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Geodetic Surveys in the United States
The Beginning and the Next 100 Years
1807-1940

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1807 - 1940

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ABSTRACT

The United States began geodetic surveys later than most of the world's major countries, yet its achievements in this scientific area are immense and unequaled elsewhere. Most of the work was done by a single agency that began as the Survey of the Coast in 1807, identified as the Coast Survey in 1836,renamed the Coast and Geodetic Survey in 1878 and since about 1970 the National Geodetic Survey, presently an office in the National Ocean Service, NOAA. An introduction containing a brief history of geodetic surveying to 1800 is followed by accounts of the American experience to 1940. Broadly speaking the 1807-1940 period is divided into three sections: The Early Years 1807-1843, Laying the Foundations of the Networks 1843-1900 and Building the Networks 1900-1940. The scientific accomplishments, technology developments, major and other interesting events, anecdotes and the contributions made by the people of each period are summarized.

PROLOGUE

Early Geodetic Surveys

And

The British-French Controversy

The first geodetic survey of note was observed in France during the latter part of the 17th and early 18th centuries and immediately created a major controversy. Jean Picard began an arc of triangulation near Paris in 1669-70 and continued the work southward until his death about 1683. His work was resumed by the Cassini family in 1700 and completed to the Pyrenees on the Spanish border prior to 1718 when the northern extension to Dunkirk on the English Channel was undertaken.

The survey created a major controversy. For the results indicated that the earth was a prolate ellipsoid, which contradicted Issac Newton's 1687 postulate that it was an oblate figure. To resolve the hue and cry that followed, the French Academy of Sciences in Paris proposed in 1733 that the length of the meridian be measured near the equator and compared with that obtained in France. Later it was decided to do the same in the Arctic region. The Torne River valley north of Tornio in Lapland on the Swedish-Finnish border was chosen as the northern site and observations were begun in 1736 and completed two years later.

The results showed conclusively that one degree of the meridian was longer in Lapland than at Paris and proved Newton's postulate to be correct. The expedition to Peru, the present day Ecuador departed in 1735 and returned nine years later with results that confirmed the Lapland finding, i.e. one degree of the meridian is shorter at the equator than in France.

Early Instrumentation

These truly remarkable efforts by the French and their associates were carried out with very primitive instruments in comparison with equipment available 50 years later, yet the very best available then. Furthermore, the observations were secured under extreme conditions especially in the high Andes of South America. In Peru, the angle observations were made with quadrants having 2-3 ft. radii and two telescopes, one fixed, the other moveable and equipped with micrometers for finer readings, the latter used perhaps for the first time. The horizon was closed on each set of observations and usually involved 6 or 7 angles. The average closing error was on the order of 2 minutes indicating the accuracy of each angle at 20" to 30".

Base lines in Peru were measured using wooden rods, each 20 feet long and were standardized daily or more often with an iron toise (about 6.4 English feet) that was carried along and kept in the shade. The base line in Lapland was measured over the frozen Torne River using similar, although longer (33 ft.) apparatus.

Great Britain

Great Britain began geodetic surveys in 1784 under the direction of Major General William Roy. A site for the first base line, about 5 miles in length, was selected on Hounslow Heath in what is present day west London and the initial measurement was made using rods of Riga pine. Large errors were noted between measurements made when the rods were wet and dry and the line was remeasured with glass tubes constructed by Jesse Ramsden. After 1791 base lines were measured with 100 foot steel chains. Jesse Ramsden's theodolite with a 3 ft. circle reading to 1" built in 1787 was used for the angle observations and despite its weight of about 300 lbs. good progress was obtained in the triangulation including a connection between Dover and France in 1787. Roy died in 1790 and after a delay of about one year, the triangulation was resumed and completed in 1822. Between 1936-1950 a new, denser network with ties to several points of the earlier triangulation was observed.

Ramsden's Direction Theodolite

Ramsden's direction theodolite is certainly among the 4 or 5 greatest technological advances ever in geodetic surveying. As a case in point, prototypes continue in use by almost all countries. In the field of general surveying however, the invention by the French of the repeating theodolite about 1790 is of equal importance for it is the basis for the instrument most surveyors have employed. Regardless of their almost universal use in the private sector, repeaters have been shown to be less accurate than direction instruments. In theory, the opposite is the case, in practice however, repeaters' more moveable parts and mechanical motions required to operate them contribute to larger error sources.

As for the French, as you might expect they still preferred repeating theodolites for higher order surveys as late as 1963 when a new connection between England and France was made. Instruments employed that year were repeating types, presumably reading to 1" with eye pieces having moveable cross hairs so that as many as 10 readings could be obtained from each pointing. One point of interest. This new connection between Portsmouth and Cherbourg was only possible because Bilby towers were available.

First Level Datum

As might be anticipated The Netherlands established the first level datum in 1682 and carried out surveys along rivers and some shoreline between 1797 and 1812. However, the first geodetic leveling was not begun until 1875. By contrast, Great Britain started their geodetic leveling in 1841 and completed it about 20 years later. In almost all instances geodetic levelings were undertaken after the triangulation was well on its way or completed.

By 1800, most of the countries of Europe had drawn up plans or were on their way in establishing triangulations that in 1842 spanned the continent from the Mediterranean Sea on the south to the Arctic regions on the north and from Ireland, England and the Atlantic Ocean on the west to the interior of Russia on the east.

Ferdinand R. Hassler -- The Founder

The United States entered this world of geodesy in 1807 and while 25 years passed before the primary work could be initiated, its achievements were soon recognized by much of the world. At the beginning and along the way for 25 years however, there were many trials and tribulations to be overcome. The country was very fortunate indeed that a man of the caliber of Ferdinand R. Hassler was selected to lead the effort for one of lesser resolve would have given up early, the problems were many and difficult. Hassler was 37 years old when he was named the first superintendent of the Survey of the Coast and 62 when he began the first major triangulation in 1832. There were many depressing and disillusioning periods for him in the intervening years.

The 1807-1940 period is divided into three sections: The Early Years 1807-1843, Laying the Foundations of the Networks 1843-1900 and Building the Networks 1900-1940. Some of the material such as that related to instruments and computations is given intoto in one section or another even though the period covered spans two or more sections. Also, the brief histories for Geodetic Astronomy, Gravity and Reconnaissance Surveys cover the years 1807-1990.

THE EARLY YEARS 1807-1843

1807: Survey of the Coast Created

Geodetic surveying began in the United States on February 10, 1807 with the creation of the Survey of the Coast by Congress in the presidency of Thomas Jefferson. Ferdinand R. Hassler, a Swiss born geodesist, who conceived the plan was placed in charge and served in that capacity on and off until his death in 1843. Nothing was accomplished for several years because appropriated funds were not released due to political opposition and unsettled conditions in Europe, the source of needed equipment. Finally in 1811, $25,000 was disbursed and Hassler immediately went to England to have instruments made to his design and specifications and to purchase other equipment and scientific books. He remained there during the War of 1812, returning in 1815.

First Field Surveys

First field surveys were carried out in 1816-17 near New York City where a small scheme of triangulation consisting of 11 points, scaled by two measured base lines was accomplished to an accuracy that would approach present day second-order, class I. Hassler performed the reconnaissance to select the station sites, directed the base line measurements and observed all the angles with the recently acquired 24 in. theodolite, built by Edward Troughton of London to his specifications.

The first point occupied for geodetic observations in the U.S. was identified as WEASEL located on a low mountain about 2 miles south of Patterson, NJ on July 16, 1817. It was marked by a 6" deep drill hole filled with sulphur. In 1934, it was reported that the top of the mountain had been blasted off destroying the station. Blasting is among the very few ways to obliterate a mark of this type.

None of the original stations are thought to exist today, although WEASEL and SPRINGFIELD were included in the primary triangulation southward from NYC observed in 1838. Station CHERRY HILL, one end of the base line at the northern end of scheme, near Englewood, NJ was destroyed by sub-division construction in the late 1970's only a few days before personnel were scheduled to move the point to a protected area. In 1987, the American Society of Civil Engineers placed a plaque at the approximate location of original station CRANETOWN, north of Montclair, NJ, noting the site as a National Historic Civil Engineering Landmark.

Hassler Dismissed

Almost immediately on its completion, politics reared its ugly head once again and Hassler was dismissed. For about 15 years he tried his hand at several occupations before being reappointed to his position in 1832. First he worked as an assistant on the U.S.-Canada northeast boundary surveys, then made an unsuccessful attempt at farming in a remote site on the St. Lawrence River where his wife left him. After that he took a position as a gager at the NY Custom House, followed by a period of unemployment during which he wrote several books on advanced mathematics and developed the polyconic map projection still used today. Finally in 1830, he received an appointment as superintendent of the new

Office of Weights and Measures. This office remained in the Coast and Geodetic Survey until 1901 when it was spun off to become the National Bureau of Standards. This was a dark period for both Hassler and American geodesy.

Hassler Reappointed

Once back on the job he immediately began geodetic surveys on Long Island, NY that have continued, more or less unabatedly until today. The instruments and equipment that Hassler had made or purchased were more than adequate for the task at hand. This was attested to by a French astronomer who said in 1832 --- at the time of construction, the instruments were twenty years in advance of the science of Europe. Having the best of tools is no guarantee, of course for the best of results. In surveying best means the most accurate and to reach that goal requires, in addition to the instrumentation, trained and conscientious personnel and proper observing procedures. The sum total of all the requirements can be broadly categorized as standards of accuracy. In that regard, Hassler set standards of highest accuracy for these early surveys that remain the hallmark of American geodetic work.

He personally made all the observations at the primary stations, yet at the same time trained his assistants James Ferguson and Edmund Blunt on the secondary surveys so that they could step in when necessary to do his job --- and they did. In the year after Hassler's death in 1843, Ferguson measured the KENT ISLAND base line in Maryland, Blunt the MASSACHUSETTS base, and they shared his role in observing the primary triangulation.

The first station occupied was BUTTERMILK on June 11, 1833. It still exists and is located on what is now the Rockefeller estate in Westchester County, NY.

The Great Theodolite

Prior to October 18, 1836, the observations were made using the 24 in. theodolite mentioned previously. On that day and until his death in 1843, he employed a 30 in. instrument that he proudly called the Great Theodolite. Designed by himself, built by Troughton, the finest instrument of its day was used first at station WEST HILLS on the northern shore of Long Island, a point that remains in place even now. Its weight of 300 lbs. was of little concern to Hassler, having used a 36 in. Ramsden theodolite, an instrument of similar weight in the trigonometrical survey of Switzerland. He simply strengthened the oversize carriage used for transporting the 24 in. instrument, a fairly heavy piece in itself weighing perhaps 200 lbs.

Two characteristics of the Great Theodolite are seldom mentioned, one, it was designed as a repeating instrument and two, it had a 24 in. vertical circle. Hassler employed it in the direction mode as did others later, until destroyed in 1873 and it must be assumed that the final construction was as a direction theodolite.

Hassler's Base Lines

The two base lines measured for the 1816-17 survey at Gravesend Bay near present day Coney Island (4.7 mi) and at Englewood, NJ (5.8 mi) were not considered accurate enough nor probably long enough to scale the primary triangulation then underway. Both bases were measured with iron chains, each link one meter in length. Accordingly, Hassler measured his only primary base line at Fire Island on the south shore of Long Island in 1834 using four 2 meter iron bars laid end to end. It was not a direct measurement. In order to take advantage of the level beach, the principal measurement followed a route from WEST BASE somewhat southerly of the direct line to a point about 255 meters west of EAST BASE. The point was connected to EAST BASE by angle and distance with the distance between the terminals obtained by computation.

His methods were acclaimed by several scientific societies, but as always the real proofs of the pudding are the agreements with the nearest base lines as computed through the triangulation. The checks were excellent, about 1:100,000 with the MASSACHUSETTS base, EPPING base, ME and KENT ISLAND base, MD, measured in 1844, 1857 and 1844 respectively and about the same accuracy with nearby EDMI lines observed in the 1970's.

Hassler's base apparatus was used for the MASSACHUSETTS and KENT ISLAND bases. The EPPING base was measured with the Bache-Wurdemann compensating equipment. The FIRE ISLAND base is 8¾ miles in length and marked at the terminals by red sandstone monuments 4 ft. high and about 1 ft. square with a rounded top and at intervals of 2,000 meters by stoneware cones. Records state the marks are lost, however it is unlikely that much of an effort was made to find them, especially the intermediate ones. With today's equipment it wouldn't take a huge effort to settle the question once and for all time.

The FIRE ISLAND base was computed through the triangulation to the line WEST HILLS - RULAND on the north side of Long Island, a line Hassler called his mountain base from which the triangulation east and north and to the south was extended. This triangulation eventually ran from Calais, ME southward to Dauphin Island near Mobile, AL then westward to New Orleans, LA a distance of 1,623 miles with the field work done between 1833 and 1898.

Massachusetts Commonwealth Survey

The Coast Survey was not the only agency establishing triangulation at the time. In 1830 the Massachusetts legislature decided to prepare maps of the commonwealth based on a trigonometric survey. Colonel James Stevens was placed in charge and began operations including the measurement of a 7.4 mile base line along the Connecticut River, near Northampton.

The measurement was carried out with compensating apparatus 50 ft. in length designed by Dr. Joseph Rice. No other information is available about Joseph Rice and little is known about his apparatus although the methodology was reported in one or two scientific journals. Nevertheless, the principle he employed was about 15 years ahead of its use in the Coast Survey, albeit his work was known there. The first application of the compensation principle was by the Ordnance Survey of Ireland on the Lough Foyle base in 1827.

A theodolite on loan from the Coast Survey was used for angle observations until its recall in 1834. After that time an instrument of their own design was employed. Stevens resigned in 1834 and Simeon Borden, formerly an assistant took over with the bulk of the work still to be done and completed the survey in 1838.

The results were not published until 1846 and the positions were given as tangent plane coordinates based on the location of the points in one of 5 zones. This was the first use of plane coordinates on a large scale in America. In 1935 it was reported that little use was made of the coordinate system, a situation not too different from that found today.

A Series of Name Changes

Hassler began using the title Superintendent of the Coast Survey in his 1836 report to the Secretary of the Treasury, the year the bureau was transferred to that department. This usage continued until 1865 where that and subsequent reports to 1877 showed United States Coast Survey. In 1878 Congress changed the name to U.S. Coast and Geodetic Survey (C&GS); in 1899 the U.S. was dropped. In the 1970's, the C&GS became the National Ocean Survey (NOS), later renamed the National Ocean Service (NOS) with the geodetic functions assigned to the National Geodetic Survey (NGS), presently an office in NOS.

The End of the Beginning

Hassler continued observing the triangulation southward and after about 10 years only had reached southern New Jersey involving but 24 stations. Upon completing the observations at station BURDEN he traveled to a station site in Delaware where during a severe storm he fell trying to protect his instruments and was badly injured. He returned to his home in Philadelphia where he died on November 20, 1843.

Thus we reach the end of the beginning. The groundwork for laying the foundation was done. By the turn of the century triangulation would span the nation north to south from Maine to Louisiana, east to west from New Jersey to California, over the Great Lakes and with work underway through the middle of the country between the Rio Grande and Canada.

LAYING THE FOUNDATIONS OF THE NETWORKS 1843-1900

The 1807-43 era in American geodesy was totally dominated by one person, Ferdinand R. Hassler. He was head and shoulders above all others. This was not the case for the 1843-1900 years, albeit several strong willed, very competent personalities prevailed for long stretches, some for almost the entire period, but none over shadowed all others as completely for as long a time as did Hassler. Among the elite group were Alexander Dallas Bache, George Davidson and Charles A. Schott.

A.D. Bache, Scientist

Alexander Dallas Bache was appointed the second superintendent of the Coast Survey in December 1843, being eminently well qualified for the post having a learned interest in many scientific activities. Born in Philadelphia in 1806, the great-grandson of Benjamin Franklin, a graduate of West Point at age 19 and served 3 years in the Engineers. Prior to his appointment, he was professor of natural history and chemistry at the University of Pennsylvania and served as superintendent of schools in Philadelphia. Later he helped form the National Academy of Sciences and was its first president.

Congressional Decisions

The Act of 1843, passed by Congress in April of that year, defined the functions and personnel responsibilities of the Coast Survey that, except for a few modifications, remained in place for more than a 100 years. In fact, the enabling act of 1947 did little more than restate the bases for the bureau that were essentially unchanged from the 1843 definitions.

One proviso in the 1843 act, unfortunately, limited the bureau's activities to the coast, and the narrowest belt of land to support the primary triangulation. Bache accepted the restriction, and immediately went ahead with a broad plan to divide the Atlantic and Gulf coasts into nine sections, where the ongoing work (geodetic, topographic and hydrographic) would be carried on simultaneously and to uniform standards. Two sections were added when the Pacific coast territories were annexed.

Congress lifted the restriction in 1871, during the superintendency of Benjamin Peirce, when it gave permission for the measurement of the Transcontinental arc. In 1878, the name was changed to U.S. Coast and Geodetic Survey to reflect the bureau's responsibilities for geodetic surveys inland.

Bache's Field Activities

Bache continued Hassler's practice of personal involvement in the field work, but didn't limit his participation mostly to geodetic surveys as did his predecessor; albeit he spent considerable time in making astronomic observations and measuring base lines. In regard to the latter, he designed and William Wurdemann, then a master mechanician in the Coast Survey, constructed compensating apparatus that was used until 1873. Seven principal base lines were measured using the Bache-Wurdemann equipment, the last being the ATLANTA base in Georgia. Bache personally directed the measurements for the first three bases at DAUPHIN ISLAND, near Mobile, AL in 1847, BODIE ISLAND, NC in 1848, EDISTO ISLAND, SC in 1850 and the sixth at EPPING, ME in 1857. Wurdemann later resigned from the Coast Survey and formed a very successful business making astronomic and geodetic instruments for clients here and abroad.

Alexander Dallas Bache died in 1867, age 61 at Newport, RI. America had lost one of its greatest scientists, however he left a legacy of excellence for his successors to build on and most were able to do so.

Superintendents

Bache was the last of the superintendents to participate extensively in field operations, the position had simply become too large and the responsibilities too great for such personal involvements. Following Bache's death in 1867, nine civilian superintendents/directors served until 1929 when the position was reserved for C&GS commissioned officers. The title was changed to director in 1920. Several of the civilian superintendents were highly regarded scientists including Benjamin Peirce (1867-74), Julius E. Hilgard (1881-85), Thomas C. Mendenhall (1889-94) and Otto H. Tittmann (1900-15). The last civilian, E. Lester Jones (1915-29) was a veterinary surgeon by profession with an outstanding record in public administration.

One of Jones' first acts was to propose a commissioned officer corps because of the difficulties in employing and retaining qualified personnel for the field work due to the frequent moves and other hardships. The proposal was accepted by the Congress and the corps came into existence during World War I. There was one complication. The formation of the corps forced the civilian personnel to accept a lesser role. In addition to the director, many of the top positions in both the field and office are reserved for officers causing occasional differences and/or resentment to arise in the civilian group towards the corps. All in all, however the arrangement has worked fairly well, both sides usually accepting the situation as that's the way it is.

One of the Giants

Bache was fortunate in recruiting a number of highly qualified engineers, mathematicians and other scientific types for the Coast Survey with the title of Assistant. In due course, many became master jack-of-all-trades being equally at home in the several Coast Survey activities that included in addition to geodesy, topographic mapping, hydrography, tides and currents, magnetism and others. Among the group was George Davidson, a native of Nottingham, England whose exceptional talents were recognized by Bache when he was head of the Philadelphia school system and Davidson was a student.

Joining the Coast Survey in 1845 at age 20 he trained in geodetic surveys and astronomy under the foremost engineers in the bureau including Bache and Robert H. Fauntleroy until 1850 when he was sent to California with 3 other civilian assistants. Travel between the Atlantic and Pacific coasts was not an easy journey in 1850. Overland routes were very limited, especially in the mountainous regions and west of the 98th meridian those that did exist often ran through hostile Indian territory. Once beyond rail and river boat services, travel was by foot or by horse or mule conveyances.

Transcontinental rail service wasn't available until 1869 and it was many years before a rail network was developed. Stage coach service from rail heads was unreliable at best and accommodations when available, were very primitive. Davidson and his colleagues travelled by ship to the Isthmus of Darien (now Panama), then by available means to the Pacific side and another ship to San Francisco, a trip that usually took several months.

There was no direct mail service with Washington for many years and the field records and computations were sent by ship as well. Duplicate and sometimes triplicate copies were made of all records and kept on site, even occasionally retained after their safe arrival was acknowledged for use in the ever expanding network.

Davidson remained on the west coast for about 45 years, the Civil War period and a few foreign assignments excepted. During his service, the Transcontinental triangulation, a k a the 39th Parallel arc was completed, primary surveys near Los Angeles and Santa Barbara Channel were underway and coastal triangulation was extended from Mexico to Canada.

Davidson is not credited with the earliest triangulation on the west coast, that accomplishment belongs to Robert D. Cutts, one of the assistants who came west with him in 1850, although we can be sure that he was a major participant. This small network covering San Francisco Bay was observed to a secondary accuracy between 1851-54, with scale provided by preliminary base lines, one at the Presidio measured in 1851 and the second, the PULGAS base near Palo Alto in 1853 and oriented by astronomic azimuths.

In 1876, Davidson was placed in charge of the western section of the 39th Parallel surveys and extensions to it. In the course of that work he measured base lines at Yolo County north of San Francisco (YOLO base 1881), LOS ANGELES base 1889, the angulation for the base expansions and the astronomy to orient the principal triangulation.

Survey vs. GLO

He was a man of strong personal opinions and was an ardent advocate for the Coast Survey to assume the surveying functions of the General Land Office (GLO), the present day Bureau of Land Management. While there was support for his proposals, it is very fortunate for both agencies that they never materialized. The Survey had done some section work for the GLO in the Florida Keys in the 1850's and the experience was not a happy one for either side.

There is no doubt that had his plan been accepted the section corners would have been located, at the very least, to a minimum geodetic accuracy thus creating a cohesive network supplemental to the national framework. However, the cost would have been enormous and Survey field personnel would assuredly have been bogged down executing time consuming short line surveys, often over rough terrain.

Sooner or later Congress would have viewed this as an endless project, and it very well might have been just that. GLO practices were right for the time, with means now available for a total upgrading of the system once all the legal ramifications for such an undertaking are settled.

Although this cause was lost, most others were successful. His ability to convince James Lick to finance the great astronomical observatory atop Mt. Hamilton is a good example of his successes. George Davidson was unquestionably the greatest field geodesist the Survey produced in the 19th century, the giant among giants for only men of that breed could have executed the triangulation through the mountain west of the time. In 1895 during William W. Duffield's superintendency (1894-97), Davidson in his 50th year of service was summarily dismissed, as were many other experienced employees. In his usual pragmatic fashion, Davidson accepted a professorship at the University of California and went on with his life doing things his way until his death in 1911.

Multi-Talented Schott

In the field of computations, Charles A. Schott stood alone during this period, much as George Davidson did in his area of expertise. Schott was born in Mannheim, Baden, Germany in 1826, a graduate of the University of Karlsruhe and joined the Coast Survey in 1848. Appointed chief of the computing division in 1856, he held the post until his resignation on December 31, 1899, after 52 years of service.

A world recognized expert on the earth's magnetic field, personally carrying out numerous field surveys in the eastern U.S. and instrumental in establishing magnetic observatories at Madison, WI and Los Angeles, CA. He had a life long interest in field activities that was culminated with the development of a contact compensating base line measuring apparatus of unique design in 1881 that bears his name and was used in the same year to measure the YOLO base in California.

As chief of the computing division he was responsible for a myriad of calculations and as was his way took a distinct interest in all of them. Much of his efforts was directed to geodetic computations, especially the adjustment of the observations and investigations of the results. One such examination carried out in 1878-79 relative to geodetic and astronomic data on the Eastern Oblique arc provided information for establishing the first national datum and conclusively showed that the Clarke spheroid of 1866 fit the U.S. better than the Bessel spheroid of 1841 then in use.

Both results were adopted, the New England datum of 1879 as it was named is the basis for all subsequent datums until 1983. The Clarke spheroid of 1866 still provides the best fit for the continental U.S., albeit the Geodetic Reference System of 1980 (GRS 80) was adopted in 1983 for other reasons.

Schott was a prodigious writer authoring more than 160 scientific articles, papers and reports including two volumes detailing the results of the primary triangulation that were hailed by geodetic circles worldwide. The volumes are The Transcontinental Triangulation and the American Arc of Parallel Sp.Pub.no.4 1900, 871pp. and The Eastern Oblique Arc of the United States and the Osculating Spheroid Sp.Pub.no.7 1902, 394pp. Charles A. Schott died in 1902. We will never see his kind again.

Quadrilaterals and Central Points

Early in Bache's tenure a decision was reached for the triangulation that only quadrilaterals with both diagonals observed, commonly called braced quadrilaterals or central point configurations would be permitted. The reason for this specification is these figures provide at least one geometric condition involving the angles, known as side conditions or equations. These equations utilize the sines of selected angles taken in a particular sequence and give a better evaluation of the worth of the angles than an examination of the triangle closures alone.

This requirement was met for all the principal triangulation and most of the secondary work except for parts of Hassler's early net and pieces of the U.S. Lake Survey triangulation observed later in the century.

Longitude by Wire

The first of several significant advances in American geodetic surveying that were to be made in the next 100 years was the development by Sears C. Walker in 1847 of a method for determining time differences between places using the electric telegraph, invented only a year earlier. As a result more accurate astronomic longitudes were determined leading to subsequent improvements in Laplace corrections to astronomic azimuths.

Once the transatlantic cables were in place later in the century the same principle was employed to determine a more accurate cardinal longitude for North America, relative to Greenwich, than had been obtained from 1065 chronometer exchanges during a previous time. This method was used until the 1920's before being replaced by radio signals.

Advances in Theodolites

Hassler's original theodolite was built by Edward Troughton of London during the period 1811-14, had a 24 in. circle, weighted more than 150 lbs. and required a special oversize carriage to transport it. In 1836 his Great Theodolite with a 30 in. circle, also constructed by Troughton arrived in the U.S. and was put to immediate use in the primary triangulation then being extended east and south of New York City.

In the early period, segments of the primary triangulation were observed with 10 and 12 in. repeating theodolites and acceptable results were obtained. The results notwithstanding, repeaters were rarely employed on primary work after this time.

In due course, several lighter, more accurate instruments were designed and/or built in the bureau's instrument division. The most notable being two 20 in. circle models in 1873 made by William Wurdemann, formerly of the Coast Survey and three improved versions of these models constructed in 1876-77 at his shops in Dresden, Germany.

The instruments were followed in the continuing evolution of smaller and equally accurate circles at 25-30 year intervals by the 12 in. circle - 3 micrometer theodolite constructed by the then chief of the division, Ernst G. Fischer about 1894 and the 9 in. circle - 2 micrometer theodolite designed by Douglas H. Parkhurst, head of the division in 1927.

All direction theodolites prior to the Parkhursts were read via 3 micrometers. In the early 1950's the Wild T-3 theodolite, with a 5½ in. glass circle read by an auxiliary telescope, replaced the 2 micrometer Parkhurst and was employed until the mid 1980's, becoming obsolete with the introduction of the Global Positioning System (GPS).

During the more than of 150 years of U.S. triangulation observations, diameters of horizontal circles ranged from 30 inches in the 1830's to 5½ inches in the 1980's. Despite the huge disparities in weight, construction and diameter of theodolite circles, the common denominator is the accuracy of the observed angles remain the same.

Instruments of the time were built to last. Hassler's 30 in. theodolite, for example was in constant use for about 37 years before being destroyed by a tornado. Its destruction is described in Sp.Pub.no.7, p.47 as follows: ..... was in continuous use till November, 1873, when it met with an accident at station SAWNEE, in Georgia. It was struck by a tornado and, not withstanding its weight of 300 pounds, was hurled from its stand and irreparably damaged.

Few theodolites before the Parkhursts had vertical circles attached. Vertical angles were observed using separate instruments with circles only slightly smaller than the horizontal ones.

Field Specifications

Prior to 1905 no published specifications existed for making horizontal observations, although the procedures adopted by the superintendent of the Survey in that year were those long in use. The lack of stated requirements was not of great concern since only 4 or 5 observing units were in the field on any given day and the observers, a very select group, were field trained, college- educated engineers.

This was not always the case in later periods. Between 1935 and 1970, for example, about 10 times that number of units often were working on a single night.

From the beginning, direction instruments were mostly employed in a pattern of taking direct and reverse measures on each point in turn seen by the station occupied, the sum total constituting a set. Several sets were observed with each set beginning on a different part of the circle. This method of observing is attributed to Bessel, albeit it was likely used in some form prior to his proposal.

Eventually sets became known as positions and the initial settings for each position were assigned specific locations on the theodolite circle. Sixteen positions evolved finally as a complete observation for the principal triangulation with a 4" rejection limit from the mean.

The Coast Survey rarely deviated from the general practice described above, but the Lake Survey did on occasion by employing the method of independent angles reasoning it would reduce the effects of tower twist, a rationale dismissed by some.

Coast Survey observers were trained to take their measures as rapidly as possible, without forcing any of the motions or miss 'em quick in the parlance.

Little information is readily available about the time required to complete observations in earlier periods and it really doesn't matter much because most occupations took a week or more and a few several months. Gardens were even planted at times. Estimates to complete the 32 pointings on each signal light when using the 12 in.- 3 micrometer theodolite was 15-20 minutes.

Once Parkhursts came into use the time was reduced by about one-third and some observers became very fast, with runs of 6-8 minutes per light and less recorded. Similar times were the rule with T-3's.

Most theodolites used by the C&GS prior to about 1950 required two observers for the most expeditious operation, one to point the instrument and read one of the micrometers and the second to read the other micrometer(s).

Personnel assigned to observing units as recorders had to have superior arithmetic skills so as to be able to instantly mean the 6 readings of seconds for 3 micrometer instruments and 4 readings for Parkhursts. Then continuing the process by reducing the readings to the initial station for each position and placing them on an abstract for inspection by the observer on completing his work. T-3's involved a slightly different process, the effort required was about the same as for the Parkhurst.

Signals: Cones, Helios, and Lights

In Hassler's time, observations were generally taken on earthenware cone targets mounted atop pole signals. Polished metal cones for reflecting sunlight, mounted in the same fashion, continued to be used for several decades at unmanned stations.

By the 1840's, heliotropes came into use continuing until 1902 when they were replaced by acetylene lamps, which in turn were replaced by automobile headlights in 1916. It was long known that daytime observations caused the triangulation to sway, probably due to unequal heating of the theodolite, despite precautions taken against it and several attempts were made in the 1880's to observe at night, even to using a selenotrope to reflect moonlight; none proved too successful.

Selenotropes required much larger mirrors than heliotropes' 2-4 inch diameter reflectors: i.e. 6 by 6 inch mirrors for 22 mile lines, 6 by 8 inch for 48 miles, 8 by 10 inch for 70 miles and lines longer than these were not uncommon in the triangulation of the time. The sway, of course could be controlled by inserting additional Laplace stations. After 1902 all primary observations were made at night.

On the Mark

Accurate plumbing of theodolites and targets over station marks is requisite in making geodetic surveys. Exact centering was always desired, however miscenterings of 0.1 to 0.2-in. and perhaps more when high towers were involved would not be unrealistic, nor cause large errors. i.e. A miscentering of 0.1-in. translate into a maximum error of 003 in an angle over 10 mile lines and for a 1-in. displacement, over the same length lines the largest error would be 03. Where tripod height stands and short towers were employed, the centering was usually done with plumb bobs.

Prior to about 1900, when optical plummets, known as vertical collimators, came into use, high signals were plumbed with a theodolite, from observations at two locations, 90 or 180 apart. The early collimators were designed for use from the top, down. Once Bilby towers replaced wooden signals, the ease in which the tripod head and light plate could be adjusted made it more practical to plumb from the station mark, upward, and the collimators were modified accordingly. Many theodolites introduced after 1950 had built in optical plummets, further simplifying the task.

Base Line Measuring Apparatus

A variety of base line measuring apparatus, usually rods or bars 2-6 meters in length, encased in tubes were developed, many ingeniously designed to resolve the problem of thermal expansion through compensating principles. The last of these apparatus and the most accurate, a duplex bar set was designed by Assistant William Eimbeck in 1897 and used by him to measure the SALT LAKE base in 1897. The equipment was employed as a field standard replacing the iced bar apparatus used previously for the standard kilometer section during the measurement of 9 bases on the 98th Meridian arc by Assistant Albert L. Baldwin with steel tapes in 1900. Eimbeck was a long time associate of George Davidson and one of those elite mountain men mentioned previously.

The first bases measured with steel tapes were the HOLTON base, IN and the ST ALBANS base, WV by Assistants Alonzo T. Mosman and R. Simpson Woodward in 1891 and 1892 respectively. Measurements were made mostly at night utilizing 4 tapes, two 50 meters in length and two 100 meters in length. A 100 meter field comparator and a one kilometer section of each base were measured using iced bar apparatus designed by Woodward when he was associated with the USLS. The apparatus consisted of a 5 meter steel bar immersed in melting ice in a Y shaped trough mounted on two 3 wheel vehicles that were moved along a portable track.

While highly accurate, it was a cumbersome device requiring about one hour to measure 100 meters. Similar equipment was long used by the Bureau of Standards to standardize tapes. No C&GS base line was completely measured with the apparatus. The 9 bases on the 98th Meridian arc were measured accordingly, except only the 100 meter comparators were established by iced bar measures, with Eimbeck's duplex bars serving as the field standard, as mentioned earlier.

The Impact of Invar

The thermal expansion problem was finally resolved with the discovery of invar, an alloy of nickel and steel having a very low coefficient of expansion by Charles E. Guillaume, a French scientist about the turn of the century. Tapes and wires became feasible for measuring distances.

Following the measurement of 6 primary base lines by Owen B. French in 1906, all bases were measured using tapes made of invar, 50 meters in length, a much more efficient and faster method than those previously employed and certainly as accurate. Base line tapes were kept in sets of 4, three for the measurements and one as a comparator, all standardized prior to and after use.

Prior to 1870, all primary base lines resulted from a single measurement with segments occasionally remeasured for verification purposes. Due to the singular nature of the observations, the validity of the measurements was primarily ascertained by knowledge of the equipment and procedures employed. Accuracy estimates were based on comparisons of the apparatus made prior to and at the completion of the work with the field standard and by duly considered error estimates for the various observations and actions involved.

In 1872-73, the ATLANTA base on Peach Tree Ridge was completely measured three times, forward in the fall, backward in the winter and forward again the following summer. Few base lines were ever completely measured twice prior to this time and to do so on 3 occasions was probably a geodetic first. Later, at least two complete measurements were made and when using invar tapes two of the measures were always made in opposite directions with the same person at the front contact or marking end of the tape to cancel the parallax effect.

Measuring base lines was a time consuming chore prior to tapes being employed. Sites often had to be graded to meet the 5% slope restriction and taking observations at 6-8 meter intervals made for slow progress, which averaged less than 0.5 mile per day for Hassler's equipment and slightly more than one mile with compensating apparatus. Once tapes were introduced, the grade allowance was increased to 10% and the much longer tapes made 5 miles and more progress per day routine.

Base line apparatus followed an evolutionary path similar to that taken by theodolites, with one distinct exception. Each new apparatus provided an improved accuracy, while there is no significant difference in the angles measured with the 3 footers in 1790 and those observed by the half footers after 1950. For example: The 3 base lines measured with Hassler's equipment had an average standard error (one sigma) of 1:200,000; compensating apparatus 1:310,000 and invar tapes 1:675,000 or better.

Geodetic Astronomy

Only a limited amount of Geodetic Astronomy was accomplished during the Hassler period with a few latitudes, azimuths, differences of longitude by the chronometer method and at least one longitude being observed. However, it was not until 1847 following Sears C. Walker's development of the telegraphic method for determining differences of longitude that all the quantities were of equal accuracy.

Astronomic latitudes were observed using the Horrebow-Talcott method following its adoption in 1851 to the present. Bache introduced the method in 1846 and the first complete set of observations was obtained by Assistant T.J. Lee at Thompson, MA in the same year. In the 1970's, in response to contentions that the Sterneck method was more accurate, observations at more than 30 stations showed that both procedures gave essentially the same results.

From 1847-1922 longitudes were determined by the telegraphic method whenever possible. After that time radio signals were employed.

Azimuths were observed by a variety of procedures, although the direction method was, by far, used the most often for primary determinations. In the direction method, observations on Polaris or whatever star was used, were taken as if it is simply another signal, following the same measuring sequence as for triangulation. A chronometer was set for estimated local time and the times of measurement were corrected later for the difference with true local time determined from observations on time stars or radio signals, obtained prior to and immediately following the azimuth observations. About 1975, digital clocks were adapted to receive the standard radio signal directly. Repeating theodolites were occasionally used for azimuth observations following the same patterns as used for angulation.

Broken Telescopes Introduced

Latitude and longitude observations were made from 1847-88 with large transit instruments made by Troughton and Simms of London that could be used as both meridian and zenith telescopes. Slightly smaller similar transits built by the C&GS Instrument Division were employed after that time until 1914, when Bamberg broken telescopes were introduced. About 1960 the Wild T-4, another broken telescope instrument, replaced the Bambergs and in the 1970's the Kern DKM-3A, a true universal theodolite was introduced. Astronomic azimuths were generally observed using regular theodolites except in the higher latitudes where any of the three astro instruments employed after 1914 could be substituted. Determining differences of longitude remained a problem for many years after 1847 because the telegraph lines required were not always available, especially in the western part of the country and Alaska, and the chronometric method continued to be used. As a matter of fact, most of the longitude bases for the several local datums in Alaska resulted from chronometric observations. On the other hand, telegraph lines were sometimes extended to places specifically to determine astronomic longitudes. One such case was at Lake Tahoe in 1893, as part of the delineation of the California-Nevada boundary, where it was necessary to string telegraph lines about 5 miles airline, all uphill from Genoa, NV.

Early on, astronomic latitudes and azimuths, because of the simpler nature of the observations, were obtained more frequently. The primary reason for the observations was to obtain deflections of the vertical at the points by taking the difference between the observed and geodetic azimuths and backing out the Laplace equation to compute the equivalent difference in longitude. When the astronomic longitude also is observed, the point is identified as a Laplace station although technically only the longitude and azimuth is required.

In due course, Laplace stations were regularly spaced throughout the country. The U.S. network was one of the few anywhere whose orientation was rigorously controlled by Laplace azimuths at prescribed intervals. This policy began about 1910 for the work still in progress and continued in the establishments of the North American datums of 1927 and 1983 (NAD27 and NAD83).

The end results of the method described above for obtaining deflections of the vertical were generally for analysis purposes only. However, there was at least one prominent instance otherwise where the method was employed to obtain such information needed to reduce the PASADENA base to the mountain line Michelson used in his experiments on the speed of light in 1922-23.

Astro-Geodetic Deflections

Astronomic azimuths as observed also were used to control the first-order taped traverses observed during the 1917-27 period. It was recognized that the Laplace corrections would be very small in that part of the country where the traverses were measured and that the observed angles could easily absorb the differences. In 1956 a program was initiated to determine astro-geodetic deflections along the 35th parallel at about 30km.(18mi) intervals as part of an international study on the shape of the earth. Most of the observations were completed, some made as part of the Transcontinental Traverse (TCT) project where more than 1,300 astronomic positions and azimuths were measured between 1961-76.

In 1974, a plan was drawn up to upgrade the network for NAD83 that included the measurement of several hundred new base lines, astronomic azimuths and required positions plus astronomic positions for about 100 points, mostly base line stations where steep-slope lines (in excess of 5) were involved. The purpose of the latter was to determine deflections of the vertical for use in correcting the observed angles. A maximum correction of 5" was found in the TETON base triangulation, Grand Tetons, WY, an amount certainly among the largest discovered to date.

Until 1960 almost all geodetic astronomy was accomplished by the C&GS. About that time, the Defense Mapping Agency (DMA) as part of the missile and satellite programs began observing astronomic positions at sites of particular interest to them. Later, DMA measured several legs of the TCT including the required astronomic positions and azimuths. Once the Global Positioning System (GPS) became operational in the mid 1980's, geodetic astronomy along with the classical methods for determining geodetic positions was obsolete. Little or no astronomic work has been done since 1985.

Towers, ... First of Wood

Classical triangulation was developed utilizing the higher elevations for station sites, for the obvious reasons. Whenever possible to do so, sturdy triangular-shaped wooden stands, about 4 ft. high, plumbed over the point, generally with a platform for the observer, were used to hold the theodolite. On a few occasions in the 19th century and after about 1965, similar stands of metal were sometimes employed.

While ground setups were ideal, it was nevertheless not unusual to elevate the instruments further in order to clear various obstructions, to extend the lines of sight, to minimize refraction conditions and similar, and this was done even in the earliest time, despite the heavy weight of the theodolites. As an example: The scaffolding and tripod at both ends of the EPPING base, ME in 1857 rose 43 ft. above the surface marks, and the pole signals extended 10 ft. higher. For almost 100 years, the structures were made of wood, in a few cases, the actual tree itself was used and in very rare instances, of masonry construction. Whenever possible, the stands holding the personnel were separate from the instrument tripods.

The sparsely settled, wide-open spaces of 19th century and early 20th century America didn't lend itself to the European practice of utilizing church spires and other high structures for triangulation station sites. Even when available very few of these buildings were ever selected for primary station locations because of stability problems and the need, in many instances for eccentric setups. As a result the tall wooden towers or signals, as they were also called, required to overcome various obstacles were often engineering and architectural gems. In some cases, especially in the high plains where earth curvature was the only obstacle, shorter double towers were topped with slender, and sometime equally as tall superstructures from which heliotropes, lights or pole targets were displayed.

Then of Steel

The era of tall wooden towers ended in 1926 when Jasper S. Bilby, then Chief Signalman C&GS, drawing on steel windmill technology used throughout the west, erector set toys, gas pipe towers built earlier by the U.S. Lake Survey and his own long experience in constructing wooden signals, designed a double tower survey signal built almost entirely of reusable steel bars and rods, held together with bolts. These especially strong structures could be erected in standard configurations to heights from 37 to 116 feet in 13 foot increments by a 5 man crew in a day or less and dismantled by a 4 man team in about half that time.

The occasional need to extend the height of in-place towers and for additional height on the highest signals available was resolved very early with one piece sections, each 10 ft. in height, that were bolted to the tops of towers. As many as 3 sections, while rare, have been added to a single tower. A few bases for 129 ft. towers were later available, but seldom employed because of the much larger area required to anchor them.

Bilby tower components could be reused on numerous, even hundreds of times and the towers were employed worldwide. Their first use was in 1927 in southern Minnesota where during the working season that included other projects in the state, 96 towers were erected. As a point of interest, the tallest built was 156 feet (about the height of a 15 story building) on the Mississippi River arc in 1929.

One of a Kind

Jasper S. Bilby joined the C&GS in the 1880's as a young man, fresh off an Indiana farm and immediately showed an uncanny ability to locate trees obstructing lines of sight, an important attribute in a time when it wasn't easy to move about. He became skilled in signal building and reconnaissance (planning surveys), and in fact, wrote the original manual on the subjects, among several special publications he either authored or co-authored. He rose through the ranks to Chief of Party and at the time of his retirement in the 1930's, he was Chief Signalman, the highest civilian position ever in the C&GS field service.

Station Monuments

Lasting station monuments, for obvious reasons, were always of fundamental importance in geodetic surveys. Where rock ledges or large boulders were available, Hassler utilized drill holes filled with sulphur or some other substance to reduce the effects of freezing. Elsewhere, buried truncated earthenware cones were the rule. The center of the smaller radius end marking the exact station. Sub-surface (underground) marks also were usually set in the same fashion. In most cases, at least one reference (witness) mark was established, drill holes and cross cuts in rock structures and truncated earthenware cones, smaller than the station marks were standard. Hassler buried the reference cones in a specific pattern, providing visible reference information to locate the general station site, and in addition buried small pieces of rubble, sea shells and the like found at the site, atop the station mark to aid in the recovery.

Reference marks serve several purposes: To aid in locating the station, to verify its position, to reset the monument and for use as substitute stations.

Versatile Concrete

Base line stations were usually marked by heavy stone posts until about 1900 when poured concrete monuments replaced them. From about 1850 to the turn of the century, stone posts (marble, sandstone and limestone) 2-3 ft. in length, and for sub-surface marks the same type of posts, bottles, earthenware jugs and crocks and similar, generally replaced cones for marking stations. However, in some instances, bolts and nails cemented in drill holes, simple drill holes, cross cuts and in fact, almost any conceivable mark, in any combination with these station markings were utilized. When necessary to bury the marks, a ditch 4-8 ft. in diameter and 8-18 in. deep, surrounding the station location was usually dug and filled with coal or charcoal. Once concrete became readily available, 2-3 ft. long tile and tin pipes filled with the substance, set over underground marks were often employed with centers marked by bolts, nails, punch holes, etc.

About 1900, cast bronze disks were introduced and shortly thereafter poured concrete monuments 3-5 ft. deep with sub-surface marks became the standard, where rock ledges and boulders were not available. Monuments of this type continued to be used until the mid 1980's.

About 1965, steel rods driven to refusal with disks attached later were set for many surveys and in fact, are the basis for what are believed to be the most stable marks by today's standards.

In the 1920's, two reference marks were specified for each station and beginning in 1927, a third reference mark was set about ¼ mile distant for use in providing azimuth control for local surveys and for determining magnetic declination. Standard azimuth mark disks replaced azimuth reference marks about 1935.

Bench mark monuments were of similar design until the late 1970's when special steel rod type marks were introduced. In the 1930's, precast concrete posts with bench mark disks attached were used for several years.

Prior to the late 1970's, all concrete monuments and disks were constructed of non-magnetic materials. Once GPS became operational, sub-surface, reference and azimuth marks were seldom set and rod type station marks predominate.

Field Communications

Communications between observing units and on station personnel were kept simple and brief. In the earliest days none were usually necessary because the pole-target signals were seldom attended and when they were, a few flashes with a mirror for identification purposes and to indicate the observations were to begin and something similar on their conclusion would generally suffice. That practice continued when heliotropes came into use during the 1840's and most stations were manned, until about 1900 when Morse code was introduced. Only a few observing units were active in this period and the need to signal more detailed information was rare.

John F. Hayford during his service with U.S.-Mexican Boundary Commission in the 1890's resolved such a need for in field communications by utilizing Morse code. Once lights replaced heliotropes at the turn of the century, most observations were made at night and there were more reasons for the observers to have direct contact with the lightkeepers. For one, identification, also lights often had to be dimmed or brightened, messages relayed in emergencies and the like. In 1902 International Morse code was adopted as the vehicle to obtain that end.

Beginning in the 1930's multiple observing parties became the rule and angle information was often transmitted to the Chief Observer (1st O) so that triangle closures could be computed and any required reobservations made while still on station.

Radios were tried early in the World War II period and caused enough problems to delay their general use for about 15 years, the major one being the conversations were picked up by nearby receivers. In one case, locals hearing the jargon, compounded by flashing lights thought foreign agents were in the area and reported the incidents to police, who went looking for spies and found instead, surveyors atop towers. And, as might be expected, there were a few complaints about profanity.

By about 1960 radio technology was improved and all units were so equipped. Another era ended. No longer would lightkeepers peer off into the darkness awaiting a light blinking Dash - Dot - Dot pause Dash - Dash - Dot or DG, translated, Done here, Go to next station.

More Territory ... More Work

Progress was slow on the principal triangulation during a few periods in the 19th century when territorial acquisitions, especially those with long coastlines such as Florida, Texas, the Pacific Coast and Alaska created a need for immediate hydrographic surveys and other required charting information. And, the Coast Survey was a small bureau, personnel-wise.

A continuing problem, political opposition to geodetic surveys never really disappeared, although not as viciously as in the Hassler years. One congressman loudly proclaimed when the C&GS was authorized to carry the work to the interior that it was proliferating worthless triangulation throughout the country, and he probably had some supporters.

The Civil War caused the longest delay as many employees went off to join the military, north and south. In 1863 when it appeared the thrust of Lee's Army of Northern Virginia was aimed at Philadelphia, Bache and Davidson were sent there to aid in planning a defense for the city. Fortunately, Gettysburg ended that threat. The Spanish-American War brought more coastal territories, the Philippine Islands and Puerto Rico among them and about the same time, the Hawaiian Islands joined the U.S., all adding to the work of the bureau.

Continent-Wide Arcs

By the turn of the century the Eastern Oblique and the 39th Parallel arcs and extensions north from central Kansas to Nebraska and south from San Francisco to Santa Barbara were completed. The 39th Parallel triangulation is 2,750 miles in length, probably the longest arc executed by a single government and connects the lighthouses at Cape May, NJ and Point Arena, CA linking the Atlantic and Pacific Oceans, symbolically as well as scientifically. During the period primary triangulation was observed in much of New England and in 1876 Assistant Charles O. Boutelle measured an arc over the Mohawk Valley connecting this work with the Lake Survey stations near Buffalo.

West of central Colorado the 39th Parallel triangulation consists of massive figures, many containing lines 100 miles and more in length, the longest being 183 miles between UNCOMPAHGRE PEAK near Ouray in Colorado and MOUNT ELLEN near Hanksville,in Utah. In the 950 mile stretch from Colorado Springs, CO to San Francisco, CA less than 40 stations were required with many of the observations made by Assistant William Eimbeck between 1876-96.

Great Hexagon and Davidson's Quadrilaterals

West of Salt Lake City is the Great Hexagon with WHEELER PEAK at its center connecting the stations on the Wasatch Mountains to the east with those about 200 miles to the west in Nevada. Due to the remoteness of the area and short working season it took 10 years to complete the observations at the 7 stations involved.

In the 1880's and 90's the only mode of travel to the station sites in the mountain west was by horse, more likely mule, and wagon. Actually, horse and mule drawn wagons were the only means of transportation to most station locations everywhere until motor trucks were introduced in 1913. The first was a White Motor Co. 1½ ton truck, with a 30 HP engine and 25 MPH top speed used by an astronomic party on the 104th Meridian arc. Instruments, equipment and supplies were heavy and wherever it could be done, roads were built up the mountain as far as possible. The one at WHEELER PEAK remains today.

Further west the triangulation is carried over the Sierra Nevada near Lake Tahoe by very large figures known as

Davidson's Quadrilaterals with sides ranging from 57 to 142 miles in length.

Longest Line Observed

In 1878 Carlisle P. Patterson superintendent of the newly named Coast and Geodetic Survey gave George Davidson authorization to establish a station on Mount Shasta, a huge mountain in northern California with an elevation of 14,162 ft. The real purpose for the project being to measure the side MT SHASTA to MT HELENA which at about 192 miles would make it the longest triangulation line ever observed. The line MT LOLA to MT HELENA one of the sides of Davidson's Quadrilaterals, 133 miles in length was selected as the base for the triangle.

Assistant Benjamin A. Colonna was chosen to make the observations at MT SHASTA and George Davidson at MT LOLA. Observations were not secured at MT HELENA, only heliotropes were shown. Colonna's description that follows of the day he was successful tells the whole story.

The complete article, Nine Days on the Summit of Mt.Shasta appears in The Journal -Coast and Geodetic Survey, June 1953 Number 5, pp. 145-152. Friday August 1, (1878) proved to be the day I had been waiting for. The wind had hauled to the northward during the night, and the smoke had vanished as if by magic. At sunrise, I turned my telescope in the direction of MT LOLA, and there was the heliotrope, 169 miles off, shining like a star of the first magnitude. I gave a few flashes from my own, and they were at once answered by flashes from LOLA. Then turning my telescope in the direction of MT HELENA, there, too was a heliotrope, shining as prettily as the one at LOLA. My joy was very great; for the successful accomplishment of my mission was now secured. As soon as I had taken a few measures, I called Doctor McLean (a visitor from Oakland,CA) and (Richard) Hubbard (a guide) to let them see the heliotrope at MT HELENA, 192 miles off, and the longest line ever observed over the world. In the afternoon the smoke had arisen, and HELENA was shut out; but on the following morning I got it again, and my mission on Mount Shasta was finished. The French have been trying for some years to measure, trigonometrically, some lines from Spain across the Mediterranean to Algiers; they have only recently succeeded, and it has been a source of great satisfaction to French geodesists. Their longest line is 169 miles. The line from MT SHASTA to MT HELENA is 192 miles long, or 23 miles longer than their longest. And the glory is ours; for America, and not Europe, can boast of the largest trigonometrical figures ever measured on the globe.

It is somewhat ironic that only a few years later a regular network line mentioned previously, UNCOMPAHGRE PEAK to MOUNT ELLEN was observed and at 183 miles is 14 miles longer than the longest French observation.

U.S. Lake Survey

The Corps of Engineers were responsible for mapping and charting the Great Lakes, and recognizing that the Act of 1843 limited Coast Survey responsibilities only to the Atlantic, Pacific and Gulf coasts, setup the U.S. Lake Survey (USLS) within the Corps to do the job. Between 1864-1900, this agency established primary triangulation throughout the lakes' area including an arc south from Chicago connecting to the 39th Parallel triangulation at Parkersburg, IL.

One event of unusual interest was the several very long lines across Lake Superior they were able to observe despite the fact they were theoretically not intervisible. While very rare, when found, these observations, known as refracted lines because the signals are seemingly lifted by atmospheric conditions so they can be sighted on, generally involve sights across water, as was the case here. One such line was reported in the 1930's Hudson River arc.

Special Surveys

In the 1880's, the Coast and Geodetic Survey (C&GS) offered a program to assist the states in establishing geodetic control. As a rule, college professors directed the activities, with students and local people carrying out the work. Several states entered the program, but only the surveys in northeastern Pennsylvania and in New York were of acceptable quality. Other surveys of special note in this period were:

California-Nevada boundary from Oregon to Lake Tahoe and its continuation, the oblique line to the Colorado River measured in 1873 by Alexis Von Schmidt, U.S. Deputy Surveyor and the subsequent resurvey of the oblique line by

Assistant Cephas H. Sinclair C&GS between 1893-99.

Assistant William C. Hodgkins' C&GS 1893 resurvey of the circular boundary between Pennsylvania and Delaware originally set by local surveyors in 1760 and verified by Mason and Dixon in 1763.

Beginning efforts in Alaska over several decades, including work on the U.S.-Canada boundary in the 1890's.

The 1893-97 remonumenting of the U.S.-Mexico border made under the direction of Assistant Alonzo T. Mosman C&GS.

The 1872-85(?) triangulation of the Adirondack Mountains, NY by Verplanck Colvin, superintendent of the Adirondack and State Lands Surveys.

As geodetic surveying in America entered the 20th century, it did so on a solid foundation built on excellent surveying practices where the quality of the observations was never compromised and the quest for higher accuracies never ended.

BUILDING THE NETWORKS 1900-1940

At the dawn of the new century, as in any year, a generation of geodesists continue to move along the path towards their rightful place in the profession, wherever that maybe. In the U.S. one man, William Bowie, by virtue of his fine analytical mind and determined nature emerged early as the best of the best and in the same fashion as Hassler, totally dominated American geodesy for more than 35 years. Born in Anne Arundel County, MD in 1872, a graduate of Trinity College, Hartford, CT with additional work at Lehigh University, he joined the C&GS in 1895.

Geodetic Chief 1909-1936

During the next 14 years he demonstrated outstanding abilities in all phases of the bureau's geodetic activities, both field and office, leading to his appointment as Chief of the Computing Division and Inspector of Geodetic Work in 1909 (a position that about 1915 became Chief, Geodesy Division), replacing John F. Hayford, who had moved on to setup an engineering department at Northwestern University. There were several huge accomplishments during his tenure and their successful conclusions can be attributed primarily to his personal involvement in each one.

In 1913, for example, he persuaded the governments of Canada and Mexico to adopt the U.S. Standard datum for their mapping, resulting in an entire continent being placed on one datum, renamed the North American datum, a first anywhere. In another case, Bowie pushed for the completion of sufficient primary triangulation in the western half of the country so that a single adjustment could be made and once Bilby towers were available, did the same for the eastern half. At the same time he proposed a method to adjust the two halves as separate pieces, yet as a single system.

He supported leveling about equally as triangulation with the result in 1929 a general adjustment for the entire country was made. Also on his watch and with his complete support, the State plane coordinate system came about in 1932 and for the first time all surveyors could use the network data. Lastly, his grand ambition was to complete the nation's primary horizontal and vertical networks and for all intents and purposes he succeeded by the time of his retirement in 1936.

Another of Bowie's interest was gravity surveys introduced in the U.S. by the C&GS in 1875 which led him to become a strong and vocal proponent for the theory of isostasy, joining Hayford in this belief. The basic principle of isostasy is that the gravitational effects of the continental masses above the geoid are about equally compensated for by lesser density masses below, the opposite being true in the case of the oceans.

Bowie was recognized nationally and internationally, a founder of the American Geophysical Union and an early president. He was also president of the Society of American Military Engineers and the International Union of Geodesy and Geophysics. Bowie was a captain in the C&GS commissioned corps, but preferred the title major, the rank he earned in World War I. William Bowie died in 1940 leaving behind a record of accomplishments that is not likely to be matched soon, if ever.

Bowie's Lieutenants

Members of the Geodesy Division making significant contributions during this period were Walter D. Lambert, Jacob A. Duerksen and Frederic W. Darling in gravity and astronomy; Sarah Beall in astronomy; Henry G. Avers, Howard S. Rappleye and Walter F. Reynolds in computations; Clarence H. Swick in gravity, astronomy and computations; Walter D. Sutcliffe in records and archives and Hugh C. Mitchell in promoting surveys in metropolitan areas, plane coordinate systems and authoring Sp.Pub.no. 242 Definition of Terms Used in Geodetic and Other Surveys, published after his retirement, the first and still the best of geodetic glossaries. Others in the division are cited elsewhere for particular efforts.

Gravity Surveys

Gravity surveys began in the U.S. in 1875 under the direction of Charles S. Peirce following the acquisition of Bessel reversible pendulum apparatus from Europe. The initial measurements with the equipment were made at Hoboken, NJ after connecting to known gravity values in France, Switzerland, Germany and England. In 1882 international connections were made with New Zealand, Australia, India and Japan, and in 1900 to Europe again.

Improvements were made to the apparatus by Peirce, Thomas C. Mendenhall, superintendent of the C&GS (1889-94) and others, the most significant being the replacement of the bronze pendulum with one made of invar in 1920. Work began on the first national gravity network in 1891 and completed in 1949, involving 1,185 base stations, all observed with pendulums.

Meters Replace Pendulums

About the same time, the first geodetic quality gravimeter, the Worden gravity meter came into use and was adopted by the C&GS in 1952 for differential measurements. Early devices of this type appeared about 1930 for use in oil exploration and were not accurate enough for geodetic work. The long reign of pendulum measured gravity was coming to a close after about 75 years, albeit the apparatus would continue to be used in absolute determinations for another 25 years.

For most of the period the C&GS was the primary mover with significant contributions made prior to 1900 by Assistants Edwin Smith, Erasmus D. Preston and George R. Putnam, in addition to Peirce and Mendenhall. After 1900, William Bowie and Walter D. Lambert led the way, with Donald A. Rice coming along after 1950 to continue their work. About 1955, plans were laid to complete the long desired 100 mile spacing network and to expand the existing 900,000 square miles of area coverage at 10 mile intervals over the entire country.

Woollard's Contributions

Beginning in 1954, George P. Woollard began observations using quartz pendulum apparatus and Worden gravimeters to create a nationwide net and completed the work in 1958 with about 175 stations established, most at regional airports. By 1963, he had extended the net worldwide involving some 1,300 points.

Woollard began making gravity measurements in the late 1930's, while at the University of Wisconsin, running traverses across the country and between the Gulf of Mexico and Newfoundland. He also played a part in getting S. P. Worden to build his geodetic gravimeter in 1948.

As the space age began, the need for higher accuracy gravity networks greatly increased. To meet that requirement, the U.S. National Gravity Base Net (NGBN) was established in 1966 in a cooperative effort by the Army Map Service, USAF 1381st Geodetic Squadron and the University of Hawaii placing stations at airports in 59 cities throughout the country. Four LaCoste & Romberg geodetic gravimeters were used and travel was by commercial airlines. In 1971, the NGBN was incorporated in the International Gravity Standardization Net 1971 (IGSN1971) along with observations from various sources connecting stations in 36 additional cities and a number of calibration line pendulum measurements. There are 1,854 ISGN stations, 379 are in the conterminous U.S.

As part of the continuing effort to improve the IGSN system, the National Geodetic Survey (NGS),between 1975 and

1979, reobserved most of the NGBN using 4 LaCoste & Romberg G meters in a simultaneous mode and ground transportation. This new network is identified as the National Geodetic Survey Gravity Network (NGSGN) and includes stations in 54 cities observed in cooperative efforts between NGS and other federal agencies. Calibration lines established by 1990 are East Coast, Blue Ridge, Mid-Continent and Rocky Mountain.

The general availability of geodetic gravimeters after 1960 and ease of operation has induced other federal agencies including the U.S. Geological Survey (USGS), State and educational institutions and private companies to carry out observations for several purposes, other than exploration. Marine gravity remains a giant undertaking that continues to be pursued. A safe prediction. The last two decades of the 20th century will be known as the period when the determination of absolute gravity, to a high accuracy became commonplace.

From Tables to Mechanical Calculators

At the beginning of the American geodetic experience, no mechanical calculators were available and the computations were made using a variety of tables including logarithms, augmented by the individual computer's arithmetic abilities. Despite of what today would be considered the most extreme of primitive computational means, the work got done.

The method of least squares was introduced in 1847 or 1848 and as early as 1868, adjustments were carried out involving closures in length, azimuth, latitude and longitude, a formidable task even in later years.

Accuracy estimates determined directly from least-squares adjustments were not routinely computed until the mid 1960's because of the additional effort involved and other approaches were taken to come up with acceptable substitutes. Charles A. Schott in the Superintendents's Report for 1865, p. 192, explains the problem and the rationale for its solution as follows: The strict application of the method of least-squares in connection with the computation of probable errors of the adjusted parts of a triangulation becomes, in our case, impractical from its laborious nature, and a shorter method must be sought and followed, which, while it is a sufficient approximation of the truth, yet furnishes us with all desirable data to judge the accuracy of our results. The approximations took several forms depending on the element (length, azimuth or position) for which the accuracy estimate was desired. Most evolved from the specific condition equation for the element and all included the probable error of the angle (or direction) derived from the adjustment. That for the length eventually became the strength of figure formula, long used to evaluate the strength of triangulation and in determining the need for additional base lines.

Doolittle Makes It Less Work

In 1878, Myrick H. Doolittle made a combination of improvements to Gauss' method for solving normal equations that continued in general use for more than 80 years. European geodetic circles insisted on dubbing the method as Gauss-Doolittle and so it remains today. However, in 1924 when F. R. Cholesky, a European (France), modified Doolittle's procedure, this method is identified as Cholesky or Cholesky-Rubin. T. Rubin, another European (Sweden), apparently discovered the same approach as Cholesky, but two years later.

Crude and cumbersome mechanical calculators appeared later in the 19th century and despite their awkwardness reduced the task of making multiplications and divisions, the major chore in computations. Later improvements, including small electric motors resulted in further reductions to the computational effort and made feasible the simultaneous solution of several hundred normal equations.

Azimuths From the South - Why ?

From 1850 to the adoption of NAD83 in 1986, azimuths in geodetic surveys were reckoned from the south, clockwise, rather than from the more logical origin, north, used by land surveyors. Walter D. Lambert in a short 1946 article and some notes compiled in 1954 gave several explanations, any of which could suffice as a good reason for the practice.

In his 1954 notes he reports that in Hassler's 1817 work and after 1832, there was no uniformity, sometimes azimuths were reckoned from the north and on other occasions from the south, and furthermore in either direction, without any specific notation whether east or west. The remainder of the notes conclude from various writings of French geodesists of the 1800-40 period that they preferred to measure azimuths from the south around to west and according to him so did their American colleagues.

His 1946 article provides probably the best rationale for the practice. Lambert noted that Charles A. Schott was a German trained geodesist and while not a student of Karl Friedrich Gauss (1777-1855) he was well aware that Gauss followed the general practice of azimuths from the south, clockwise, in his Hanoverian triangulation. And, further, that Schott joined the Computing Division shortly before 1850, was highly regarded from the beginning and it was very likely he was responsible for the bureau adopting the practice. After 1986, azimuths are measured clockwise from north.

U.S. Horizontal Datums

In 1879 the first national datum was established and identified as the New England datum. Station PRINCIPIO in Maryland, about midway between Maine and Georgia, the extent of the contiguous triangulation was selected as the initial point with its position and azimuth to TURKEY POINT determined from all available astronomic data, i.e. 56 determinations of latitude, 7 of longitude and 72 for azimuth.

Later its position was transferred to station MEADES RANCH in Kansas and the azimuth to WALDO by computation through the triangulation. The Clarke spheroid of 1866 was selected as the computational surface for the datum in 1880, replacing the Bessel spheroid of 1841 used after 1843. Prior to 1843, there is some evidence that the Walbeck 1819 spheroid was employed.

The datum was renamed the U.S. Standard datum in 1901 and in 1913 the North American datum (NAD) as Canada and Mexico adopted the system. In 1927 an adjustment of the first-order triangulation of the U.S., Canada and Mexico began and was completed about 1931. The end result was the North American datum of 1927 (NAD27).

It was not a simultaneous solution because it was simply economically impractical to do so with the available computing equipment. Nonetheless, it was the largest geodetic computation effort to that time. More importantly, the resulting datum was the first to be oriented by Laplace azimuths strategically spaced throughout the triangulation. The azimuth to WALDO in the datum definition was changed by about 5" due to the inclusion of a Laplace azimuth at the nearby SALINA base line. Its inclusion in the NAD27 definition was only for completeness purposes since the datum is actually oriented by 175 Laplace azimuths held fixed in the adjustment as noted previously.

Hayford Ellipsoid

In 1909, John F. Hayford using data only from the U.S. triangulation determined new dimensions for the figure of the earth, appropriately named the Hayford spheroid. The International Geodetic and Geophysical Union adopted the parameters in 1924 as the basis for the International Ellipsoid of Reference and it is presently used in several countries.

Earlier he had perfected the strength of figure formula used in deciding where base lines are required in the triangulation. The original concept was developed and used in the U.S. Lake Survey and later improved by William H. Burger (C&GS). Hayford also was the co-author with Thomas W. Wright, formerly of the Lake Survey, of the widely used text Adjustment of Observations. He served with the C&GS for 20 years and was Chief of the Computing Division and Inspector of Geodetic Work for about 10 years.

First National Accuracy Standards

In 1921 a committee decided that the C&GS nomenclature for accuracies of geodetic surveys of Primary, Secondary and Tertiary would henceforth be identified as Precise, Primary and Secondary. Looking back over more than 70 years it appears now to have been a political decision, probably some agency objecting to the tertiary classification for their work. As usual with such edicts, it created nothing but confusion.

Accordingly in 1925, the Federal Board of Surveys and Maps adopted the now familiar standards of Firstorder, Second-order and Third-order accompanied by the also familiar 1:25,000, 1:10,000 and 1:5,000 length and position closures, that were reaffirmed in 1933 and remained in place until 1957.

Traverse Replaces Triangulation 1917-1927

By 1900 the C&GS had observed about 5,150 miles of first-order triangulation and the USLS about 1,650 miles. Between 1900 and 1925 about 13,000 miles of the same class triangulation was measured in the western half of the country including the 1,460 mile 49th Parallel arc straddling the U.S.-Canada border from the Lake of the Woods, MN and the Pacific Ocean observed jointly with the Geodetic Survey of Canada (GSofC).

Due to the high cost of building wooden towers, little or no triangulation was observed from 1900-27 in the eastern part of the country. First-order traverse was substituted because routes could be selected along railroads, with the measurements facilitated by utilizing the rails to support the tapes throughout and then projecting the distances to the stations offset from the tracks. Between 1917 and 1927 some 3,300 miles of traverse were observed in 13 states, all east of the 98th Meridian arc except for about 100 miles in South Dakota.

After the development of the Bilby tower in 1926, survey methods for the eastern half of the country reverted to triangulation and between 1927 and 1931 about 9,000 miles of first-order work was accomplished. Among the major pieces of work completed after 1900 were the 98th Meridian arc, 1,720 miles in length observed 1897-1907; 49th Parallel arc, mentioned previously, about 1,460 miles long measured in 1924 and the last of the great triangulations, the Atlantic coast arc, perhaps 1,600 miles in length from Providence, RI to Key West, FL completed in 1932.

NAD 27

In the adjustment that created NAD27, all the first-order triangulation and about 100 miles of first-order traverse for a total of 15,050 miles were included in the western half computation. For the eastern half adjustment only the triangulation west of the Eastern Oblique arc amounting to 11,850 miles was used including USLS (1,650 miles) and GSofC (630miles) work, but none of the first-order traverses. Other omissions were: International Boundary Commission (IBC)-GSofC triangulation observed before 1920 from Lake Superior westward to Namakan Lake (about 200 miles) because the connection to the 98th Meridian arc was a first-order traverse measured on the frozen Rainy River in Minnesota and a 200 mile section of the Mississippi River arc from St. Louis northward completed in 1931, possibly because the records were not yet received. The work to the east of the Eastern Oblique arc, including the entire Atlantic coast arc and other triangulation in parts of Virginia, North and South Carolina, Georgia and Florida was left out because traverses were involved.

By 1950 it was evident that NAD27 had many problems caused by large loops in the west and an insufficient number of base lines and Laplace azimuths. Estimates made then suggested that half again as much of the 26,900 miles of triangulation included in the computation and twice as many base lines (112 included) and Laplace azimuths (175 included) would be needed.

By 1940, this amount of new work was largely available, made possible by civil works' funds allotted to aid the unemployed, but no one in 1927 foresaw this happening. Hindsight, of course is always better than foresight.

Reconnaissance Surveys

Reconnaissance surveys, the in-field planning and selection of locations for triangulation stations were always part of geodetic operations in the U.S. However, it didn't become a separate and distinct function until the 1880's when multiple observing parties began to come on the scene. Up to then, there was only an occasional need to plan more than a few figures ahead and this could easily be done by the units as work progressed.

The strength of triangulation depends solely on well-shaped triangles and sufficient redundant observations to verify the acceptability of the angle measurements. The latter was the basis for adopting the specification, during Bache's time, that all triangulation was to consist of braced-quadrilaterals and/or central point configurations.

How High is Enough ?

Fulfilling these basic criteria often required towers for intervisibility and deciding on their heights was a problem within itself. Prior to Bilby towers, the cost and time needed to erect wooden signals was a major factor for making an additional effort to assure that a minimum height would suffice. Profiling lines by various means, including the determination of elevations from vertical angles and estimated distances, and by barometric observations were common solutions to the problem at all times. The effect of the earth's curvature and refraction often had to be worked into the equation, as well. For examples: On a 10 mile line, absolute flat terrain, 15 ft. towers at each end, or 58 ft. at one end, would be required for minimum clearance; and for a 20 mile line, same situation, 58 ft. at each end, or 230 ft. at one end.

There were two schools of thought, however, on how extensive the profiling effort should take. One side contended that regardless of the effort, blocked lines would happen, and the usual solutions, raising the heights of towers or adding another station would be less costly overall. Others thought otherwise. And many who traveled some distance to reach the station site, only to find a line not visible, would agree with the latter.

The Job Entailed

Selecting base line sites and planning the base expansion net to the triangulation was another responsibility. Depending on the length of the base that could be accommodated by the location, the connecting figure had to be very carefully chosen, so as to minimize the number of observed angles involved in the expansion of the distance, and that they would be the strongest possible. Prior to the availability of EDMI, the ratio of triangulation lines and bases was about 3:1 on the average, albeit some approached 10:1.

Traverse, unlike triangulation and trilateration, has no strength of figure per se, and the general instructions were to select points about equally spaced and in a straight a line as possible. More frequent astronomic azimuths and positions, than required for triangulation, were observed to help control sway in the survey.

In addition to selecting the station sites, lines to be observed and height of towers required, the reconnaissance engineer was responsible for preparing a sketch showing that information, ties to established control and marks of other agencies, and topographic features such as landmarks that might serve as intersection stations. Also, prepare descriptions on how to reach the proposed station sites, recovery notes for old stations,indicate types of marks to be set at each station, setup contacts with public officials and property owners and specify any arrangements made with the owners in regard to crop damage, etc.

Party Makeup and Can Do Spirit

Reconnaissance parties generally consisted of a Chief of Party (Assistant prior to about 1910), one or two assistants, and the necessary vehicles and equipment, usually an absolute minimum. As a case in point. In 1911, Jasper Bilby and one assistant ran the reconnaissance for the 104th Meridian arc from Colorado Springs, CO, to the Canadian border, about 720 miles, in a little over 3 months, selecting sites for 74 primary stations, 23 supplementals and 2 base lines. His equipment was 3 mules, 1 wagon, 1 riding saddle, necessary tools for repairing the outfit, 1 tent, cots and bedding for 2 persons, and a few cooking utensils. He also had a 4-inch surveyor's transit, a prismatic azimuth compass, a field telescope, binoculars, a set of drawing instruments and all available maps.

In later years, trucks were substituted for the mules and wagon, and living conditions were different and usually better, but all else, including the work itself, remained substantially the same. GPS changed all this and reconnaissance surveys are considerably simpler today, no intervisibilities required for example, yet geometry and other factors are no less important than previously.

No formal reconnaissance was usually made in leveling. Bench mark setters selected the locations and set the marks, at intervals as called for by the project instructions, sometime prior to the observations.

NOTE: (C&GS) following names, for events after 1920, indicates they were commission corps officers at the time.

Alaska - Hawaii - Philippines

By 1940 first-order triangulation on NAD27 had been extended to Skagway in southeast Alaska and earlier in the century first-order surveys from Shelikof Strait to Cook Inlet to Anchorage and on to Fairbanks were completed on an independent datum. Lower-order surveys computed on several independent datums covered much of the coastal areas including the Aleutians. In 1943 Skagway and Fairbanks were connected by first-order triangulation bringing NAD27 to the main land mass, albeit it would be more than a decade before all of Alaska was on a single datum.

Between 1900-40 geodetic surveys, mostly second-order triangulation, were established in the Philippines, Hawaiian Islands, Puerto Rico-Virgin Islands and the Panama Canal Zone with positions based on datums specifically developed for each region. Surveys of the islands west of Hawaiian chain, including Midway were based on local astronomic datums. Surveys on Midway Island were completed late in November, 1941 and personnel were en route by C&GS ship to Pearl Harbor on December 7, 1941. Their arrival was delayed due to running zigzag courses under radio silence causing a fear for several days that they had been lost in the first actions of the war.

Most of the work in Puerto Rico and the Hawaiian Islands was upgraded in the 1960-80 period. During the same time frame, new surveys were carried out on Guam, American Samoa and for the Defense Department, on Kwajalein in the Marshalls.

The Philippines presented a unique situation because of the agreement that 50 years after the war ended in 1898, the islands were to become an independent nation. The role of the C&GS was therefore an advisory one to the Insular Government and to this end about 1906 a processing office, including computations and map making functions was set up in Manila. All the geodetic records were held there and only the lists of adjusted geographic positions were furnished the Washington office.

Much of the geodetic work, primarily second-order triangulation, as noted earlier, including the connection to the British surveys on Borneo, was completed when the war began in 1941. An extremely difficult task to accomplish because of the tropical jungle, mountainous terrain and occasionally hostile natives.

The processing office was taken over by the Japanese early in 1942 and destroyed in 1944 during the retaking of the islands, with a loss of most of the geodetic records. George D. Cowie (C&GS), in charge of the office was killed in the bombing of the city on Christmas Eve, 1941, and several C&GS employees and a few families were imprisoned by the Japanese for the duration. One prisoner, Joseph W. Stirni (C&GS) was killed in 1945 when a ship taking him to Japan was torpedoed. Two others, Clarence F. Maynard, a civilian mathematician and George E. Morris (C&GS) were captured on Bataan, survived the Bataan Death March and imprisonment in Korea. Maynard returned to the Philippines after the war, remaining until all C&GS personnel were recalled in 1950. On his return, he was Chief, NY Computing Office for several years.

Earthquake Investigations

Following the 1906 San Francisco earthquake, a selected scheme of triangulation from Monterey to Fort Ross involving primary, secondary and tertiary stations and a detached net of tertiary points at Point Arena were reobserved to determine the amount of crustal motion. This was the first time in the U.S. that triangulation was reobserved for this purpose. Displacements were computed for all points in the disturbed area resulting from the 1906 event and where possible for stations effected by an earthquake in 1868 also.

Between 1922-24, the primary triangulation from Lake Tahoe to San Francisco to Santa Barbara and eastward to southern California was reobserved for the same purpose. Extensions were reobserved in 1924-25 northward to Point Arena, east to Carson Sink, NV and to western Arizona as further verification of stability of the terminal points.

One special point of interest arose from a discussion of the computations. Arthur L. Day, Director of the Carnegie Institution's Geophysical Laboratory wrote to Bowie and Walter F. Reynolds, Chief Section of Triangulation, in 1931 supporting a suggestion made by a reviewer of the results, Harry O. Wood in 1930 that circular errors, representing the precision of the observations be determined in the adjustment and shown on the sketches with the movement vectors.

The request has to be among the first anywhere for such information. Both nicely sidestepped the issue knowing full well determining such estimates was impractical at the time, especially so because the C&GS used the method of condition equations for their adjustments and that method was the least amenable to providing such data. In fact no method could readily do the job then. It wasn't until about 40 years later that circular errors and error ellipses were routinely computed.

Other crustal movement resurveys included the 1929 Newport Beach to Riverside arc, CA following the Long Beach 1933 earthquake with little movement indicated. Also, during the 1930's several lines were releveled in San Francisco, San Jose, Los Angeles and vicinity, San Diego area and the Imperial Valley, CA, with all showing some displacements. One or two arcs and a number of level lines in California and other parts of the country were observed specifically for future crustal motion studies.

Speed of Light

In 1922-23, the most accurate invar taped base line ever, with a precision of 0.2ppm one sigma, was measured near Pasadena, CA. The sole purpose for the 20.9 mile base line was to provide Albert A. Michelson with the best possible distance between points on Mount Wilson and San Antonio Peak used in his experiments to determine the speed of light.

To assure the least loss of accuracy in projecting the measured distance to the line between the two points, the base was measured parallel to that line and to its approximate length. Astronomic positions were determined to correct the angles for the deflection of the vertical. The work was carried out under the direction of Clement L. Garner (C&GS), later to succeed William Bowie as Chief, Geodesy Division.

Bowie and the C&GS were interested in Michelson's experiments in the hope that means could be found to measure distances using light. It was not to be. The experiments were not totally successful and the Great Depression began, leaving Erik Bergstrand to develop the equipment 25 years later, in Sweden.

The 1938 AMSTERDAM Avenue base line in New York City presented a similar problem, but here the stations were atop high buildings. It was necessary first to project the base vertically to temporary points offset from the stations and then a lateral shift to the station marks.

Early Urban Surveys

Between 1903-08 a first-order triangulation network encompassing greater New York City was observed; Cincinnati did the same on their own in 1912-13 with Hugh C. Mitchell, on assignment from the C&GS in charge and in the mid 1920's, combined first-order triangulation and traverse systems were established for Rochester, NY and Atlanta, GA. These were the forerunners of the numerous State-wide, county and urban nets observed later in the century. Prior to 1940, several cities developed networks on their own or with private sector assistance. As a case in point, first-order control surveys and associated topographic mapping for a number of municipalities were accomplished by the R.H.Randall Co. of Toledo, OH between 1920-34.

Tangent plane coordinate systems, most at ground level, were setup for these early urban surveys. After the advent of the State coordinate system,only the Cleveland Regional Geodetic Survey (CRGS) adopted a tangent plane ground level grid.

SPCS - UTM and Oscar S. Adams

In 1933-34, Oscar S. Adams ably assisted by Charles N. Claire developed the State Plane Coordinate System (SPCS) at the request of George F. Syme a North Carolina Highway engineer. Syme died shortly after the North Carolina system was developed being succeeded by O.B. Bestor to carry on the cause. Bestor was in charge of the State local control project established in 1933, later identified as the North Carolina Geodetic Survey. Most State and the few county projects involved in this program also were so named. Colonel C. H. Birdseye of the USGS, with a strong interest in Statewide coordinate grids also participated in the several conferences leading to the decision to honor Syme's request.

The first tables for computing Lambert coordinates were developed for North Carolina and the first tables for the transverse Mercator grid were for New Jersey. Tables were prepared for all States early in 1934. For the first time all horizontal control stations previously defined only by latitudes and longitudes would be available in easy to use plane coordinates.

Adams had many notable accomplishments prior to this work. For example, he authored or co-authored 22 Special Publications and Serials dealing mostly with map projections and adjustments. This group includes Sp.Pub.no.28 Application of the Theory of Least Squares to the Adjustment of Triangulation issued first in 1915 which provides the mathematical basis for adjustments by condition equations and observation equations on the ellipsoid and still remains a viable part of the literature.

He was actually the father of NAD27 since he gave Bowie's adjustment proposal life and personally made many of the computations. Later he was directly involved with the creation of the Universal Transverse Mercator (UTM) system used by the U.S. Army worldwide, although his association with the project is not well known. Adams also collaborated with Bowie in 1918 in developing the Military Grid System, the forerunner of UTM, dividing the country into seven zones, 9 of longitude wide, with the polyconic projection the basis for the grid.

Great Depression Surveys

The 1930's saw a huge increase in funds for public works as part of the effort to get the country out of the Great Depression and the C&GS field and office staffs were significantly increased. At the height of the program more than 1,000 employees were in the field and as many as 12 observing units, from a single party were working some nights.

For the first time ever a number of second-order arcs were observed by geodetic parties, bringing grumbles from purists and rightfully so, the savings in time and effort were very small. In addition about 23 States and a few counties setup geodetic surveys, under the overall supervision of the C&GS, with the intent to establish second-order horizontal and vertical control at the local level.

In the earliest stages all States participated and more than 10,000 unemployed surveyors, engineers and technicians were given meaningful jobs, albeit the pay was less than $20 a week. Most of the 23 geodetic surveys accomplished some work although only a few made substantial contributions. Among those that did were: Alabama, Florida, Georgia, Louisiana, Massachusetts, New Jersey, North Carolina, Oklahoma, South Carolina and Tennessee; among the counties: Monroe and Westchester in New York and the regional geodetic survey in Cleveland, OH. Except for Massachusetts and Westchester county, where first-order triangulation also was observed, all surveys involved traverses.

Whether the expenditure of the funds had the desired overall economic effect is still being debated, however there is no doubt the funds spent were highly beneficial to the geodetic control program as many thousands of new stations and bench marks were established. To wit, there were more than 100,000 points of all orders of accuracy in the horizontal net by 1940.

Geodetic Leveling, Datums, and Instruments

Geodetic leveling has always played second fiddle to horizontal surveys. Perhaps this is so because leveling is perceived as a simple procedure, although it most certainly is not. Some form of leveling, mostly trigonometric in nature was always observed in order to provide elevations needed to reduce base lines and angle observations to sea level. As a matter of fact, the observations were often carried out as a separate event using specially constructed vertical circle only instruments.

As work on the Transcontinental arc progressed westward it was recognized that vertical angle elevations would not be of sufficient accuracy for the purpose. Accordingly a line of precise levels following the route of the triangulation was begun in 1878 at the Chesapeake Bay and reached San Francisco in 1907.

In 1898, an adjustment was made of the first 25 circuits and a second in 1903 to include the large amount of new data observed in the interim. Partial adjustments were carried out in 1907 and 1912 to include the ever increasing work. In 1929 a general adjustment was made which included 45,000 miles of U.S. first-order leveling and 20,000 miles of similar accuracy Canadian surveys, with sea level planes at 26 tidal stations held fixed. The Canadians had recently published the results of their observations and didn't accept the combined adjustment values. Difference of elevations at common bench marks didn't exceed 0.5 ft. The U.S. data also includes precise leveling observed by the Corps of Engineers, U.S. Geological Survey and other organizations.

By 1940, about 260,000 miles of first- and second-order leveling had been observed. The elevation datum was known as the Sea Level Datum of 1929 (SLD29) until 1973 when the name was changed to the National Geodetic Vertical Datum of 1929 (NGVD29).

Prior to 1899, geodetic leveling in the U.S. was observed using wye levels and target rods. Long telescopes were common to such instruments and critics claimed Americans bought their levels by the yard. In 1899, the Fischer level designed by Ernst G. Fischer of the instrument division, a dumpy type and speaking rods replaced the earlier equipment and were used for almost 70 years with only slight modifications. Invar strips were added to the rods in 1916.

Mt. Whitney - Precisely How High ?

Elevations of high mountains are rarely determined by spirit leveling, most being the result of trigonometric methods, a k a zenith distance/vertical angle elevations. As a matter of fact, the highest mountains are seldom occupied for horizontal positioning either for obvious reasons, clouds and weather conditions among them. Despite these negative possibilities, in August 1925, Lansing G. Simmons (C&GS) was sent to Lone Pine, CA to observe first-order leveling from bench marks on the Owens Valley line to the summit of Mount Whitney, the highest peak in the then 48 states. The purpose was for crustal motion studies where future relevelings would give indications whether the mountain was growing or not. Since it was late in the season, Simmons decided to level from the summit down, but found the summit trail from Whitney Portal, about 14 miles west of Lone Pine, blocked by rock sides and learned furthermore that no horses had been over the route in several years. He then decided to horsepack the outfit to Army Pass at an elevation of 11,000 ft. about 10 miles south of Mount Whitney, from where the party would backpack the equipment to a base camp at 14,000 ft., about one mile south of the summit.

Despite some of the 8 man party suffering from the altitude, that was further compounded by living in pup tents, with the only water from melting snow and the only fire from a gasoline stove, they were able to complete the leveling from the summit, marked by a USGS disk set in 1901, to a permanent bench mark near the base camp in a week's time, a vertical distance of about 500 ft. Bad weather set in with snow, hail, cold and high winds and there being little chance with September approaching for better conditions, the camp was backpacked to Lone Pine Lake near Whitney Portal at an elevation of about 8,400 ft. where the leveling was picked up again for the 13-14 miles into Lone Pine.

Two years went by without the Forest Service or local people clearing the trail to Mount Whitney so in June 1928, John H. Brittain (C&GS) was ordered to Lone Pine to form a party, complete the first-order leveling from Whitney Portal to the summit and with authorization to open the trail. He made his first camp at the 10,400 foot level, opened the trail to 11,500 ft. taking only one day to do the job and completed the leveling to that point. From a second base camp at 12,000 ft., leveling was run to the summit marked by the USGS tablet described earlier by Simmons. This was a remarkable piece of work. To carry the elevations over a vertical distance of 6,126 ft. and extremely rough terrain in 18 days of leveling required determination and esprit de corps that would rarely be found today.

No resurvey has been made to date. Simmons and Brittain went on to long and distinguished careers in the C&GS. Simmons was the Chief Geodesist for about 20 years, retiring in 1967 and Brittain at the time of his retirement in 1961 was Chief, Geodesy Division. Lansing G. Simmons died in 1986, at age 84.

The experience here seems to have discouraged further attempts to level to the summits of high peaks even when roads are available such as to Pikes Peak and Mount Evans in Colorado, both over 14,000 ft. However, with increasing interest in replacing conventional leveling with GPS observations, the tests presently underway (1994) might consider including first-order leveling to these and other readily accessible peaks as part of the examinations.

As geodetic surveying in the U.S. entered the fifth decade of the 20th century, the first-order triangulation and leveling were basically complete. Future priorities would be to fill in the gaps, strengthen and update the networks and carry out new adjustments of NAD and SLD (NGVD). All would come to pass and much more in the next 50 years.

This brief and informal history of U.S. geodetic surveys covers the more significant happenings plus a few of the more interesting incidents in the period 1807-1940. The decades to follow would be a most dynamic and amazing era as the surveying world would ever see with new instrumentation, methodology and computers eventually dominating the scene.