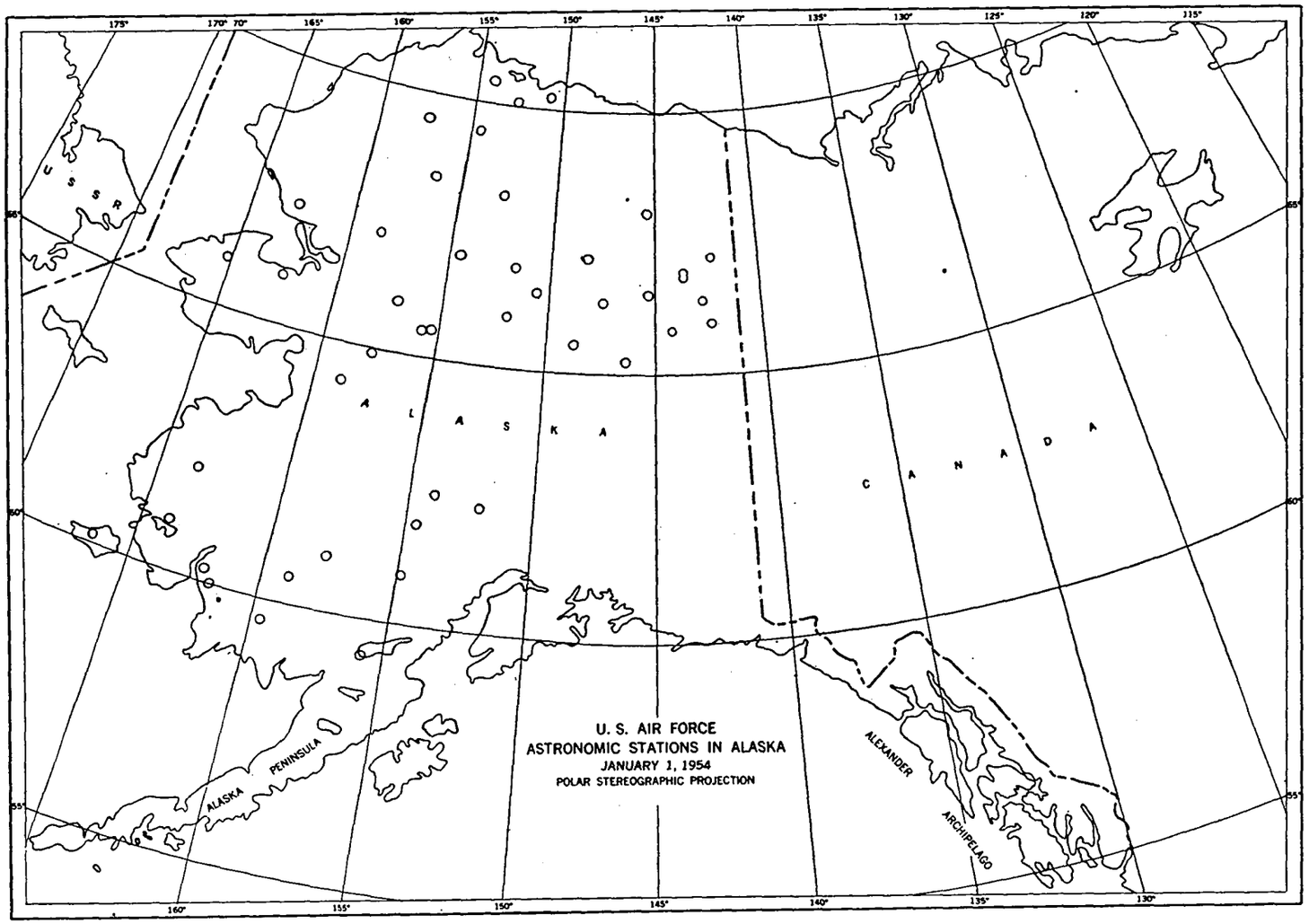


FIGURE 17.—Astronomic stations in Alaska.

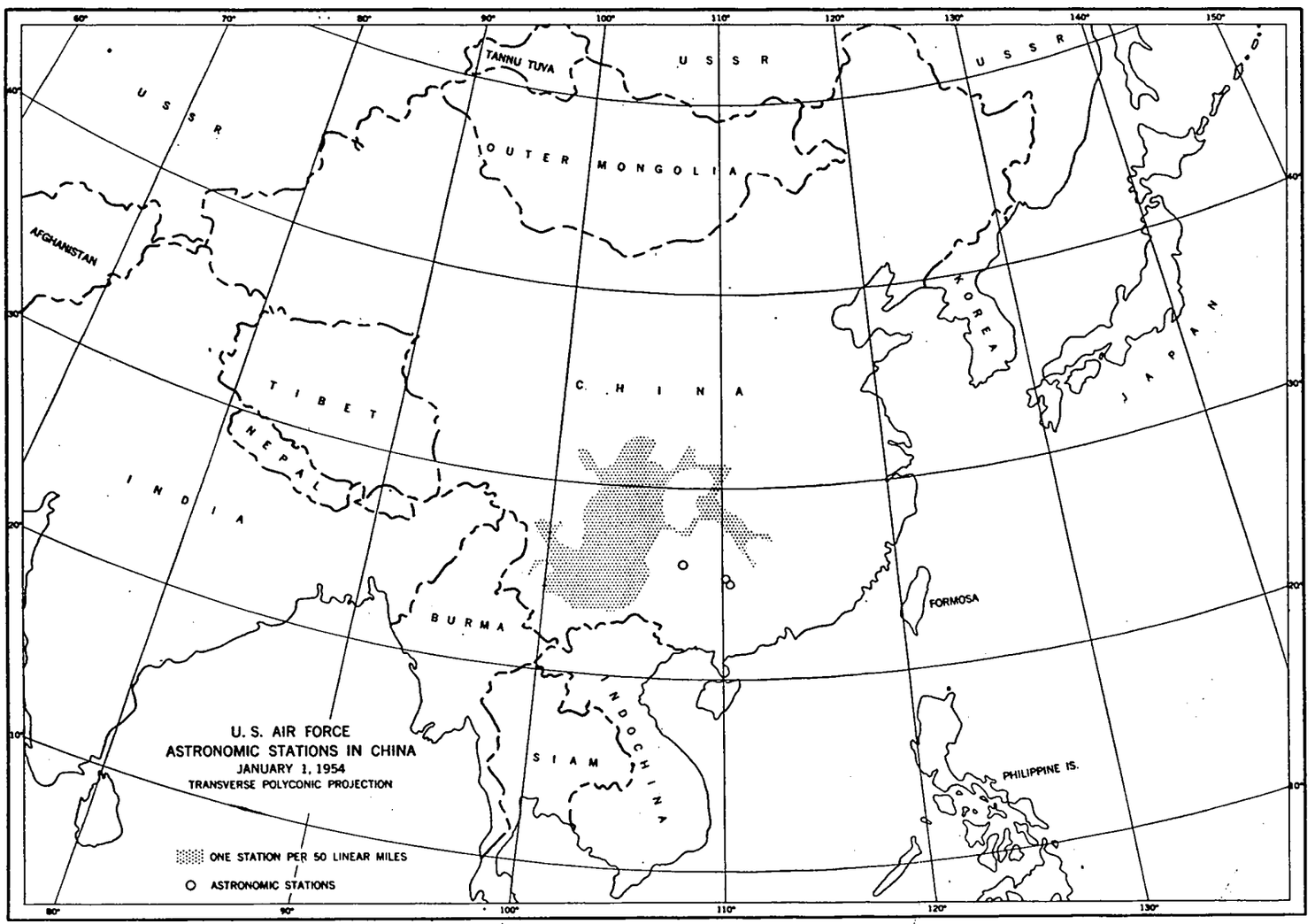


FIGURE 18.—Astronomic stations in China.

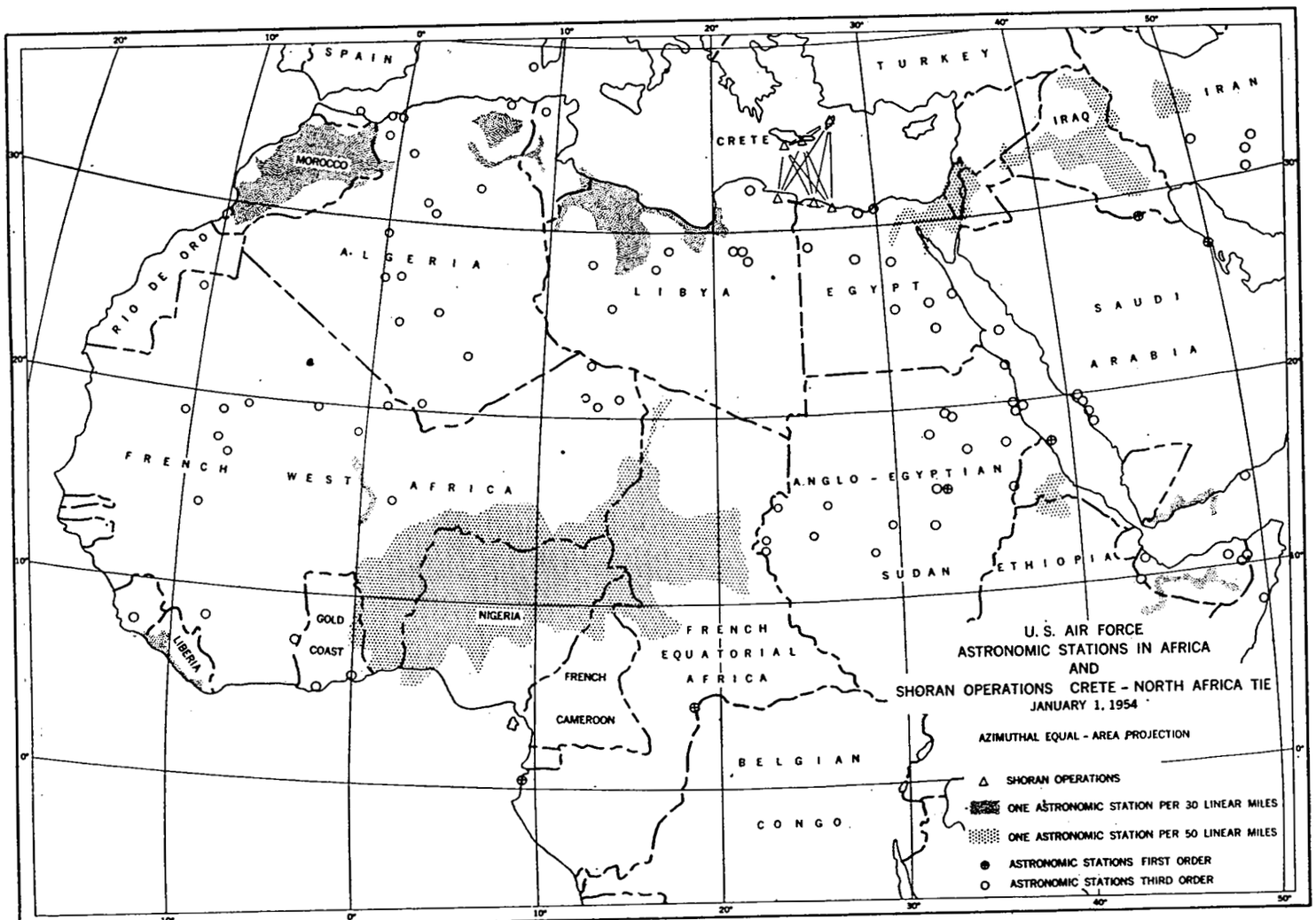


FIGURE 19.—Astronomic stations in Africa, and Shoran operations, Crete-North Africa tie.

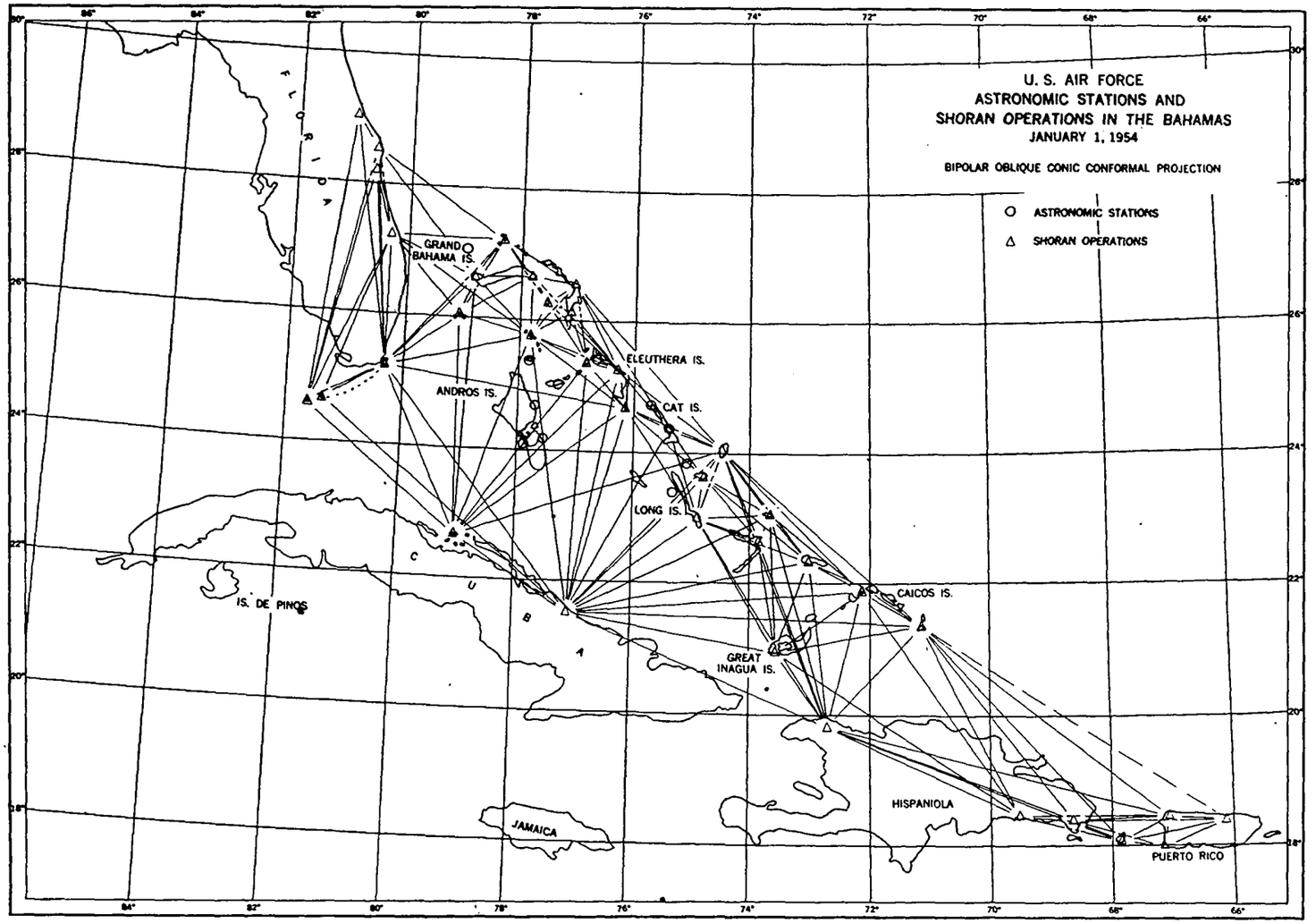


FIGURE 20.—Astronomic stations and Shoran operations in the Bahamas.

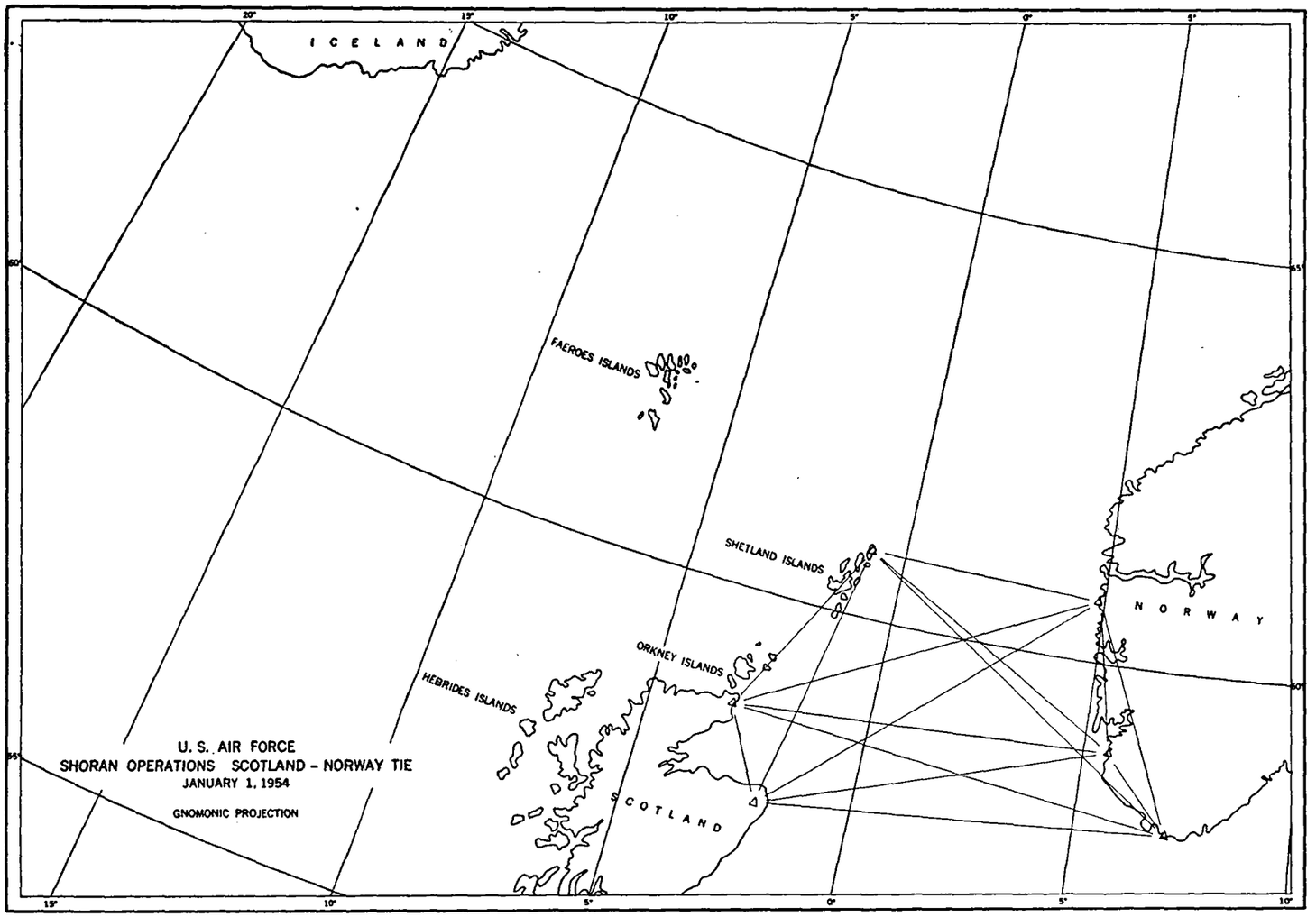


FIGURE 21.—Shoran operations, Scotland-Norway tie.

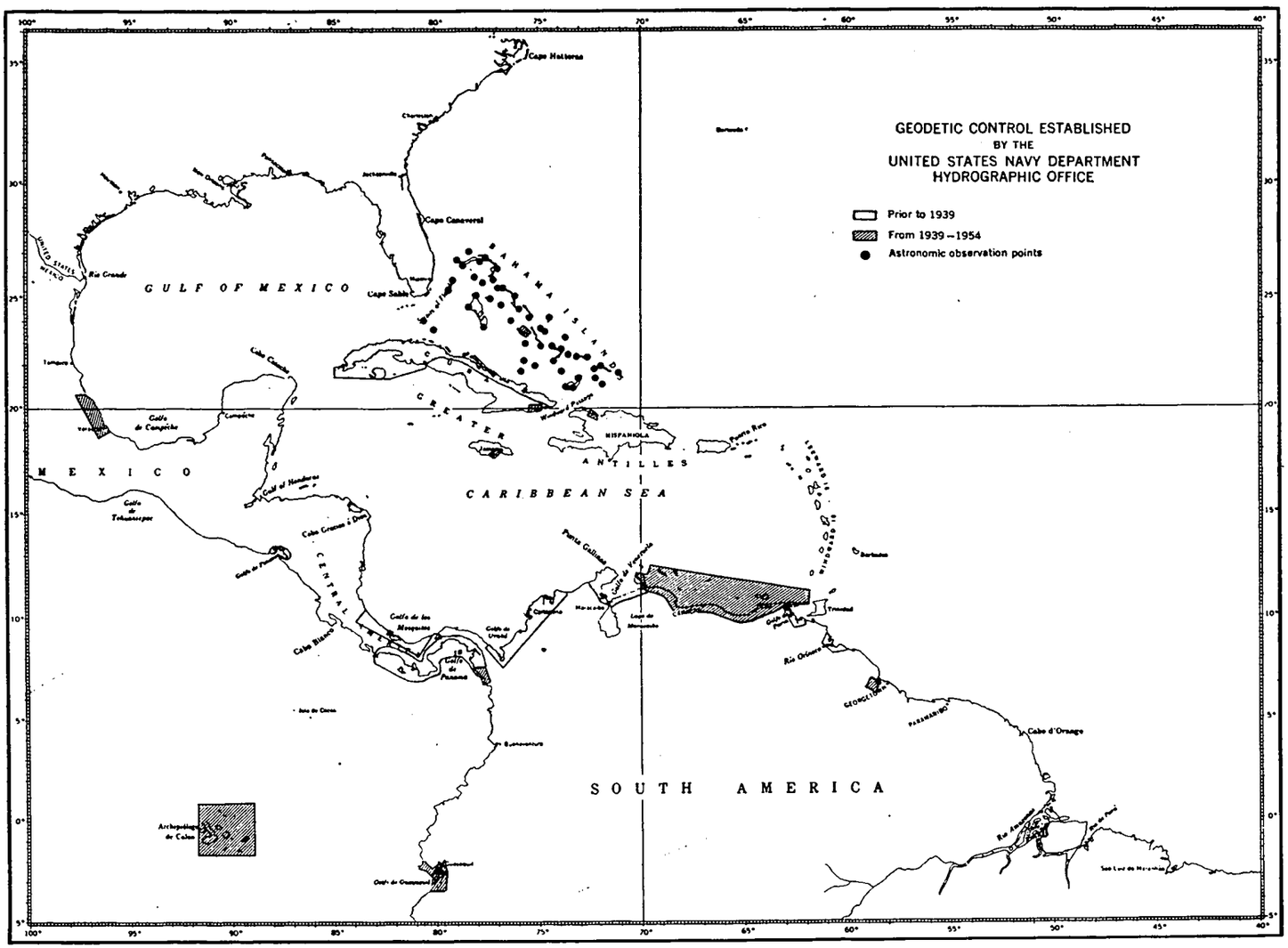


FIGURE 22.—Geodetic control in Mexico and South America.

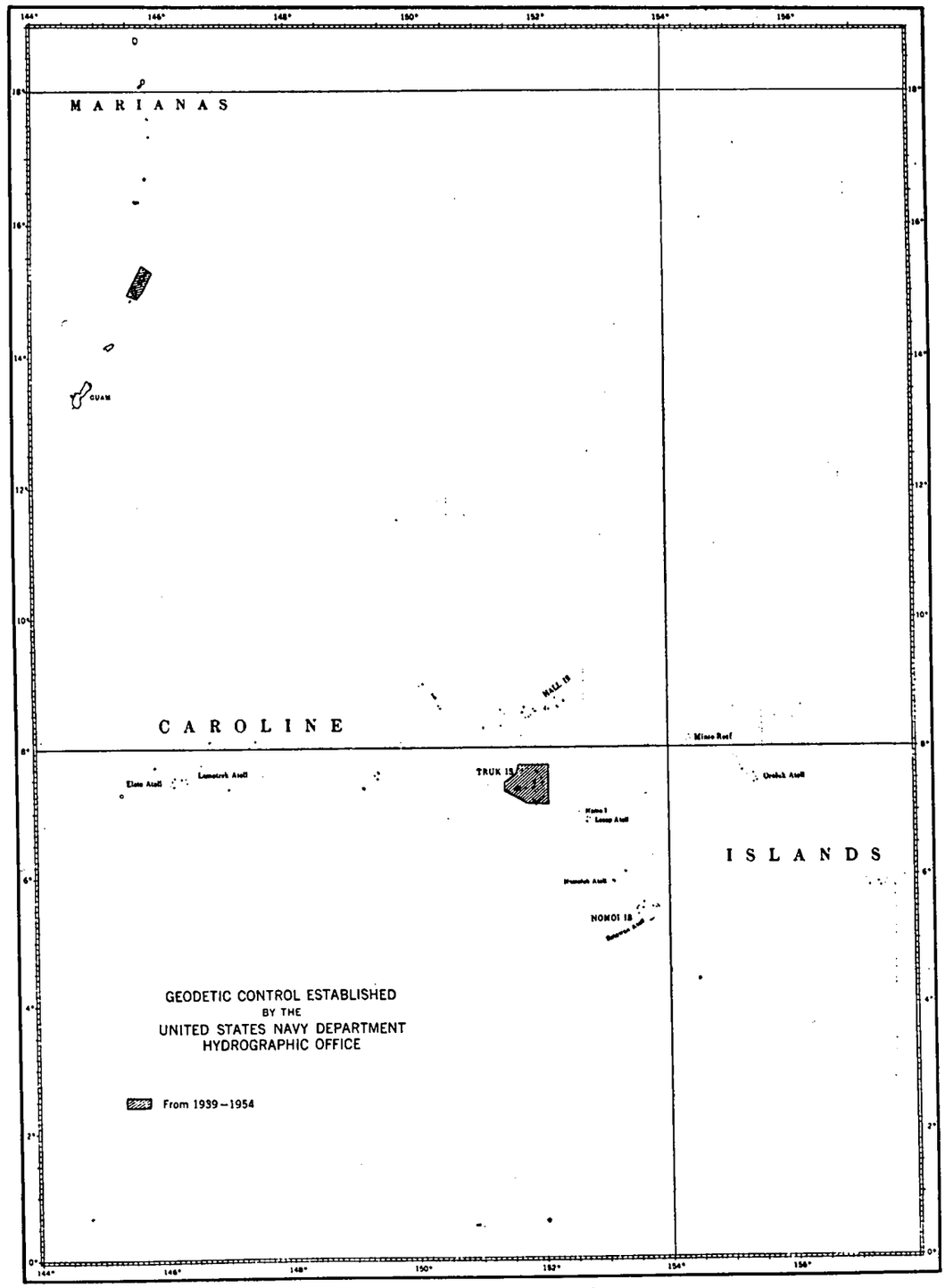


FIGURE 23.—Geodetic control in the Caroline Islands.

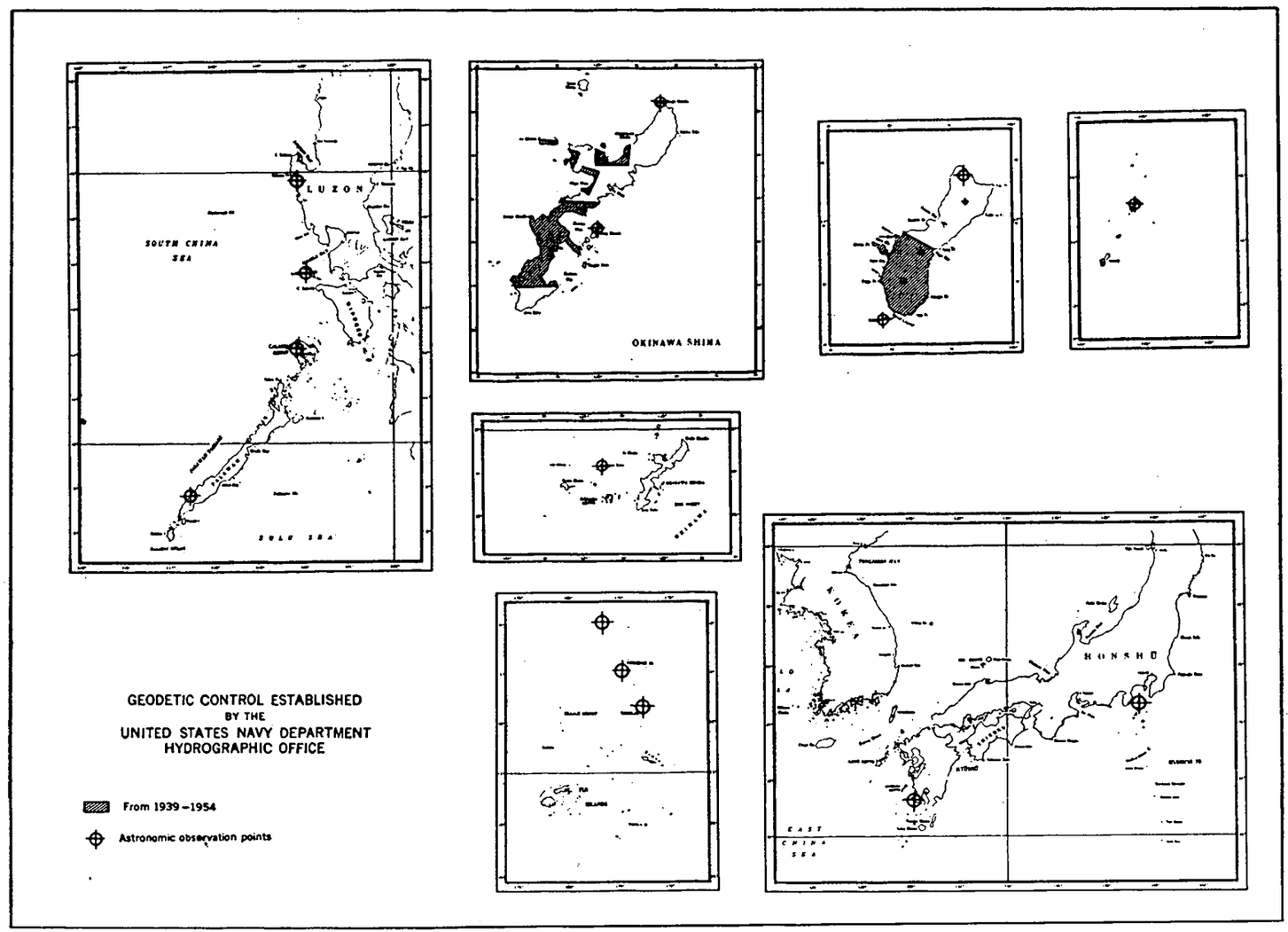


FIGURE 24.—Geodetic control in the South Pacific.

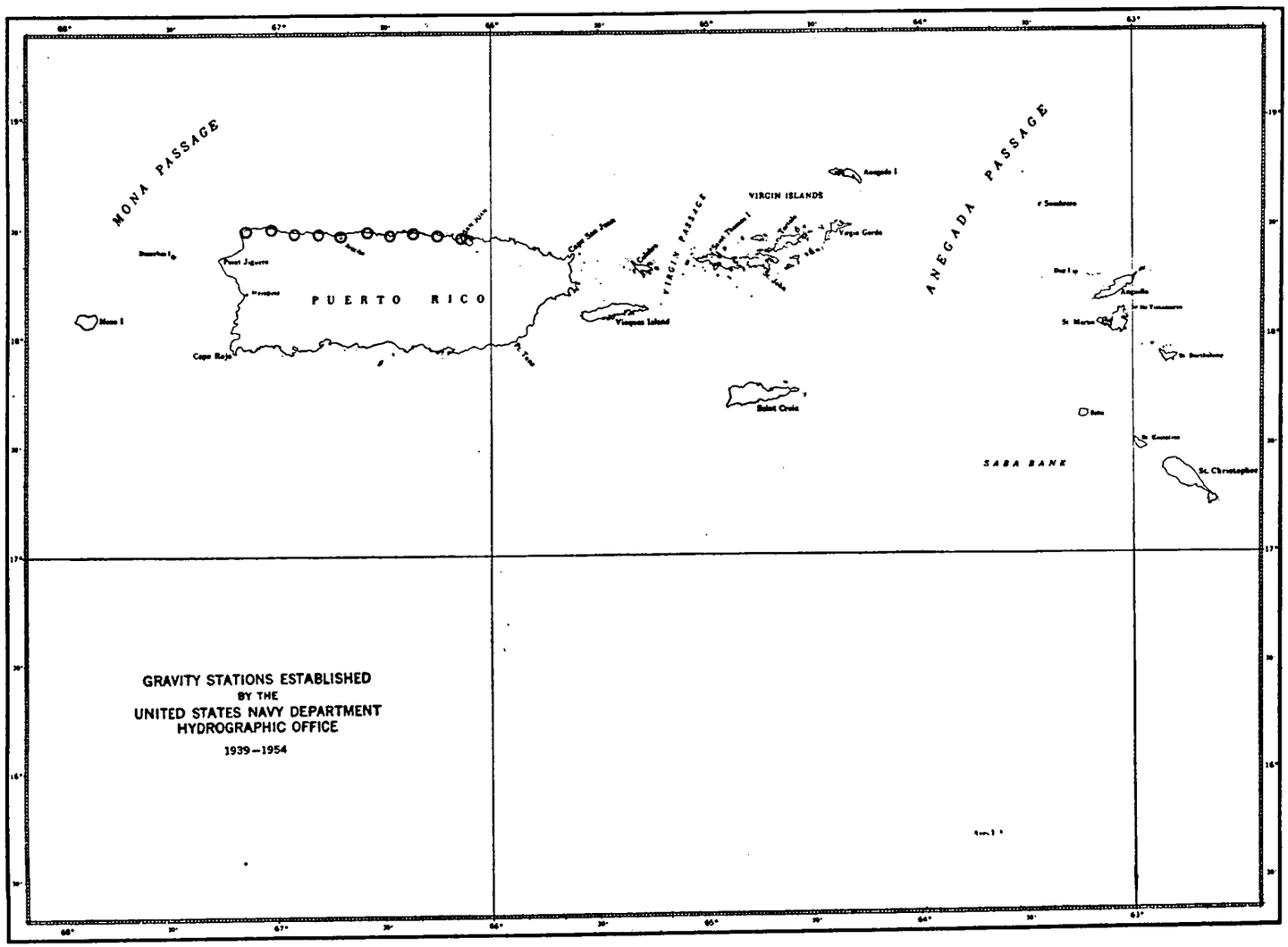


FIGURE 25.—Gravity stations in Puerto Rico

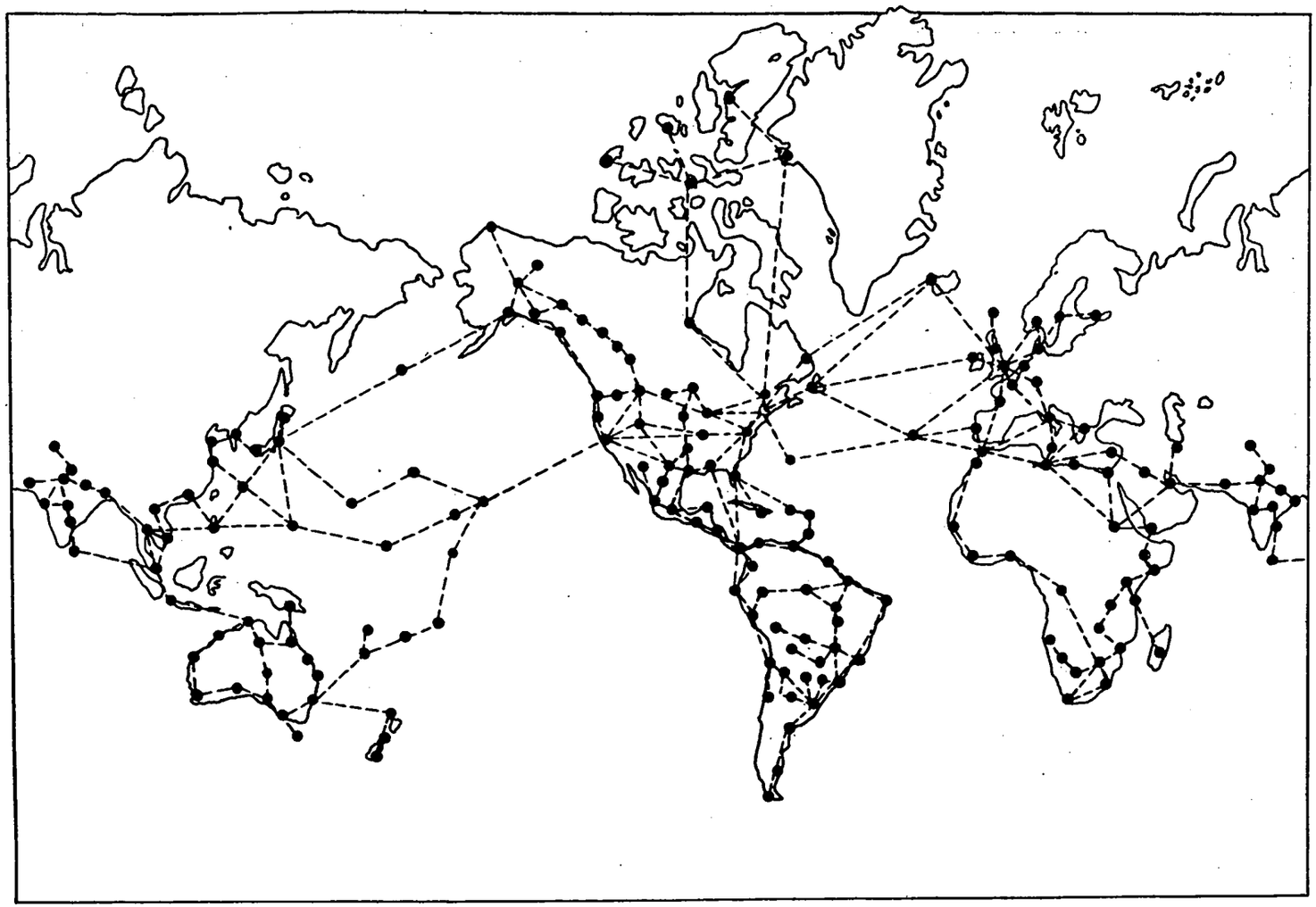

FIGURE 26.—Worldwide gravity measurements, 1948–53, by G. P. Woollard.

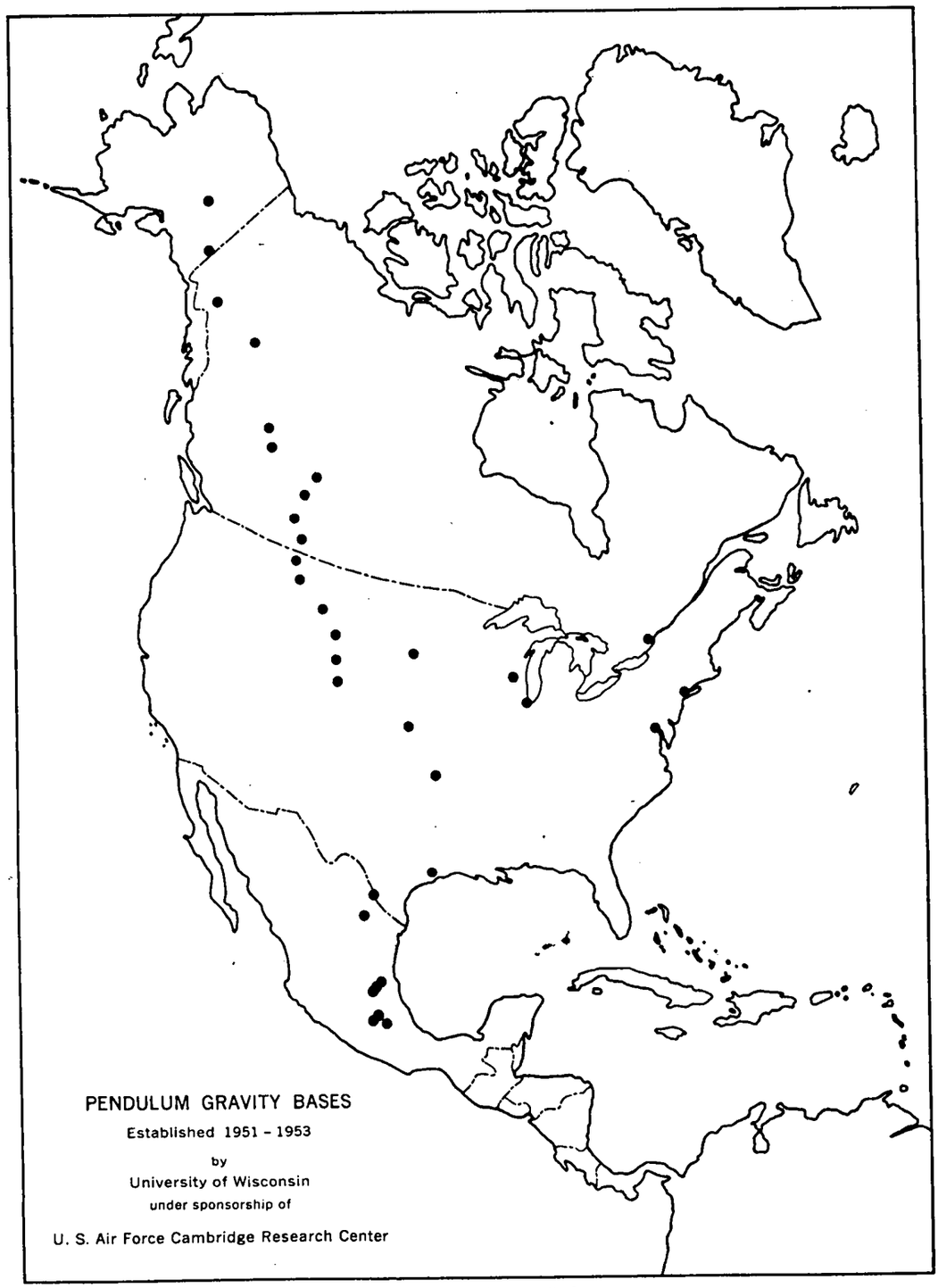


FIGURE 27.—Pendulum gravity bases.