Conclusion of the Age of Bowie, 1900–1940

By Joseph F. Dracup

Reconnaissance surveys, the in-field planning and selection of locations for triangulation stations, were always part of geodetic operations in the U.S. The practice didn't become a separate and distinct function until the 1880s, however, when multiple observing parties began to come on the scene. Until 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.


COURTESY NOAA ARCHIVES

William Bowie, Chief of the Coast and Geodetic Survey, 1909-1936

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 that all triangulation was to consist of braced-quadrilaterals and/or central point configurations. This specification was adopted in the mid-1850s, during the time of Alexander Bache, the second superintendent of the Coast Survey.

Geodetic History Summary

Last installment (July/August '96):
- **Building the Networks**

This installment:
- **Conclusion of the Age of Bowie**

Coming up:
- **Birth of the EDM: the 1940s**
- **Breaking with the Past: 1950-1970**
- **The Age of Geodesy: 1970-1990.**

How High is Enough ?

Fulfilling these basic criteria often required towers for intervisibility. Deciding on the height of the towers was a problem in itself. Prior to Bilby towers, the cost and time needed to erect wooden signals was a major factor for making an additional effort to ensure 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 example: On a 10-mile line, with absolute flat terrain, 15-foot high towers at each end, or a 58-foot tower at one end, would be required for minimum clearance; for a 20-mile line in the same situation, same situation, 58-foot towers at each end or a 230-foot tower at one end would be required.

There were two schools of thought, however, on how extensive the profiling effort should be. One side contended that regardless of the effort, blocked lines would occur, and the usual solutions—raising the heights of towers or adding another station—would be less costly overall. Those who traveled some distance to reach the station site, only to find a line not visible, would disagree.

Selecting Sites

Selecting base line sites and planning the base expansion net to the triangulation was another issue. 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 to make sure that they would be the strongest possible. Prior to the availability of electronic distance measuring instruments (EDMI), the ratio of triangulation lines and bases was about 3:1 on the average, although 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 as 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. The engineer also would prepare descriptions on how to reach the proposed station sites, make recovery notes for old stations, indicate types of marks to be set at each station, set up contacts with public officials and property owners, and specify any arrangements made with the owners in regard to crop damage.

Party Makeup and Spirit

Reconnaissance parties generally consisted of a chief of party (called an "assistant" prior to about 1910), one or two assistants, and the necessary vehicles and equipment, usually an absolute minimum. In 1911, Jasper Bilby and one assistant ran the reconnaissance for the 104th Meridian arc from Colorado Springs, Colorado, to the Canadian border—about 720 miles, in a little over three months, selecting sites for 74 primary stations, 23 supplementals, and 2 base lines. His equipment was three mules, one wagon, one riding saddle, necessary tools for repairing the outfit, one tent, cots and bedding for two persons, and a few cooking utensils. He also had a four-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 everything else, including the work itself, remained substantially the same.

More recently, GPS changed nearly everything. Reconnaissance surveys are considerably simpler today. No intervisibilities are required, nor is geometry a primary factor, but project station spacings and locations remain no less important.

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.


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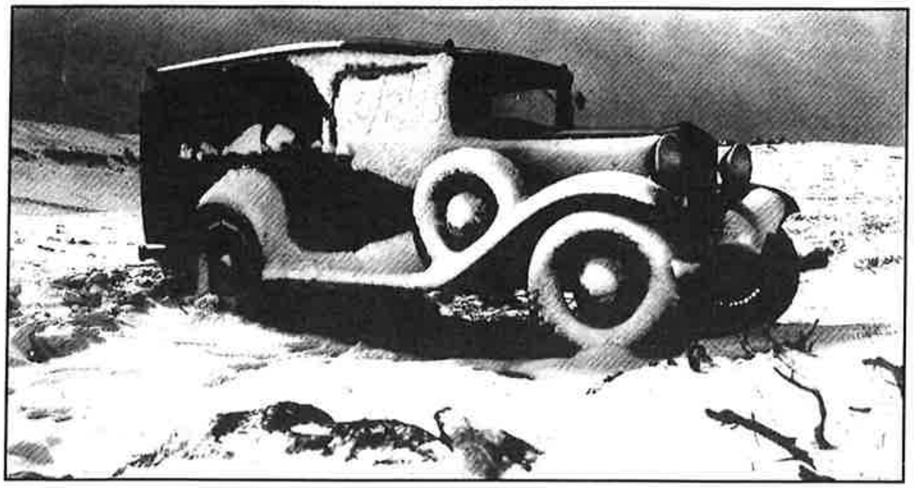
Bamberg Astronomic transit set up in Astronomic tent.

Alaska, Hawaii, and the Philippines

Early in the 20th century, first-order surveys in Alaska from Shelikof Strait to Cook Inlet to Anchorage and on to Fairbanks were completed on an independent datum. By 1940, first-order triangulation on NAD27 had been extended to Skagway in southeast Alaska. 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, although it would be more than a decade before all of Alaska was on a single datum.

Between 1900 and 1940, 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 the Hawaiian chain, including Midway, were based on local astronomic datums. Surveys on


COURTESY NOAA ARCHIVES

Truck of the party of O. S. Griswold, Thermopolis, Wyoming, June 2, 1935.

Midway Island were completed in late 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 for several days under radio silence, causing a fear 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 1960-1980 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 the islands were to become an independent nation 50 years after the Spanish-American War ended in 1898. The role of the C&GS was therefore an advisory one to the Insular Government. In 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 was completed when the Second World War began in 1941. It was primarily second-order triangulation, including the connection to the British surveys on Borneo. This was an extremely difficult task 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. 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, but 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 of the New York 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 affected by an earthquake in 1868.

Between 1922 and 1924, 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, Nevada, 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. Harry O. Wood, a reviewer of the results, suggested 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. Arthur L. Day, Director of the Carnegie Institution's Geophysical Laboratory, wrote to William Bowie, Chief of the Geodetic Section, and Walter F. Reynolds, Chief of the Section of Triangulation, in 1931 supporting the suggestion. The request has to be among the first anywhere for such information.

Both Bowie and Reynolds sidestepped the issue, knowing full well that determining such estimates was impractical at the time. C&GS used the method of condition equations for their adjustments—a method that was the least amenable to providing such data. In fact no method could readily do the job at that time. 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 in California, following the Long Beach 1933 earthquake. Little movement was indicated. Also, during the 1930s, several lines were releveled in Cali-

**Editor's Note: (C&GS) following names indicates that they were commission corps officers in the Coast and Geodetic Survey at the time.*

COURTESY NOAA ARCHIVES

Survey mark set by a public works agency party in Pennsylvania for boundary survey and bench mark, February 19, 1934. More than 10,000 unemployed surveyors, engineers, and technicians participated in the surveys nationwide.

fornia, including San Francisco, San Jose, Los Angeles and vicinity, the San Diego area, and the Imperial Valley. All showed 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 1922-1923, the most accurate invar taped base line ever, with a precision of 0.2 ppm one sigma, was measured near Pasadena, California. The sole purpose of 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 which were used in his experiments to determine the speed of light.

To ensure 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 in order to correct the angles for the deflection of the vertical. The work was carried out under the direction of Clement L. Garner (C&GS), who was later to succeed William Bowie as Chief of the Geodesy Division.

Bowie and the C&GS were interested in Michelson's experiments in the hope that the means could be found to measure distances using light. The experiments were not totally successful. The Great Depression began, and funds were not available for such work. It was not until 15 years later that Erik Bergstrand developed the equipment in Sweden.

The 1937 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 and 1908, a first-order triangulation network encompassing greater New York City was observed; Cincinnati did the same on their own in 1912 and 1913 with Hugh C. Mitchell, on assignment from the C&GS, in charge. In the mid 1920s, combined first-order triangulation and traverse systems were established for Rochester, New York, and Atlanta, Georgia. These were the forerunners of the numerous statewide, 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, Ohio, between 1920 and 1934.

Tangent plane coordinate systems, most at ground level, were set up 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 and 1934, Oscar S. Adams, 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. He was succeeded by O. B. Bestor. 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 similarly 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.

During this period, the first tables for computing Lambert coordinates were developed for North Carolina and the first tables for the transverse Mercator grid were established 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 Special Publication Number 28, *Application of the Theory of Least Squares to the Adjustment of Triangulation,* first issued in 1915. This provided the mathematical basis for adjustments by condition equations and observation equations on the ellipsoid and still remains a viable part of the literature.

Adams was actually the father of NAD27 because 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 degrees of longitude wide, with the polyconic projection the basis for the grid.

Great Depression Surveys

The 1930s 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 nights.

For the first time ever, a number of second-order arcs were observed by geodetic parties. This brought grumbles from purists and others who complained that the savings in time and effort were very small. About 23 states and a few counties set up 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. More than 10,000 unemployed surveyors, engineers and technicians were given meaningful jobs, although the pay was less than $20 a week. Most of the 23 geodetic surveys accomplished some work but only a few made substantial contributions. Among them 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, Ohio. 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, but there is no doubt the funds spent were highly beneficial to the geodetic control program. Many thousands of new stations and bench marks were established. 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. 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. 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. A second adjustment followed 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 Canadian government had 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, the 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, also known as "zenith distance/vertical angle elevations." 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, California, to observe first-order leveling from bench marks on the Owens Valley line to the summit of Mount Whitney, the highest peak in the 48 states. The purpose was for crustal motion studies where future relevelings would give indications of 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 slides and learned that no horses had been over the route in several years. He then decided to move the outfit by horseback 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.

Some of the eight-man party suffered from the altitude, living in pup tents, with the only water from melting snow and the only fire from a gasoline stove. But they were able to complete the leveling in a week's time. The leveling ran from the summit, marked by a USGS disk set in 1901, to a permanent bench mark near the base camp—a vertical distance of about 500 feet. Bad weather set in with snow, hail, cold, and high winds. There was little chance with September approaching for better conditions. The camp was backpacked to Lone Pine Lake near Whitney Portal at an elevation of about 8400 feet where the leveling was picked up again for the 13 miles into Lone Pine.

Two years went by without the Forest Service or local people clearing the trail to Mount Whitney. 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 feet, taking only one day to do the job, and completed the leveling to that point. From a second base camp at 12,000 feet, 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 6126 feet and extremely rough terrain in 18 days of leveling required determination 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. Brittain at the time of his retirement in 1961 was Chief, Geodesy Division. Lansing G. Simmons died in 1986 at age 84.

The experience 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, those conducting the tests presently under way 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).

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 to 1940. The decades to follow would be the most dynamic and amazing era that the surveying world would ever see, with new instrumentation, methodology and computers eventually dominating the scene.

NGS Offers New Geoid Height and Deflection Models

The National Geodetic Survey (NGS) is publishing an improved geoid height model called GEOID96 that covers the United States, including Puerto Rico and the Virgin Islands. GEOID96 geoid heights are based on the Geodetic Reference System of 1980 (GRS80). They are appropriate for converting Global Positioning System (GPS) ellipsoidal heights based on the NAD83 datum into orthometric heights based on the NAVD88 datum. GEOID96 was developed using gravity data from NGS and the Defense Mapping Agency (DMA) (now known as the National Imagery and Mapping Agency), from terrain data from NOAA's National Geophysical Data Center (NGDC), from the joint NASA/DMA global geopotential model, and from numerous cooperative survey projects.

GEOID96 consists of a grid of model geoid height values with a 2-minute by 2-minute spacing in latitude and longitude. The software program GEOID is provided with GEOID96 to simplify extracting and interpolating values from the grid to discrete points. GEOID96 displays about 2.5 cm accuracy (one sigma) between points spaced at 50 km or greater. The long wavelength discrepancies apparent in earlier geoid models have been removed by the use of GPS on leveled bench marks in the conterminous United States. This trend removal does cause GEOID96 to be biased relative to a geocentric ellipsoid; this bias is deliberate. GEOID96 was developed to support direct conversion between NAD83 GPS heights and NAVD88 orthometric heights. Along with these geoid models, NGS is publishing an improved surface deflection of the vertical model called DEFLEC96. These deflections are based on GRS80 and are appropriate for Laplace corrections and deflection corrections based on NAD83 values.

DEFLEC96 is developed from the same gravity and terrain data and GPS observations at leveled benchmark data sets that were used to compute GEOID96, ensuring compatibility. The software program DEFLEC is provided to simplify extracting and interpolating values from the grid to discrete points.

The data will be available on a single CD-ROM from NGS, as well as in regional groupings available on diskettes. The expected prices are $50 for all of the products on CD-ROM, or $30 for the first diskette and $15 for additional diskettes. In addition, NGS plans to publish all of the components of the geoid height and deflection of the vertical models on its Internet sites: <ftp.ngs.noaa.gov> for FTP and <http://www.ngs.noaa.gov> on the Web; and at 301/713-4181 for its bulletin board system. For telephone information, call 301/713-3242.