CHAPTER 2

Geographic Datums

A fundamental concept in the survey of a large area—for example, the United States—is the establishment of a single geographic datum in order that the survey may perform fully the function of accurately coordinating all surveys and charts within the area. This was recognized at an early period in the history of the Coast Survey. With few exceptions, all the horizontal control work of the Bureau is now referenced to a single geographic datum. This is a fact of great practical significance to the engineer who uses the control data or the surveys based on such control. It is important to remember, however, that this was not always the case but took many years to achieve. There are therefore many early topographic and hydrographic surveys in the Bureau archives that have never been converted to the latest datum. This chapter deals with some of the factors underlying the geodetic survey of a country, the development of the various geographic datums of the United States, and the final adoption of the North American 1927 Datum as the standard for all survey work of the Bureau.

A datum is any numerical or geometrical quantity or set of such quantities which may serve as a base for other quantities.[1]

A geographic datum—also called a horizontal or geodetic datum—is the adopted position in latitude and longitude of a single point to which the charted features of a region are referred. More specifically, it consists of five quantities: the latitude and longitude of an initial point, the azimuth of a line from this point to another point to which it is tied by the triangulation, and two constants necessary to define the terrestrial spheroid. It forms the basis for the computation of horizontal control surveys in which the curvature of the earth is considered.

Geographic datums are to cartography what tidal datums are to hydrography. Just as soundings must first be reduced to the same plane of reference

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[1] For a group of statistical references, the plural form is *data*, as geographic data for a list of latitudes and longitudes. Where the concept is geometrical, rather than statistical, the plural form is *datums*, as, for example, two geodetic datums. MITCHELL, DEFINITIONS OF TERMS USED IN GEODETIC AND OTHER SURVEYS 21, SPECIAL PUBLICATION NO. 242, U.S. COAST AND GEODETIC SURVEY (1948).

before studies of changes can be made, so must maps and charts be referred to the same geographic datum before features in the horizontal plane can be compared. This is particularly true in the case of comparisons between recent surveys and those of an early date, many of the latter having been based on independent datums. Unless datum corrections are applied, faulty conclusions as to changes will result. (*See also* Chap. 3.)

21. THE FIGURE OF THE EARTH

If the surface of the earth were a plane, as some ancient peoples supposed, the mapping of a large country like the United States, while still a tremendous undertaking, would nevertheless be a relatively simple one, and the science of geodesy could never have arisen. The elementary geometry of Euclid, which makes the three angles of a triangle equal 180 degrees, would suffice to measure and represent the earth's geographical features. But since the earth is not flat, the problem of mapping large areas is a complicated process. The geometry of Euclid is not applicable, and a body of principles which takes into account the size and shape of the earth must be applied, if accurate results are to be obtained. This constitutes the science of geodesy.

While it is customary to associate the concept of roundness of the earth with the period when Columbus attempted to reach Asia by a westward course, actually the notion of a spherical earth dates back many centuries before the beginning of the Christian Era. Just when the transition of thought from a flat to a round earth took place is somewhat doubtful; however, to Pythagoras, the Greek philosopher who lived about 540 B.C., appears to be due the first clear statement regarding the spherical shape of the earth. While various suggestions have been advanced as to the basis on which he reached this conclusion—one is the philosophical one that the sphere being the most perfect of solid figures, the earth should have that form—the important point is that he did so consider it, and this concept of a spherical earth flourished until blotted out during the Middle Ages.

The acceptance of the Pythagorean theory led to conjectures as to the earth's circumference. Many estimates were made, but the earliest of record was the one by Eratosthenes, the librarian of Alexandria, about 240 B.C. His method, though crude in measurement and based on several assumptions (none of which was exactly true, but the errors of which must have cancelled out), gave a re-

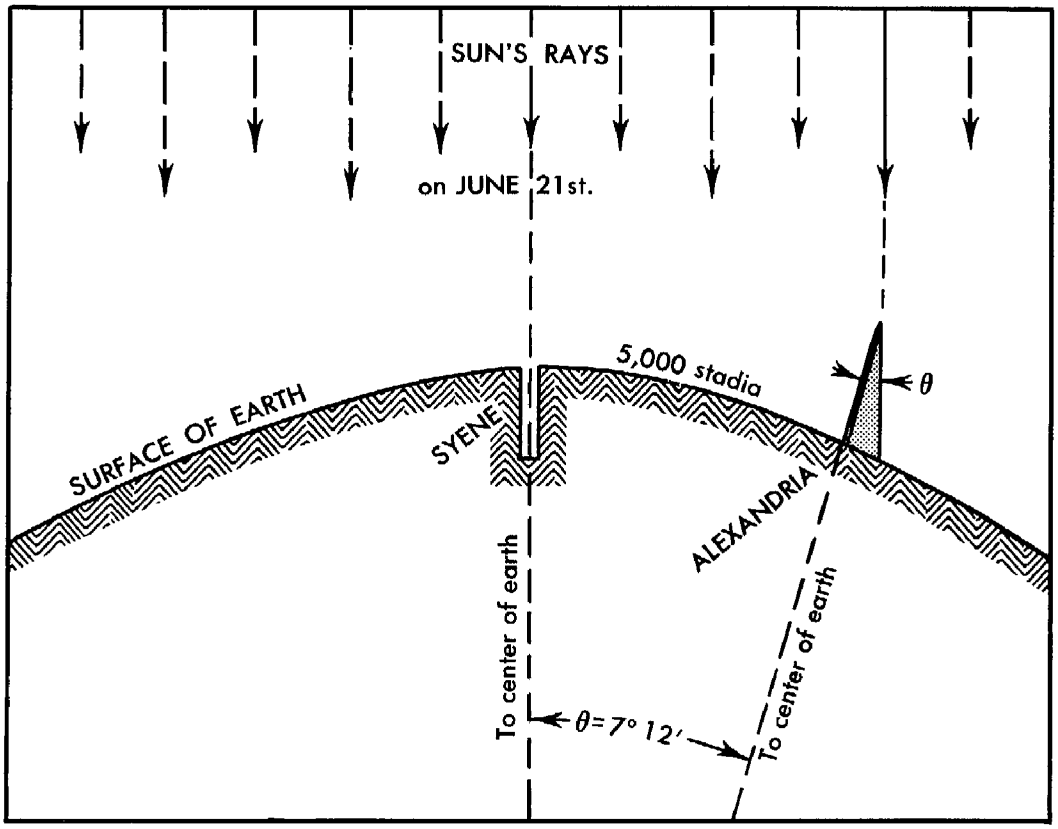

FIGURE 29.—Eratosthenes' method of calculating the earth's circumference in 240 B.C.

markably close approximation to present-day values, and was the forerunner of the modern method of meridian-arc measurement.[2]

As man began to extend his horizons through explorations on land and sea, there was increased demand for more accurate maps based on geographical locations by means of latitude and longitude, which necessitated a more accurate knowledge of the size and shape of the earth.

The numerous mountain ranges, valleys, and ocean deeps may give the impression that the earth is an irregular mass. While such irregularities are of

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[2] Tradition has it that there was a well in Syene in southern Egypt which the sun's rays penetrated only on June 21, the day of the summer solstice; that is, the sun at that time cast no shadow of a vertical object (*see* fig. 29). This would place Syene on the Tropic of Cancer. As its distance from Alexandria was known to be 5,000 stadia, assuming that Alexandria is directly north of Syene, all that was necessary was to measure the angle of the noonday sun on June 21. The inclination of the sun's rays to the vertical in Alexandria was found to be 1/50 of the circle, or 7° 12′. So a meridian of the earth must be 50 times 5,000, or 250,000 stadia—about 28,000 miles. This is remarkably accurate (within 12 percent) especially since neither Syene is on the Tropic of Cancer nor Alexandria on the same meridian with Syene, but 3° west of it; nor is the distance 5,000 stadia, but, rather, 4,530. RAISZ, GENERAL CARTOGRAPHY 17 (1938).

concern to the topographer and hydrographer in their surveys, they are insignificant for practical purposes when their relation to the size of the earth is considered. For example, while the highest known elevation (Mount Everest in the Himalayas) is 29,028 feet,[3] and the greatest known ocean depth (the Mariana Trench in the Western Pacific, about 200 miles southwest of Guam) is 36,198 feet,[4] on a globe 1 foot in diameter the irregularities would be represented by bulges or depressions of no more than one-hundredth of an inch. But even when these features are ignored, the shape of the earth cannot be considered spherical.

The true figure of the earth, as distinguished from its topographical surface, is taken to be the surface which coincides with the mean surface of the oceans, and which is everywhere perpendicular to the direction of the force of gravity. Under the islands and continents, this surface may be conceived to be that which would coincide with the water surface in narrow, sea-level canals if they were extended inland through the continents. It is tilted upward toward the high lands and has a reverse tilt under the oceans (*see* fig. 30). This figure is quite irregular and no geometric solid exactly fits its shape. Because of this it has been given the name *geoid,* meaning earth-shaped.

Obviously, we cannot use the geoid as a surface of reference for computing survey data, even if its exact shape were known, because it would lead to difficulties and complications in geodetic and cartographic work which would hardly be justified by the results obtained. One of the problems of geodesy has therefore been to find a geometric surface that closely approximates the true or geoidal surface on which the triangulation can be computed. This search for an accurate figure of the earth is not peculiar to any one country,

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[3] For a discussion of the height of Mt. Everest, including the 1952–1954 determination, *see* Gulatee, *Mount Everest—Highest Point on Earth,* 4 JOURNAL, COAST AND GEODETIC SURVEY 113 (1951), and *The Height of Mount Everest, A New Determination (1952–1954),* 7 JOURNAL, COAST AND GEODETIC SURVEY 154 (1957).

[4] This value (an echo sounding of 11,034 meters) was reported to the International Oceanographic Congress in Sept. 1959 by the Academy of Sciences of the U.S.S.R. as having been obtained at position 11°21′8″ N., 142°12′6″ E. by the Soviet ship *Vityaz.* THE WORLD ALMANAC 582 (1962) from information furnished by the National Science Foundation and the U.S. Navy. *See also* Kort, *Scientific Research of Vityaz During IGY,* 37 INTERNATIONAL HYDROGRAPHIC REVIEW 137 (July 1960). Other recently recorded values for the greatest depth in the Mariana Trench are: 35,800 feet by the bathyscaph *Trieste* from a pressure-gage determination on Jan. 22, 1960, and 35,700 feet by the Scripps Institution of Oceanography from a sonic-sounding survey in July 1959. Lyman, *Trieste's Record Depth Recalculated,* 86 UNITED STATES NAVAL INSTITUTE PROCEEDINGS 99 (July 1960). Previously, a record depth of 5,940 fathoms (35,640 feet) was obtained by echo sounding in Oct. 1951 by H.M.S. *Challenger* at position 11°21′8″ N., 142°12′6″ E. by the Soviet ship *Vityaz.* THE WORLD ALMANAC 582 (1962) from in- feet) obtained by the same ship. *The Deepest Ocean Sounding,* 5 JOURNAL, COAST AND GEODETIC SURVEY 59 (1953). The greatest ocean depth was formerly believed to be in the Philippine Trench to the east of the island of Mindanao where the U.S.S. *Cape Johnson* found a depth of 5,740 fathoms (34,440 feet). *Id.* at 60. For a discussion of the great ocean depths and a table of the principal deeps discovered, *see* *Ocean Depths,* 49 THE MILITARY ENGINEER 213 (May–June 1957).

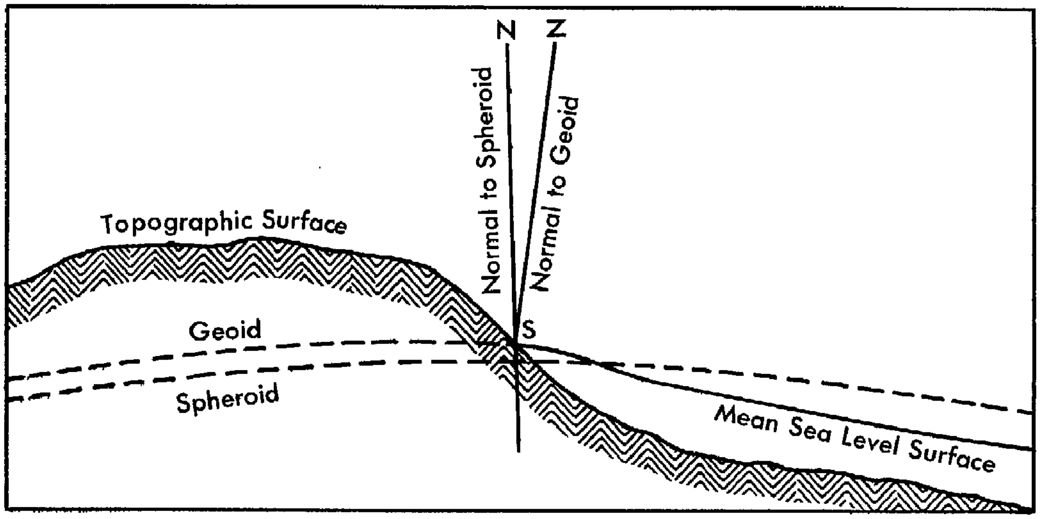

FIGURE 30.—Relationship of spheroid, geoid, and topographical surface. *NS* is the normal to the spheroid; *ZS* the normal to the geoid, or direction of the plumb line; and angle *ZSN* the deflection of the plumb line, or station error, at station *S*.

and scientists the world over have been identified with the problem at one time or another.

When the first measurements of arcs of the meridian were undertaken for the determination of the size and shape of the earth, it was, of course, supposed that the earth was a perfect sphere and computations of its size made accordingly. No one thought of it as flattened at the poles. It was Sir Isaac Newton who first propounded the revolutionary theory that the earth must have the form of an oblate spheroid (a sphere flattened at the poles) because of its axial rotation.[5]

Newton's theory was subject to much criticism and skepticism, particularly in France, where the Cassinis had extended the meridional arc through Paris for 8½° and concluded that the earth instead of being flattened at the poles took the opposite form and was actually elongated through the polar axis. In other words, their calculations showed the earth to be a prolate rather than an oblate spheroid.[6] We, of course, now know this was due to certain inaccuracies in their work. But the battle between the "earth flatteners" and the

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[5] Geometrically, the oblate spheroid may be considered as generated by revolving an ellipse about its minor axis; hence the name "ellipsoid of revolution," which is used interchangeably with "spheroid." From the nature of the figure, any section parallel to the equator is a circle, and any section through the poles is an ellipse.

[6] A prolate spheroid is generated by an ellipse revolving about its major axis. In this spheroid, the lengths of the degrees of latitude decrease from the equator to the poles. (In the oblate spheroid the reverse is true.) It was this decrease in value that led the Cassinis to conclude that the earth was a prolate spheroid.

"earth elongators" was on, and was kept alive as additional measurements tended to confirm first one theory, then the other.

The matter was finally set at rest when the French Academy sent two expeditions, widely spaced as to latitude, to measure meridian arcs by triangulation. One was to Lapland in latitude 66° N. and the other to Peru in latitude 1½° S. The results proved conclusively that the earth was flattened at the poles—a tribute to Newton's marvelous insight into the laws governing the mechanics of the universe. No closer approximation to the true figure has ever been needed for practical geodetic work. But the amount of the flattening or ellipticity still remained to be determined accurately.[7]

211. SPHEROIDS OF REFERENCE

Geodesists were very active during the 19th century in making geodetic measurements to determine the lengths of the axes of the generating ellipse, corresponding to the polar axis and the equatorial diameter of the earth. With each new accession of data and development of scientific thought, new values were derived. Between 1799 and 1951, there were 26 determinations of the dimensions of the earth, the values of the flattening ranging from 1/288.5 to 1/334.29.[8]

From the standpoint of the Coast Survey, the two most important determinations of the elements of the spheroid, insofar as the Bureau's work (geodetic and cartographic) is concerned, are those made by Bessel in 1841 and by Clarke in 1866. In both cases, the calculations were based upon the measurement of meridian arcs in various parts of the world outside the continent of North America. Clarke's investigation is generally regarded as the more precise and later observations have shown that for this part of the globe it represents the true figure somewhat better than the spheroid of Bessel. The comparative values are as follows:

	Semimajor Axis (*Meters*)	Semiminor Axis (*Meters*)
Bessel (1841)	6,377,397.2	6,356,079.0
Clarke (1866)	6,378,206.4	6,356,583.8

These represent flattenings or ellipticities of 1/299.15 and 1/294.98, respectively.

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[7] If a is the semimajor axis of the earth and b the semiminor axis, then the flattening f is defined as $\frac{a-b}{a}$.

[8] *Elements of Various Earth's Ellipsoids*, 6 JOURNAL, COAST AND GEODETIC SURVEY 31 (1955). In these determinations, the meridian-arc method was principally used. In this method, in its simplest form, the linear distances between three points on a meridian are measured by triangulation and the angular distances between them determined from the observed differences in their astronomic latitudes. For other determinations, including those from satellite data, *see* Thomas, *Use of Near-Earth Satellite Orbits for Geodetic Information,* Technical Bulletin No. 11 (Table 3), U.S. Coast and Geodetic Survey (1960). (*See also* note 13 *infra.*)

The Bessel spheroid of 1841 was used in the Bureau's work between 1844 and February 1880,[9] when the Clarke spheroid of 1866 was adopted.[10] This is the spheroid that is in use today and on which all the formulas, tables, and computations are based. In referring to reference spheroids it is customary to append to the word "spheroid" the name of the investigator and the date of making the determination, thus: "Bessel spheroid of 1841," "Clarke spheroid of 1866," etc. The date of adoption for a particular triangulation has only a local value.

Prior to the adoption of the Bessel 1841 spheroid, the work of the Bureau must have been computed on some other spheroid, but no specific reference could be found in the official documents. It is noted, however, that in the computations of the 1834–1839 triangulation of Long Island, reference is made to a flattening of 1/302. The nearest approach to this value is the Walbeck spheroid of 1819, which has a flattening of 1/302.78.[11]

A noteworthy contribution to the science of geodesy was made in 1909 when Hayford, a geodesist in the Coast Survey, investigated the figure of the earth using the large triangulation net then existing in the United States, and taking into account the unequal density of the earth's crust. The practical result of this investigation was a new figure of the earth somewhat larger than Clarke's with a flattening of 1/296.96. This was adopted with some slight modification by the International Geodetic and Geophysical Union in 1924 (now the International Union of Geodesy and Geophysics) as the best available figure for the earth as a whole and designated it the International Ellipsoid of Reference.[12] While this spheroid probably best approximates the geoidal surface, the Bureau has never changed over to it, expediency dictating against undertaking a task of such magnitude (recomputing all the existing triangulation) without any practical advantage accruing to its geodetic or cartographic work.[13]

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[9] Annual Report, U.S. Coast and Geodetic Survey 53 (1880). The dimensions of this spheroid were first published in Dec. 1841 in No. 438 of "Schumacher's Astronomische Nachrichten," being a correction to an earlier determination by Bessel in 1837, the latter calculation having been based on an error in the computation of one of the French meridian arcs which Bessel used in his investigation. This resulted in a semimajor axis 240.30 meters less and a semiminor axis 129.47 meters less than the 1841 values, giving a flattening of 1/300.7. There is no indication that the 1837 spheroid was ever used in Coast Survey work.

[10] Annual Report, U.S. Coast and Geodetic Survey 136 (1884).

[11] *Elements of Various Earth's Ellipsoids, supra* note 8.

[12] The internal inconsistency in Hayford's value for the semiminor axis and his determined flattening was removed and a flattening of 1/297.0 exactly, substituted. The derived values are: semimajor axis = 6,378,388 meters, semiminor axis = 6,356,912 meters. For a summary of Hayford's investigation and the basis for his determination, *see* Shalowitz, *The Geographic Datums of the U.S. Coast and Geodetic Survey,* 12 FIELD ENGINEERS BULLETIN 10, 27, U.S. COAST AND GEODETIC SURVEY (1938). It is now known that Hayford's semimajor axis is probably some 200 meters too large (*see* note 13 *infra*).

[13] In 1956, a new determination was made of the figure of the earth by the Army Map Service based on four arcs: a meridional arc extending from South Africa to Scandinavia, a meridional arc from Chile to Canada, a parallel traversing the United States, and a parallel extending from western Europe to

It is appropriate to note here that while no closer approximation to the true figure of the earth has been found necessary for practical geodetic work than is given by the spheroid, with its northern and southern hemispheres symmetrical and equal, it has been postulated for many years that based upon certain considerations of an astronomic and physical geography nature, the earth has the shape of an ovaloid, with the southern hemisphere somewhat larger than the northern.[14]

22. GEOGRAPHIC DATUMS IN CONTERMINOUS UNITED STATES

With the adoption of a spheroid of reference for the country, the Bureau was faced with the important scientific and practical problem whether to adopt a single geographic datum for the country as a whole or whether to use several such datums. The early leaders wisely decided in favor of a single datum. They predicated that decision on the consideration of astronomic and geodetic determinations of points on the surface of the earth.

(*a*) *Astronomic Determinations.*—The position of a point on the surface of the earth, with reference to the equator and to a principal meridian, may be determined by observations on the stars. These consist in measuring the angular distance that the particular heavenly body is above the observer's horizon, as indicated by the spirit level on his instrument. Since gravity acts at right angles to this level surface, the astronomic observations are referred to the direction the plumb line assumes at the point of observation. This direction is normal to the geoidal surface, since the latter is by definition a surface that is everywhere normal to the force of gravity. Thus, it is not necessarily normal to the spheroidal surface. In general, the geoidal surface is higher than the spheroidal surface under the land and lower at sea. The two intersect each other at some distance seaward of the shoreline. (*See* fig. 30.)

(*b*) *Geodetic Determinations.*—By geodetic determinations are meant those latitudes and longitudes that are computed through the network of triangles from the measured angles and distances by starting from some pre-

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Siberia. The first two arcs are the longest of their kind ever available—about 100°. An assumed flattening of 1/(297 ± 1) yielded a value of 6,378,260 ± 100 meters for the semimajor axis. Chovitz and Fischer, *A New Determination of the Figure of the Earth from Arcs,* 37 TRANSACTIONS, AMERICAN GEOPHYSICAL UNION 534 (1956). The Army Map Service determination would come down to something like 6,378,150 meters, if the accepted satellite flattening of 1/298.3 were used. The National Aeronautics and Space Administration has indicated that their observations show a value of 6,378,163 meters for the semimajor axis with a flattening of 1/298.24.

[14] MERRIMAN, ELEMENTS OF PRECISE SURVEYING AND GEODESY 239–241 (1899). Studies of variations in satellite orbits also suggest the earth's shape as resembling a pear with the stem end up. *Earth's Shape,* 40 TRANSACTIONS, AMERICAN GEOPHYSICAL UNION 172 (June 1959).

determined position of one of the triangulation stations. Geodetic coordinates are determined with respect to the normal to the spheroid at the point of observation and not with respect to the plumb-line direction at the point (*see* fig. 30). Where the geoid and the reference spheroid coincide or are parallel the normal will have the same direction as the plumb line and the astronomic and geodetic values at that point will be in agreement. At all other points, differences will be found to exist, their magnitude depending upon how closely the adopted spheroid fits the geoid at those particular points.[15] For the Clarke spheroid of 1866, differences varying up to a minute of latitude have been found to exist. These differences between observed and computed positions corresponding to the astronomic and geodetic values of the point are variously referred to as *plumb-line deflection, deflection of the vertical,* or *station error.*[16]

Accurate surveys of large areas cannot therefore depend only upon astronomic determinations. The survey of a local area can be oriented by determining astronomically the latitude and longitude of one point and the azimuth of one line, and from these values computing the remaining points of the survey by the ordinary trigonometric methods. This will usually suffice if the survey is a detached one such as of an offlying island or some outlying section. But if such survey is joined to or overlapped by other surveys similarly oriented, discrepancies will arise. Each survey will be consistent within itself on the adopted spheroid, but common points will be found to have different geographic values.

In any engineering or scientific undertaking, involving a large area, it is important that full coordination and correlation be obtained between the surveys, maps, and charts of the country. A hydrographic or topographic feature can have but one latitude and longitude, and it must be the same on every map or chart on which it appears. Because of the deflection of the vertical this can be accomplished only through the use of a single geographic datum for the entire country; that is, by referring all the triangulation to the latitude and longitude of a single point whose position on the spheroid is determined from a consideration of the astronomic and geodetic values of common points in the system. This is the true geodetic process.

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[15] If the reference spheroid and the geoid coincided throughout, positions on the earth could be satisfactorily determined from astronomic observations alone, limited to the precision of the observations.

[16] One of the classic examples of a decided deflection of the vertical is the island of Puerto Rico where the distance between the astronomic latitude stations at Ponce on the south coast and San Juan on the north coast was found to be about 1 mile longer than the distance as computed through the triangulation. This was due to the irregular distribution of masses at the surface, since the island consists of a high mountain range running east and west, with the deep water of the Atlantic to the north and the Caribbean to the south.

221. INDEPENDENT DATUMS

In beginning the mapping of any large area such as the United States, it is inevitable that, for a time, many detached systems of triangulation will exist, each based on one or more astronomic determinations of latitude, longitude, and azimuth; that is, on its own independent datum.[17] This was the condition of the primary triangulation in the United States during the first fifty years or so of the Bureau's active operation. Some of the detached portions were the early triangulation in New England and along the Atlantic coast; the transcontinental triangulation along the 39th parallel centered on St. Louis, and another portion of the same triangulation in the Rocky Mountain region; and three separate portions of triangulation in California in the latitude of San Francisco, in the vicinity of the Santa Barbara Channel, and in the vicinity of San Diego. With the lapse of time, these separate systems expanded until they touched or overlapped, causing gaps, overlaps, or offsets at the junctions.[18]

This condition prevailed until 1899 when the transcontinental arc of triangulation was completed, thereby connecting the various detached systems into one continuous triangulation. The work was then ripe for establishing a single geographic datum for the whole country.

222. SELECTING A STANDARD DATUM

The selection of a single geographic datum for the United States was governed by both theoretical and practical considerations. Of the former may be mentioned the requirement that the adopted datum must not differ widely from the ideal which would place the triangulation system in such position that no serious error would occur in any part of the system. Of the latter may be mentioned, first, the desirability that the adopted datum should produce minimum changes in the various Bureau publications, including its charts; and, second, the desirability, other things being equal, of adopting that datum which allowed the maximum number of geographic positions already in the office files to remain unchanged, thereby requiring a minimum amount of new computation.

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[17] An independent datum is established primarily for horizontal control over a limited area with reference to an assumed starting point, whose position on the spheroid of reference by latitude and longitude and whose azimuth to an adjacent station have been determined astronomically, but which has not been connected to the standard datum of the continental area (*see* 223).

[18] CHURCH, TRIANGULATION IN RHODE ISLAND 9, SPECIAL PUBLICATION No. 62, U.S. COAST AND GEODETIC SURVEY (1920).

223. UNITED STATES STANDARD DATUM

In determining the best geographic position of the station that was to define the adopted datum, the plumb-line deflections were studied at a large number of triangulation stations throughout the country, where both astronomic and geodetic determinations were available, with an assumed value for one of the stations. From these data, the latitude, longitude, and azimuth for station *Meades Ranch* in central Kansas was computed which made the sum of the squares of the differences between the astronomic and geodetic values of the latitudes, longitudes, and azimuths a minimum. This best theoretical value on the adopted spheroid of reference was found to be so close to the value based on the datum in use in New England that the latter was adopted in order to save the labor of recomputing all the triangulation in the northeastern part of the country.[19] The adoption of this datum, therefore, did not change the geographic positions of the then completed triangulation in New England and along the Atlantic coast to North Carolina, nor in the states of New York, Pennsylvania, New Jersey, and Delaware.

On March 13, 1901, the adopted datum was officially given the name "United States Standard Datum." It is defined by station *Meades Ranch,* whose position on the Clarke spheroid of 1866 is as follows:

Latitude $= 39^\circ 13' 26''.686$
Longitude $= 98^\circ 32' 30''.506$
Azimuth to station *Waldo* $= 75^\circ 28' 14''.52$.[20]

224. NORTH AMERICAN DATUM

Early in 1913, the United States Standard Datum was adopted by both the Dominion of Canada and the Republic of Mexico for their triangulation. This was an important development in international scientific cooperation because it placed nearly the whole of North America on a single datum and made it possible to coordinate the surveys of practically an entire continent. Such an ideal arrangement had never been accomplished in any other part of the world. To reflect the continental character the datum had now assumed, the name was changed to "North American Datum." But it is important to remember that

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19. Station *Meades Ranch,* which had been established in 1891, was selected as the basis for the geographic datum because it was near the center of area of the United States, and because it was common to two great arcs of triangulation extending across the country—one along the 39th parallel and the other along the 98th meridian.

20. Although the azimuth to station *Waldo* was included in the fundamental data for *Meades Ranch,* this azimuth is now of secondary importance since in the latest adjustment the azimuths throughout the net are controlled by many Laplace azimuths (true geodetic) scattered through it (*see* note 21 *infra*).

while the two designations are different they refer to the same datum. They may be used interchangeably unless the date of adoption is material.

225. NORTH AMERICAN 1927 DATUM

At the time of the adoption of the United States Standard Datum and the North American Datum, the primary triangulation system consisted of a meager skeleton joining the arc near the Atlantic coast with the arc near the Pacific coast. This system was gradually expanded into a large number of interconnected loops.

As the various arcs in the loops were observed they were adjusted by the Method of Least Squares to the arcs already completed in order that the results would be consistent when made available for engineering purposes. When any loop was completed, the total discrepancy in closure was adjusted into the last arc that closed the loop. This method had the disadvantage that it forced distortions into the new arcs which should have been distributed through loops including both the new and the old arcs. It was, however, the only feasible method to use until the main framework of the national net had been completed, since it would have been quite impracticable to readjust the entire net, or even a large portion of it, each time a new arc was added.

(*a*) *Western Adjustment.*—With the completion in 1926 of the triangulation framework in the western half of the control net, extending from the meridian of 98° to the Pacific coast, the logical necessity arose for undertaking a unified adjustment of the whole region, one that would give a control framework of such high accuracy as to permit new arcs to be added without undue distortion.[21] This was no small undertaking, and special methods had to be devised so that the cost would not become prohibitive. The method adopted

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[21] *Laplace Azimuths.*—An important development in the science of geodesy also contributed to the desirability of an overall adjustment of the network. When the earlier datums were adopted, it had not yet been fully established that an arc of triangulation tended to swerve from its true orientation as the distance from the starting point increased. Hence, in the earlier adjustments all azimuths carried through the triangulation were made to depend upon the single standard azimuth adopted for the line *Meades Ranch* to *Waldo*. When the final adjustment was made, information had accumulated which showed that geodetic and astronomic longitudes anywhere in the United States were subject to probable errors of less than 0″.5, and that about the same degree of accuracy could be expected for astronomic azimuths. The geodetic azimuths, however, were found to be subject to probable errors as great as 5″. Therefore, by introducing a number of observed astronomic azimuths into the triangulation the probable azimuth errors were reduced and the orientation of the network in the new adjustment greatly strengthened. But since astronomic observations are referred to the direction of the plumb line and not to the normal to the spheroid, they had to be corrected for the deflection of the vertical (*see* 22(*b*)). This was done by first determining the astronomic longitude at a station and comparing it with the geodetic longitude (the longitude carried through the triangulation). This gave the deflection of the vertical in an east-west direction within a small fraction of a second. This value was then used to correct the astronomic azimuth and thus obtain a true azimuth to be held fixed in the adjustment of the triangulation. This corrected azimuth is known as a *Laplace azimuth*, and the station as a *Laplace station*.

was somewhat similar to that used in the adjustment of a first-order level net. By the use of junction figures, the adjustment was divided into a number of different parts which could be carried on simultaneously, thus making it possible to complete the work within a reasonable time. (*See* fig. 12.)[22]

In this adjustment, the latitude and longitude of station *Meades Ranch* on the reference spheroid were held fixed because the figure of the earth investigation in 1909 had shown that its position on which the United States Standard Datum (and North American Datum) depended, approached closely the ideal for the country.[23]

While the position of station *Meades Ranch* remained the same, all other stations in the net were changed in position. The changes were small in the vicinity of *Meades Ranch* but at greater distances they were fairly large. In the State of Washington, for example, the change in position was slightly over 1″ in latitude (31 meters) and nearly 1.″4 in longitude (29 meters).[24]

In strictness, it was not a new datum since no changes were made in the dimensions of the spheroid nor in the position of the initial station, but it was nevertheless designated "North American 1927 Datum" in order to guard against the readjusted data becoming confused with the old data. The new name for the datum therefore indicates new positions for the stations of the net rather than changes in the fundamental properties of the datum, except for the value of the azimuth to station *Waldo* which was reduced by 4.″88, making the present value 75°28′09.″64 (*see* 223).[25]

Points are said to be on the North American 1927 Datum when they are connected by a continuous triangulation through which the latitudes, longitudes, and azimuths have been computed on the Clarke spheroid of 1866, starting from the adopted position of station *Meades Ranch,* and rigidly adjusted to the scheme of the readjusted triangulation.

(*b*) *Eastern Adjustment.*—A short time after the western half of the national net had been readjusted, the eastern half was recomputed in the same way. The two adjustments resulted in a very accurate net for the whole country. Since their completion, new arcs have been fitted into the net without undue distor-

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[22] ADAMS, THE BOWIE METHOD OF TRIANGULATION ADJUSTMENT, SPECIAL PUBLICATION NO. 159, U.S. COAST AND GEODETIC SURVEY (1930).

[23] In this investigation, 765 astronomic stations were used. CHURCH (1920), *op. cit. supra* note 18, at 11.

[24] HORIZONTAL CONTROL DATA 15, SPECIAL PUBLICATION NO. 227, U.S. COAST AND GEODETIC SURVEY (1957).

[25] The new value for the azimuth from *Meades Ranch* to *Waldo* on the North American 1927 Datum may be found in SUTHERLAND, FIRST-ORDER TRIANGULATION IN KANSAS 13, SPECIAL PUBLICATION NO. 179, U.S. COAST AND GEODETIC SURVEY (1934).

tion and only rarely has it been necessary to upset the adjustment of small sections of the net to force some arc of the main net to take its share of loop-closure discrepancies. (*See* fig. 12.)[26]

23. GEOGRAPHIC DATUMS IN ALASKA

In Alaska, as in conterminous United States (*see* Part 3, 35), commercial considerations governed largely the distribution of surveys. Development of the fishing industry in Southeast Alaska, opening of the gold fields in the Klondike region and around Nome, beginning of the Alaska railroad in Resurrection Bay, all emphasized the need for early publication of charts. This meant the execution of triangulation in various detached areas, each of which was based on independent astronomic data. These detached portions were extended from time to time until many of them overlapped. With this overlapping came the difficulty of making the charts fit. Each chart was correct in itself, but when joined together the shoreline would not fit. To correct this, it was necessary to adopt a geographic datum for each area where overlapping triangulation existed.

Over the years, four principal datums were established in Alaska—Southeast Alaska, Yukon, Valdez, and Unalaska. Only the first two will be described—the first, because the bulk of the topographic and hydrographic surveys of Southeast Alaska are plotted on this datum, having been made prior to the connection with the North American 1927 Datum; the second, because it is the official datum for the Alaska-Canadian boundary.[27]

231. SOUTHEAST ALASKA DATUM

Field work for the triangulation of Southeast Alaska dates back to 1882. Toward the end of 1901, nine different groups of triangulation had been joined together to form one continuous scheme on one datum, known as the "Southeast Alaska Datum." Eight astronomic longitude stations, all chronometric, and 32 astronomic latitudes were used in this adjustment. Various astronomic azimuths were also held fixed because the triangulation was considered too weak to carry the azimuth.

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[26] HORIZONTAL CONTROL DATA, *op. cit. supra* note 24, at 14.

[27] For information regarding the other two datums, together with the various independent astronomic datums that were used in Alaska, *see* Shalowitz, *supra* note 12, at 27.

The Southeast Alaska Datum applies to all triangulation in Alaska between Dixon Entrance and Mount St. Elias. With the extension of triangulation through British Columbia by the Canadian Government, a connection was effected between the work in Southeast Alaska and the work in conterminous United States. This permitted the recomputation of the work on the North American 1927 Datum. This has been completed as far as the triangulation is concerned, but many of the hydrographic and topographic surveys are still on the old datum. These are being corrected as occasion demands.

232. YUKON DATUM

This datum was used for the triangulation along the 141st meridian, the boundary between Canada and Alaska, and covers the area from Mount St. Elias to the Arctic Ocean. The Yukon Datum is based on one astronomic station near the crossing of the 141st meridian and the Yukon River. The datum is defined in terms of the coordinates of station *Boundary* at the Yukon River, astronomically determined as follows:

Latitude = $64°40'51.''42 \pm 0.''164$
Longitude = $141°00'00.''00$
Azimuth to station *Bald* = $27°00'00.''00$.[28]

While the connection with the North American 1927 Datum changed the geographic positions of the boundary monuments and the triangulation stations used in their determination, the monuments will, however, be considered for treaty purposes as defining the 141st meridian. Hence, the Yukon Datum will remain the official datum for the 141st meridian work.

233. CONSOLIDATION OF DATUMS

As of 1963, the whole of Alaska—from Dixon Entrance to the Arctic Ocean and to Bering Strait—including the Aleutian Islands and the Alaska Peninsula, has been consolidated by one continuous triangulation and placed on the North American 1927 Datum.

A noteworthy event occurred in 1951, when the distant, offshore islands in the Bering Sea were connected to the triangulation network on the mainland of Alaska, thereby placing the Bering Sea area on the North American 1927

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[28] JOINT REPORT UPON THE SURVEY AND DEMARCATION OF THE INTERNATIONAL BOUNDARY BETWEEN THE UNITED STATES AND CANADA ALONG THE 141ST MERIDIAN FROM THE ARCTIC OCEAN TO MOUNT ST. ELIAS 132, U.S. DEPARTMENT OF STATE (1918).

Datum. The true geographic positions of the islands were thus determined for the first time (*see* fig. 31).[29]

24. OTHER DATUMS

Besides the datums developed for conterminous United States and for Alaska, the Coast Survey has necessarily had to adopt other standard datums for use in outlying areas too distant from continental United States to permit tie-ins—for example, in the Philippine and Hawaiian Islands—or where for other reasons tie-ins could not be effected—for example, in Puerto Rico and the Canal Zone.[30]

241. PHILIPPINE ISLANDS

In the Philippine Islands, the triangulation developed along the same lines as the triangulation in the United States. Military and commercial considerations necessitated the beginning of work at different points throughout the islands, each control scheme being on its own geographic datum as determined by astronomic observations connected with that particular scheme. Later, as the work was extended to the south and embraced additional astronomic stations, a standard datum for the islands was established in 1911 in order that no serious error would occur in any part of the system. This is known as the "Luzon Datum" because it is derived wholly from observations on Luzon Island, although supplemented by theoretical inference and approximate results from other regions. It was not termed a Philippine datum because the incompleteness of available data made it unwise to adopt the latter name.

242. HAWAIIAN ISLANDS

The work in the main Hawaiian group between Hawaii and Kaula is based on the "Old Hawaiian Datum," a name derived from the fact that it is the same geographic datum that was in use for triangulation of the islands Oahu and Hawaii before the office adjustment was begun. To the westward

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[29] Pierce, *Datum Connection to the Bering Sea Islands*, 5 JOURNAL, COAST AND GEODETIC SURVEY 3 (1953). The trilateration method was used (a measurement of the sides of a triangle, as distinguished from triangulation, in which the angles are measured), the distances being measured by electronic methods. The longest distance measured was 501 statute miles. *Ibid.* For a discussion of the accuracies attained on this project, *see* Meade, *Preliminary Adjustment of Shoran and EPI Observations in the Bering Sea*, 5 JOURNAL, COAST AND GEODETIC SURVEY 10 (1953).

[30] These datums are more fully described in Shalowitz, *supra* note 12, at 18–23. For a discussion of the use of satellites as a means of connecting islands to continental geographic datums, *see* Thomas, *supra* note 8, at 4.

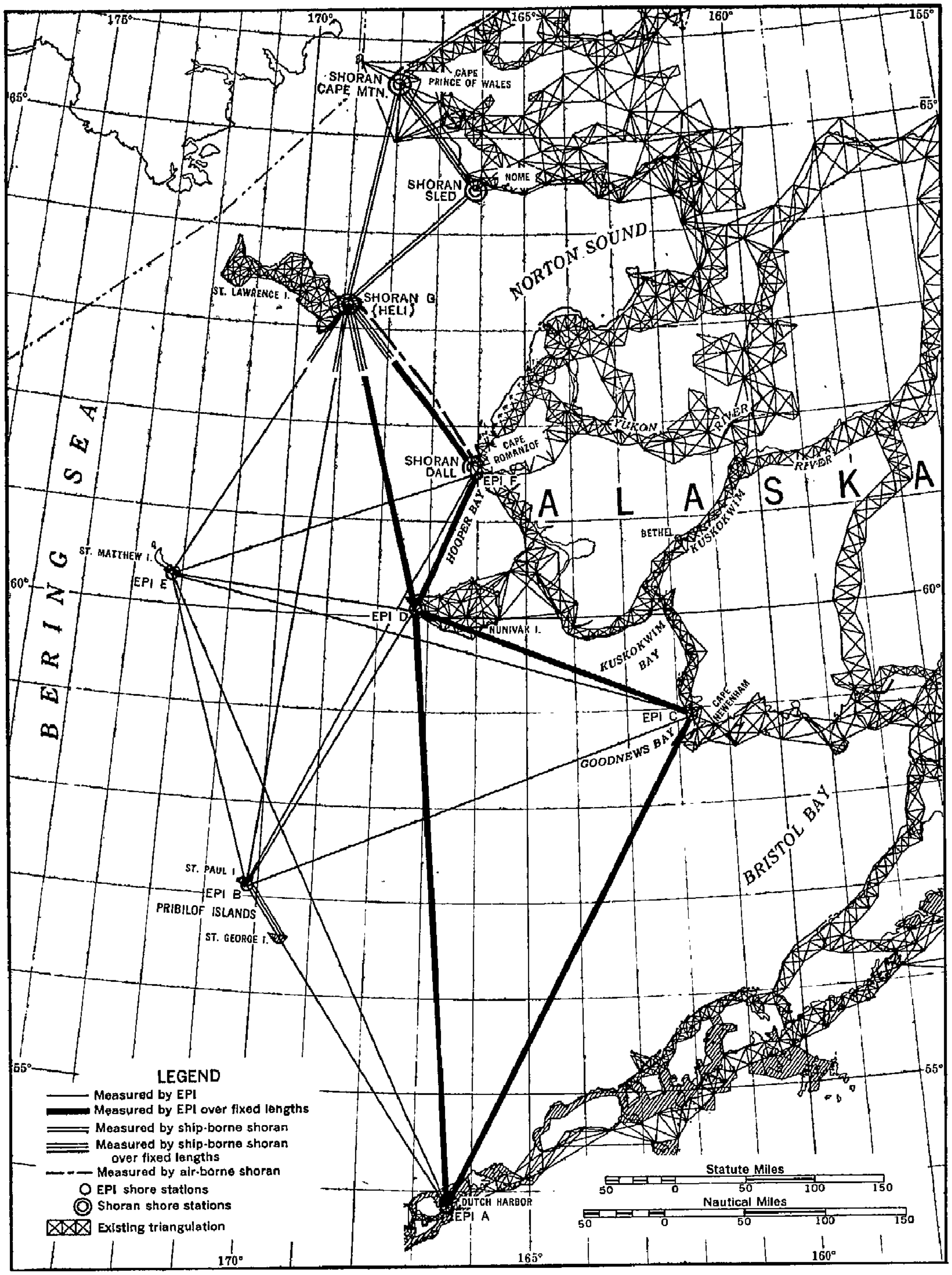

FIGURE 31.—Extending the North American 1927 Datum to the distant, offshore islands in the Bering Sea by E.P.I. and Shoran trilateration.

of Kaula, there is no connected triangulation and the surveys of the various shoals and islands are in the nature of detached surveys controlled by their own independent astronomic observations.[31]

243. PUERTO RICO AND VICINITY

Prior to 1901, the triangulation on Puerto Rico was based on the "San Juan Astronomic Datum" and the other islands had their own independent datums. With the completion of the interisland connection and a study of a number of astronomic observations on the island of Puerto Rico and adjacent islands, the "Puerto Rico Datum" was established as the best geographic datum for Puerto Rico, Mona Island, Vieques, Culebra, and the Virgin Islands.

This work is now tied to the North American 1927 Datum through Hiran surveys along the Atlantic Missile Range.

244. THE CANAL ZONE

Although the Canal Zone is under the jurisdiction of the Canal Zone Government, both the Atlantic and Pacific approaches to the Canal have been surveyed by the Coast and Geodetic Survey (*see* 5641). The main scheme of triangulation across the Canal Zone was done by the Isthmian Canal Commission but the adjustment was made by the Coast Survey. Prior to 1911, two datums were in use (both astronomic), one at each end of the Canal. When a triangulation connection was made between the two areas and the work adjusted, discrepancies were found to exist between the two datums. A single standard datum, the "Panama-Colon Datum," was then adopted for the entire Canal Zone. This was accomplished by selecting a station central to the whole area and computing its latitude and longitude through the triangulation from both ends of the scheme. The values were then averaged after correction for the computed effects of topography and compensation.

This work is now tied to the North American 1927 Datum by work of the Inter-American Geodetic Survey of the Corps of Engineers.

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31. The incongruity that might result in the charts from the lack of a single geographic datum for this portion of the Hawaiian Islands is offset by the absence of important geographic features in the area and by the smallness of chart scale that would be required to include all or a part of these islands on one chart. Hiran distance and line crossing azimuth surveys are now practically completed to place the islands from Hawaii to Kure on a single datum.

25. SPHEROIDS AND DATUMS

From what has been said about spheroids and datums, it is clear that no relationship exists between a geographic datum as such and a spheroid of reference. It is a misnomer, for example, to refer to the Clarke spheroid of 1866 as a datum, as is sometimes done. Points may be inconsistently located on the same spheroid, as where the triangulation of a country consists of a network of independent triangulation systems, each based on its own astronomic position but computed on the same spheroid of reference. Unless the various systems are connected and adjusted they would not be on the same datum. It follows then that points to be on the same geographic datum must necessarily be referred to the same spheroid, but points referred to the same spheroid need not be on the same geographic datum. In all the survey work of the Bureau, only one spheroid of reference has been used since 1880—the Clarke spheroid of 1866—but as has been seen a number of geographic datums were used.