History of Geodetic Surveying, Part II

Following in Hassler's Footsteps

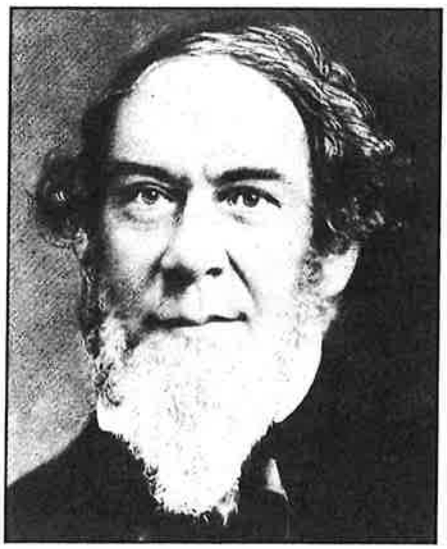
By Joseph F. Dracup

The first half of the 19th century in American geodesy was totally dominated by one person, Ferdinand R. Hassler. This was not the case for the years 1843-1900. Several strong-willed, very competent personalities prevailed for long stretches, some for almost the entire period, but none overshadowed 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. He was eminently well qualified for the post, with a learned interest in many scientific activities. Born in Philadelphia in 1806, Bache was the great-grandson of Benjamin Franklin. He graduated from West Point at age 19 and served three 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.

Bache continued Hassler's practice of personal involvement in the field work but did not limit his participation mostly to geodetic surveys as his predecessor had done; although he spent considerable time in making astronomic observations and measuring base lines. 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, Alabama in 1847, BODIE ISLAND North Carolina in 1848, EDISTO ISLAND, South Carolina in 1850 and the sixth at EPPING, Maine, 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, Second Superintendent of the Coast Survey, 1843-1867

Alexander Dallas Bache died in 1867, age 61 at Newport, Rhode Island. America had lost one of its greatest scientists, but he left a legacy of excellence for his successors to build on. 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 Coast & Geodetic Survey (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 required us to land on the tundra and wait an hour or so for the weather to improve.

On May 13 at approximately 9:00 P.M., a high enough ceiling, sufficient lighting conditions, and the absence of snow on the jetty provided us with the opportunity to get our long-awaited photography from which the intensive DTM of the jetty would be compiled. Chip is an excellent pilot, both in our fixed-wing Cessna 206 and in the helicopter, and he very efficiently executed his stereoscopic runs over the jetty while the weather permitted. We immediately processed the film in our makeshift photolab (in the hotel laundry room) and were delighted to find that all exposures were acceptable. A few hours later, it was snowing again.

We left St. Paul on May 14, and returned to Anchorage via Dutch Harbor in the Aleutians. The helicopter was shipped back to Anchorage by air, to Seattle by ship, and then trailered to our offices in Smith River without incident.

Only once did we encounter structural icing that required us to land on the tundra and wait for the weather to improve.

Back in the safety of the office, our photogrammetrists used the imagery to gather some 100,000 DTM points, accurate to +/- 0.03 foot, to intensively define the geometric shape of the jetty's surface. To have performed this project strictly by ground survey methods would have required literally weeks of time while exposing the survey personnel to significant risk of inury. Future geometric studies of this jetty will use the same control monumentation, coordinate system, and elevation datum to compare subsequent measurements against this baseline study, in order to monitor and evaluate changes that will occur on this expensive structure. It has been shown that careful monitoring and preventive maintenance of these very expensive fixed works is cost effective, as repairs can be performed at a fraction of the cost of renovation following a catastrophic failure or slipout.

The Pribilof Islands, though very remote and isolated, are truly spectacular. We feel very fortunate to have been a part of this interesting and challenging survey, and extend our thanks to Dennis Markel, Ray Bottin, Bob Peak and Scott Kool of the Corps of Engineers for their foresight, encouragement and guidance on this interesting and challenging project. We look forward to returning to the islands in 1996 for a follow-up survey.

Nominations Sought for ACSM for 1996

The ACSM Constitution requires that the Election Committee shall order a notice for nominations for the offices of President-Elect, Vice President, and Directors to be elected.

The elections for next year include:

- A President-Elect from AAGS (minimum of one nominee who normally will be the incumbent Vice-President);
- A Vice-President from NSPS (minimum of two nominees);
- Three Directors from NSPS (minimum of five nominees); and
- One Director from ACA (minimum of two nominees).

Nominations for President-Elect will be made by the AAGS Nominations Committee; Nominations for Vice President and three Directors will be made by the NSPS Nominations Committee; and nominations for one Director will be made by the ACA Nominations Committee. Nominees must be voting members (member, fellow, honorary, or life) of the member organization from which they are selected.

ACSM members may submit names of other members who are willing to serve or they may submit their own names for consideration by the appropriate member organization nominations committee. Submission must be made in writing, must include a brief biography, and must be sent to the chair of the appropriate member organization nominations committee.

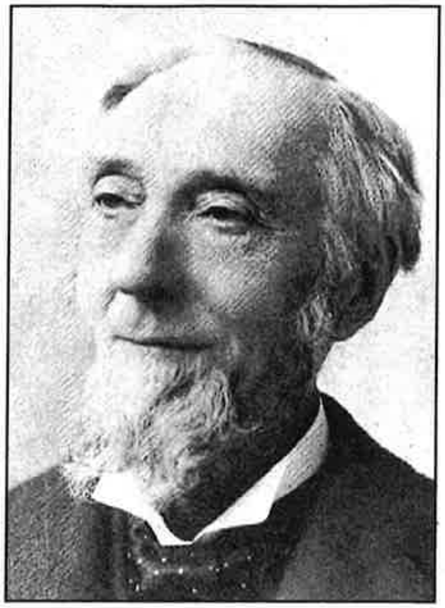
Nominations committee chairs are as follows: Stephen C. Guptill (ACA); Robert F. Packard (AAGS); and Sam Best (NSPS).

The constitution also provides that "In addition to the nominations prepared by the member organization nominating committees, nominations may be made by nominating letter(s) signed by not fewer than five (5) percent or 250, whichever is smaller, voting members of the appropriate member organizations. The nominating letter shall include a recent photograph and a biographical sketch of the nominee. All nominating letters must be received at ACSM headquarters no later than November 1." Names signed on the petition are to be printed as well, for verifications of the signatures, and the date of signature is to be given. A recent 5x7-inch glossy, black and white photograph with a brief biographical sketch of the nominee, in accordance with the standard ACSM format available from headquarters, shall accompany the nominating letter. Details are in Article V of the ACSM Constitution and ACSM Nominations Guidelines, copies of which are available on request from:

ACSM
5410 Grosvenor Lane
Bethesda, MD 20814-2122
Phone: 301/493-0200.

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 which involved 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 were (and still are) reserved for officers which caused occasional differences and/or resentment to arise in the civilian group towards the corps. All in all, however, the arrangement has worked fairly well, with both sides usually accepting the situation.



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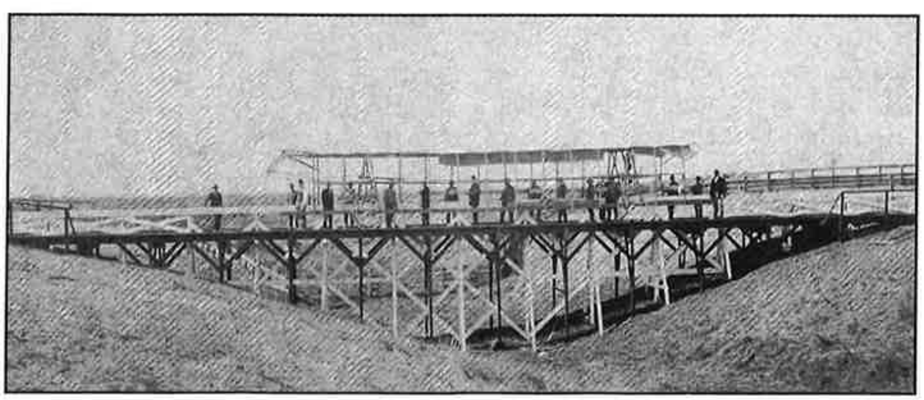
George Davidson, foremost American field geodesist of the 19th century, served mostly on the Pacific Coast during his career from 1845 to 1894.

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 masters in Coast Survey activities including 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.

Davidson joined 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 three 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, usually meaning horseback.



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The YOLO base line in 1881. This "dry slough" trestle was 115 feet long, 22 feet high at the footpath, 25 feet at the rail.

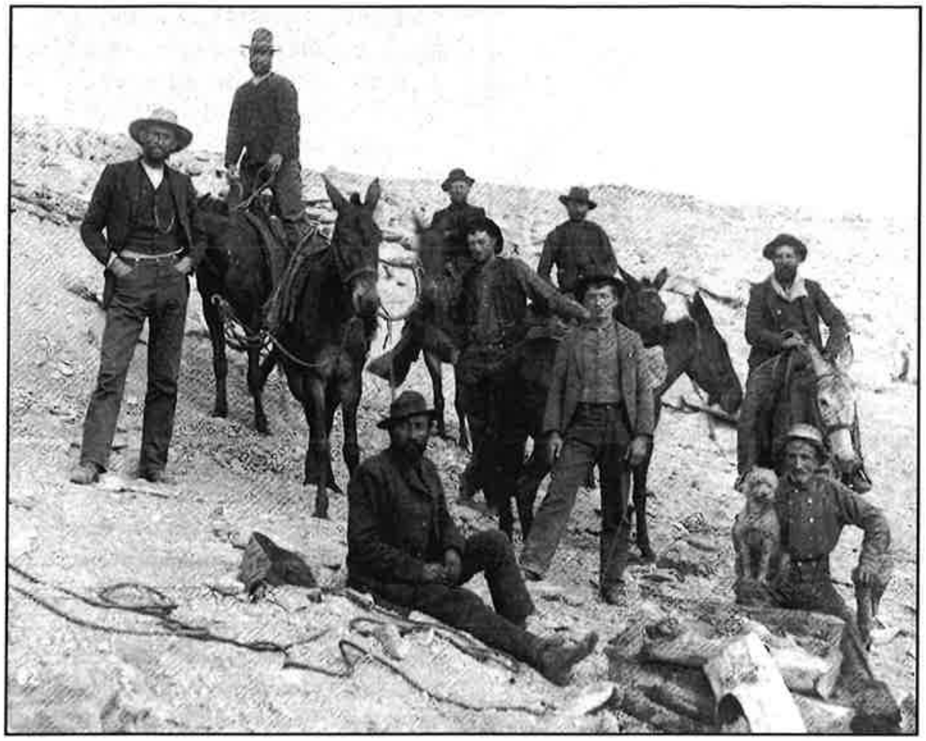
Transcontinental rail service wasn't available until 1869 and it was many years before a rail network was developed. Stagecoach service from rail heads was unreliable at best and accommodations, when available, were very primitive. Davidson and his colleagues travelled by ship to the Isthmus of Darien (now Panama), then by horseback 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. Field records and computations were sent by ship. 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, except for the Civil War period and a few foreign assignments. During his service, the Transcontinental triangulation, also known as the 39th Parallel arc, was completed; primary surveys near Los Angeles and Santa Barbara Channel were under way; 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 Davidson in 1850. 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.

Survey vs. GLO

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



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Triangulation Field Party, 1890

1881), LOS ANGELES base 1889, the angulation for the base expansions and the astronomy to orient the principal triangulation. He was a man of strong personal opinions and was an ardent advocate for the Coast Survey's assumption of 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 fortunate for both agencies that they never materialized. The Survey had done some section work for the GLO in the Florida Keys in the 1850s and the experience was not a happy one for either side.

There is no doubt that if Davidson's plan had 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 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 the means available for a total upgrading of the system once all the legal ramifications for such an undertaking were settled.

Although this cause was lost, most others were successful. Davidson's 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—a "giant among giants." Only men of this 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 field geodesy. Schott was born in Mannheim, Baden, Germany in 1826, a graduate of the University of Karlsruhe who 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, he personally carried out numerous field surveys in the eastern U.S. and was instrumental in establishing magnetic observatories at Madison, Wisconsin, and Los Angeles, California. He had a life-long interest in field activities that culminated with the development of a contact compensating base line measuring apparatus of unique design in 1881. The apparatus, which bears his name, 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 took a distinct interest in all of them.

Much of his effort was directed to geodetic computations, especially the adjustment of the observations and investigations of the results. One such examination, carried out in 1878-79—which related to geodetic and astronomic data on the Eastern Oblique arc—provided information for establishing the first national datum. Schott's work 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, and the New England datum of 1879 (as it was named) was the basis for all subsequent datums until 1983. The Clarke spheroid of 1866 still provides the best fit for the continental U.S., although the Geodetic Reference System of 1980 (GRS 80) was adopted in 1983 for other reasons.

Schott was a prodigious author, writing 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 (C&GS Special Publication No.4, 1900, 871 pp.) and *The Eastern Oblique Arc of the United States and the Osculating Spheroid* (C&GS Special Publication No.7, 1902, 394 pp.) Charles A. Schott died in 1902.

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 was that these figures provide at least one geometric condition involving the angles, known as side conditions or equations.

These equations use 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 post-Hassler era 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 1920s when it was replaced by the use of radio signals.

Advances in Theodolites

Hassler's original theodolite was built by Edward Troughton of London during the period 1811-14, had a 24-inch circle, weighed more than 150 pounds, and required a special oversize carriage to transport it. In 1836 his "Great Theodolite with a 30-inch 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 1800s, segments of the primary triangulation were observed with 10- and 12-inch repeating theodolites and acceptable results were obtained. But advances in instruments led to less use of repeaters 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 were two 20-inch 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- to 30-year intervals by the 12-inch circle -3 micrometer theodolite constructed by the chief of the division, Ernst G. Fischer about 1898; and the 9-inch 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. It was not until the early 1950s that the Wild T-3 theodolite, with a 5½ inch glass circle read by an auxiliary telescope, replaced the 2 micrometer Parkhurst. The Wild T-3 theodolite was employed until the mid 1980s, 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 1830s to 5½ inches in the 1980s. Despite the huge disparities in weight, construction, and diameter of theodolite circles, the common denominator is the fact that the accuracy of the observed angles remains the same.

Instruments of the time were built to last. Hassler's 30-inch theodolite, for example, was in constant use for about 37 years before being destroyed by a tornado. Its destruction is described in C&GS Special Publication No. 7:

> *[The theodolite]... 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.*

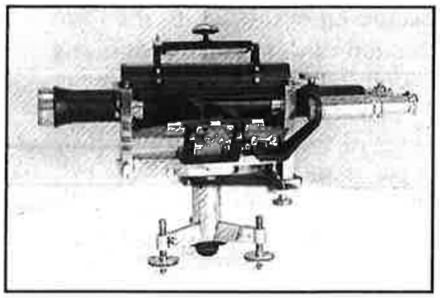
Few theodolites before the Parkhursts had vertical circles attached. Vertical angles were observed using separate instruments with circles only slightly smaller than the horizontal ones.

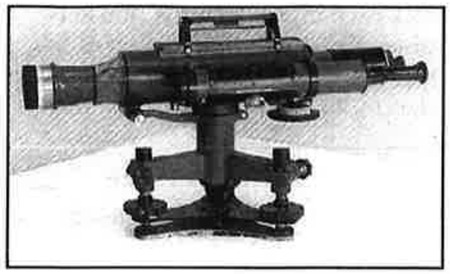
Field Specifications

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 four or five observing units were in the field on any given day and the observers, a very select group, were field-trained, college-educated engineers.

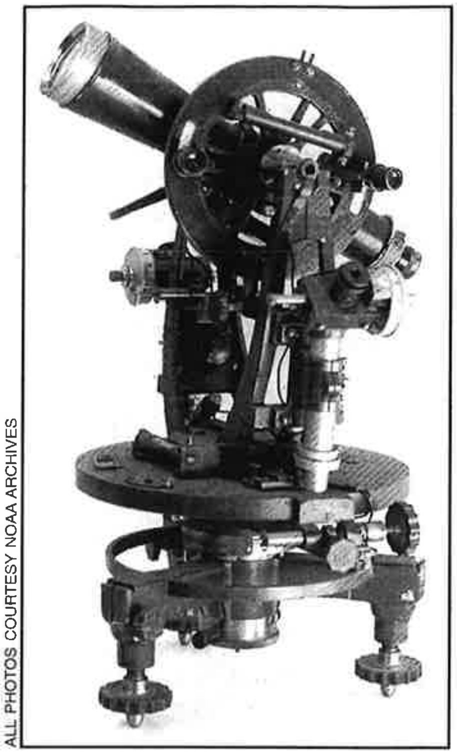
This was not always the case in later periods. Between 1935 and 1970, for example, about ten times that number of units often were working on a single night.

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,





Instrument advances: Geodetic level constructed by Wurdemann was used in the 1870s (above left). Ernst G. Fischer built a smaller model in 1900 (above). Parkhurst theodolite, introduced in the 1920s, (right) had vertical circles attached.



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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, although 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-inch 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. Personnel reasoned that the method 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. This method was termed "miss 'em quick" in the parlance.

Little information is readily available about the time required to complete observations in earlier periods. The time required really didn't matter much, because most occupations took a week or more. A few lasted several months; some even had vegetable gardens. Estimates to complete the 32 pointings on each signal light when using the 12 inch -3 micrometer theodolite was 15-20 minutes.

Once Parkhurst models came into use, the time was reduced by about one-third and some observers became very fast, with runs of 6-8 minutes and less per light recorded. Similar times were the rule with T-3s.

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 calculate the mean of six readings of seconds for 3-micrometer instruments and four readings for Parkhursts. The process continued 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-3s involved a slightly different process, but 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. By the 1840s, heliotropes had come 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. Several attempts were made in the 1880s to observe at night, even using a selenotrope to reflect moonlight; none proved too successful.

Selenotropes required much larger mirrors than the heliotropes' 2-4 inch diameter reflectors: A mirror 6 by 6 inches was required for 22 mile lines, 6 by 8 inch for 48 miles, 8 by 10 inch for 70 miles. 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 mis-centerings of 0.1 to 0.2-inch and perhaps more when high towers were involved would not be unrealistic, nor did they cause large errors. A mis-centering of 0.1-inch translates into a maximum error of 0.03" in an angle over 10 mile lines and for a 1-inch displacement, over the same-length lines, the largest error would be 0.3". 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 with 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 to 6 meters in length, and encased in tubes, were developed, many ingeniously designed to resolve the problem of thermal expansion through compensating principles. The last and most accurate apparatus, 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 nine 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, Indiana, and the ST ALBANS base, West Virginia by Assistants Alonzo T. Mosman and R. Simpson Woodward in 1891 and 1892 respectively. Measurements were made mostly at night using four tapes, two 50 meters in length and two 100 meters in length. A 100-meter field comparator and a 1-kilometer section of each base were measured using an 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 three-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 nine bases on the 98th meridian arc were measured accordingly, except that the 100-meter comparators were established by iced bar measures.

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 six 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 four, 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 three 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 the employment of tapes. Sites often had to be graded to meet the 5 percent 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 percent and the much longer tapes made progress of five miles and more 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, there was a big improvement in accuracy of measuring base lines. For example, the three 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.

Next: Triumph of the Mountain Men: Geodetic astronomy, observation towers, field work, and the status of triangulations.