Triumphs of the Mountain Men

By Joseph H. Dracup

During the second half of the 19th century, important advances were made in the methods and materials of geodetic surveying. As the Industrial Revolution swept across America, surveyors were refining their techniques, converting wood towers into steel and concrete, and pushing their arcs across the continent. The era was marked by dramatic stories of professional accomplishments.

Geodetic Astronomy

Only a limited amount of geodetic astronomy was performed during the Hassler period in the early 1800s. A few latitudes, azimuths, differences of longitude by the chronometer method, and at least one longitude were observed.

In 1846, Alexander Bache, second superintendent of the Coast Survey, introduced the Horrebow-Talcott method for observing astronomic latitudes. The first complete set of observations was obtained by assistant T.J. Lee, at Thompson, Massachusetts, in the same year.

The method was adopted in 1851 and astronomic latitudes have been observed using the Horrebow-Talcott method ever since. In the 1970s, there was some concern that another procedure, called the Sterneck method, was more accurate. However, observations at more than 30 stations showed that both Sterneck and Horrebow-Talcott procedures gave essentially the same results.

At about the same time as the introduction of Horrebow-Talcott, Sears C. Walker developed a method using telephone lines to determine differences in longitude. From 1847 to 1922, longitudes were determined using this 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, the most commonly used method for primary determinations.

In the direction method, observations on Polaris, or whatever star was used, were taken as if it was simply another signal, following the same measuring sequence as for triangulation. A chronometer was set for estimated local time. The times of measurement were corrected later with true local time determined from observations on time stars or radio signals. These signals were obtained prior to and immediately following the azimuth observations.

By 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

From 1847 through 1888, latitude and longitude observations were made with large transit instruments constructed by Troughton and Simms of London that could be used as both meridian and zenith telescopes. Slightly smaller similar transits built by the Coast & Geodetic Survey 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 1970s, the Kern DKM-3A, a true universal theodolite, was introduced.

Astronomic azimuths were usually observed using regular theodolites except in the higher latitudes, where any of the three astro instruments employed after 1914 might be substituted. Determining differences of longitude remained a problem for many years after 1847 because the telegraph lines required were not always available. Telegraph lines were sometimes extended to places specifically to determine astronomic longitudes, but the chronometric method continued to be used in the western U.S. and Alaska. In fact, most of the longitude bases for the several local datums in Alaska resulted from chronometric observations.

At Lake Tahoe in 1893, as part of the delineation of the California-Nevada boundary, it was necessary to string telegraph lines about five miles, all uphill from Genoa, Nevada. Early on, astronomic latitudes and azimuths were ob-

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"Why Should I Join a Section?"

Some of us were members of ACSM for years before we ever joined a section. I can attest that section membership has vastly expanded what I get out of ACSM, and what I can give back as well. There's no better place to meet the other ACSM members in your area informally, to expand your professional contacts, and to learn from those more experienced (or less experienced) than yourself. The sections are where the 30-year mapping veteran and the student from the local university can sit down and exchange battlefield stories and bright ideas. Such contacts often result in the germination of new regional programs or workshops, which benefit local members (and prospective members) in the short run, to and help further the goals of ACSM in the long run. For those who have trouble making it to national conventions, section workshops and programs can help you to continue your professional development closer to home. And for many of us, the section is where we most often get that rewarding sense that something we've done has contributed to the progress of our profession.

"How Do I Join a Section?"

This varies from one section to the next. If you are a member of ACSM living in Alaska, for instance, you are automatically on the membership list of the Alaska Section, whether you choose to actively participate in local programs or not. In this section, there are no additional dues. To join the New England Section, on the other hand, you would request an application form from the section secretary, and (upon acceptance) pay a nominal section dues fee, which goes to support section programs and mailings. Contact one of the section addresses (or one of the council officers) for more information on the section nearest you.

"What if There's No Section in My Area?"

At the very least, use the contact addresses below to determine whether you might like to join the section nearest to you. The New England Section has several members from New York, New Jersey and Canada who've chosen this route. They may not make it to many of the section meetings (though we have a couple of notable marathon-driver exceptions), but they get our newsletters, and they make their mark on section discussions and plans by mail, fax, phone, and E-mail.

And for the ambitious upstarts out there: why not found a new section in your area? The Council of Sections is here to help you get started. We can provide you with guidelines and tips, and we're developing a section starter guidebook, containing sample section newsletters, examples of section activities, and copies of the Constitutions and Bylaws of existing sections. In addition, contributions from several existing sections have enabled us to establish a section starter fund, which is available to help defray your initial start-up costs. Just contact one of the Council Officers below for more information.

Those of us who have belonged to a section for a while, who have seen what they can accomplish—well, we tend to be true believers. We've found them to be terrific places to network with fellow professionals and to mingle with local members of MOs to which we don't belong, and with which we might not otherwise come in contact. We believe all of ACSM benefits from section activities, and we know you'd benefit individually, too. Why not join us ? Find out more about joining (or starting) a section by calling a council officer today. Or come to the "coffee hour" in Nashville (8-9 a.m., Monday, November 13, 1995), and stay, if you like, to observe the council meeting.

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Triangulation party on Uncompaghre Peak, Colo., 1895, site of one of the longest network lines ever established—183 miles.

tained more frequently, because of the simpler nature of the observations.

The primary reason for the observations was to obtain deflections of the vertical at the points. The deflections could be computed 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 is also observed, the point is identified as a Laplace station, although technically only the longitude and azimuth are required. In due course, Laplace stations were regularly spaced throughout the country. The U.S. network was one of the few in which orientation was rigorously controlled by Laplace azimuths at prescribed intervals. This policy began about 1910 for work still in progress and continued in the establishment 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: the method was used to obtain the information needed to reduce the PASADENA base to the mountain line which Michelson used in his experiments on the speed of light in 1922-23.

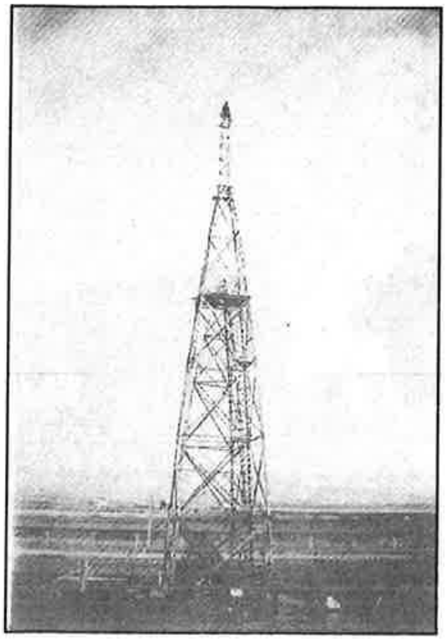
Astrogeodetic Deflections

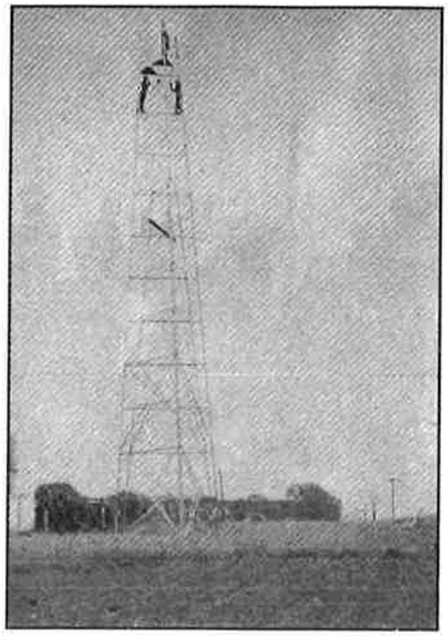
Astronomic azimuths were also used to control the first-order taped traverses observed during the 1917 to 1927 period. It was recognized that the Laplace corrections would be very small in that part of the country where the traverses were measured and that the observed angles could easily absorb the differences. In 1956, a program was initiated to determine astrogeodetic deflections along the 35th parallel at about 30-km (18-mile) intervals as part of an international study on the shape of the earth. Most of the observations were completed; some were made as part of the Transcontinental Traverse (TCT) project in which more than 1300 astronomic positions and azimuths were measured between 1961 and 1976.

In 1974, a plan was drawn up to upgrade the network for NAD83. The plan included the measurement of several hundred new baselines, 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, Wyoming—one of the largest discovered to date. Until 1960, almost all geodetic astronomy was accomplished by the C&GS. Then, 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, the 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 1980s, 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 using the higher elevations for station sites for obvious reasons. Nevertheless, it was not unusual to elevate the instruments further in order to clear various obstructions, to extend the lines of sight, and to minimize refraction conditions. This was done even in the earliest period, despite the heavy weight of the theodolites. As an example, the scaffolding and tripod at both ends





BOTH PHOTOS COURTESY NOAA ARCHIVES

Towers of wood (left) reached only about 50 feet. Metal towers (right) designed by Bilby reached over 100 feet.

of the EPPING base, Maine, 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). In very rare instances, masonry construction was used. Whenever possible, the stands holding the personnel were separate from the instrument tripods.

The sparsely settled, wide-open spaces of 19th- and early 20th-century America were not suitable for the European practice of placing triangulation station sites on church spires and other high structures. Even when available, very few of these buildings were 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) 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 sometimes equally tall, superstructures, from which heliotropes, lights, or pole targets were displayed.

The era of tall wooden towers ended in 1926 when Jasper S. Bilby, then Chief Signalman C&GS, designed a double tower survey signal built almost entirely of reusable steel bars and rods, held together with bolts. Bilby used steel windmill technology that was common throughout the west. He had long experience in building wooden signals, and also used designs from gas pipe towers built earlier by the U.S. Lake Survey.

These 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. Bilby tower components could be reused often, even hundreds of times, and the towers were employed worldwide. They were first used was in 1927 in southern Minnesota where 96 towers were erected during the working season that included other projects in the state . The tallest tower 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 1880s as a young man, fresh from an Indiana farm. He immediately showed an uncanny ability to locate trees obstructing lines of sight, an important talent at a time when it wasn't easy to move across the countryside. He became skilled in signal-building and reconnaissance (planning surveys), and, in fact, wrote the original manual on these subjects among several special publications. He rose through the ranks to Chief of Party. At the time of his retirement in the 1930s, he was Chief Signalman, the highest civilian position in the C&GS field service.

Station Monuments

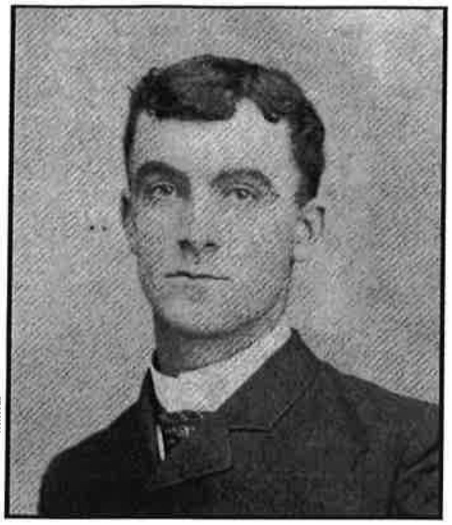
Lasting station monuments, for obvious reasons, were always of fundamental importance in geodetic surveys. Reference marks serve several purposes: to aid in locating the station, to verify its position, to reset the monument, and to use as substitute stations. Where rock ledges or large boulders were available, Hassler used 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 marked the exact station. Subsurface (underground) marks 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. In addition, he buried small pieces of rubble or sea shells found at the site atop the station mark to aid in its recovery.

Durable Concrete

Baseline 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, were used. For subsurface



Jasper Bilby, designer of the Bilby tower, at age 20.

marks, the same type of posts, bottles, earthenware jugs and crocks 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 used.

When it was necessary to bury the marks, a ditch 4-8 ft in diameter and 8-18 in. deep, was dug around the station location 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, and punch holes.

About 1900, cast bronze disks were introduced and shortly thereafter poured concrete monuments 3-5 ft deep with subsurface marks became the standard, where rock ledges and boulders were not available. Monuments of this type continued to be used until the mid 1980s. About 1965, steel rods driven to refusal with disks attached later were set for many surveys and are the basis for what are believed to be the most stable marks by today's standards. In the 1920s, two reference marks were specified for each station; beginning in 1927, a third reference mark was set about 1/4 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 1970s when special steel rod type marks were introduced. In the 1930s, precast concrete posts with bench mark disks attached were used for several years. Prior to the late 1970s, all concrete monuments and disks were constructed of nonmagnetic materials. Once GPS became operational, subsurface, reference and azimuth marks were seldom set and rod type station marks became predominant.

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. When they were, a few flashes with a mirror for identification purposes and to indicate that observations were to begin and conclude would generally suffice. That practice continued when heliotropes came into use during the 1840s. 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 1890s, resolved the need for in-the-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 identification, lights often had to be dimmed or brightened and messages relayed in emergencies. In 1902 International Morse code was adopted as the vehicle to obtain that end.

Beginning in the 1930s, multiple observing parties became the rule and angle information was often transmitted to the Chief Observer 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. However, they caused enough problems to delay their general use for about 15 years. The major problem was that conversations were picked up by nearby receivers. In one case, local residents heard the jargon, compounded by flashing lights, which made them think that foreign agents were in the area. They reported the incidents to police, who went looking for spies and found surveyors atop towers instead. As might be expected, there were a few complaints about profanity.

By about 1960, radio technology had improved and all units were so equipped—and 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 charting information. The Coast Survey was a small bureau in terms of personnel. One continuing problem, political opposition to geodetic surveys, never really disappeared, although it was not as vicious as in the Hassler years. A 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 at 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. It connects the lighthouses at Cape May, New Jersey, and Point Arena, California, 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 UNCOMPAGHRE PEAK near Ouray in Colorado and MOUNT ELLEN near Hanksville, in Utah. In the 950-mile stretch from Colorado Springs, Colorado, to San Francisco, California, less than 40 stations were required. Many of the observations had been made by Assistant William Eimbeck between 1876 and 1896.

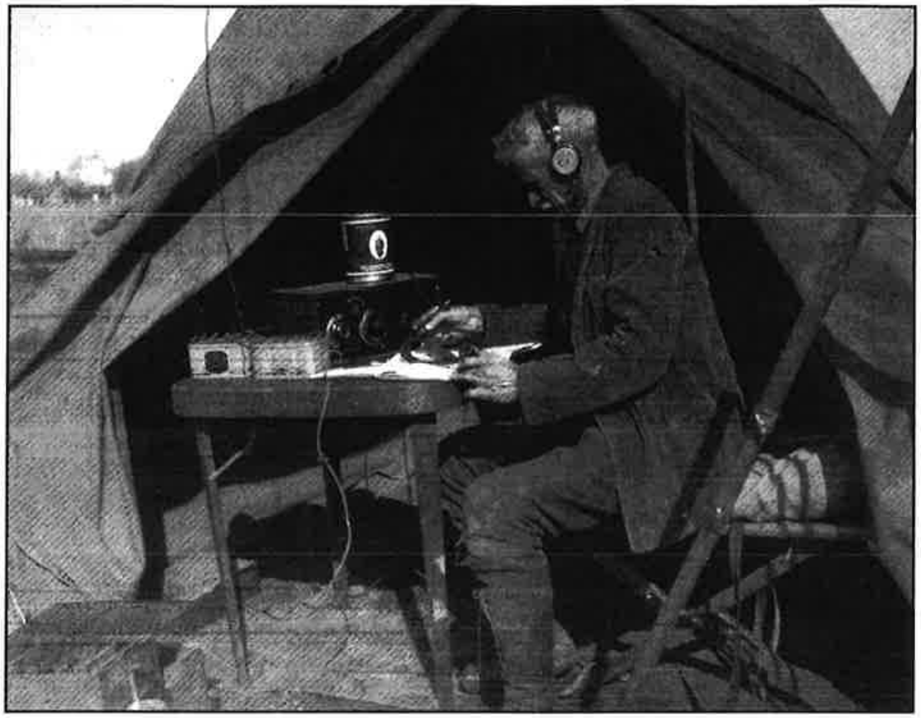
Great Hexagon and Davidson Quadrilaterals

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.

Because of the remoteness of the area and the short working season it took 10 years to complete the observations at the seven stations involved. In the 1880s and 1890s the only mode of travel to the station sites in the mountain west was by horse, more likely mule, and wagon. Actually, horse-, or more likely, 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. Farther 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.

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 of the project was 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 and 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 of the day he was successful follows and tells the whole story. The complete article, "Nine Days on the Summit of Mt.Shasta" appears in *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



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Field parties used Morse code and telephone wires to communicate.

> 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, Calif.] 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.

Only a few years later a regular network line mentioned previously, UNCOMPAGHRE PEAK to MOUNT HELENA was observed. At 183 miles, it is 14 miles longer than the longest French observation.

U.S. Lake Surveys

The Corps of Engineers were responsible for mapping and charting the Great Lakes. Once it was known that the Coast Survey didn't have the resources or intentions to extend surveys to that region of the country for at least several decades, the U.S. Lake Survey (USLS) was set up within the Corps to do the job. Between 1864 and 1900, this agency established primary triangulation throughout the lakes area including an arc south from Chicago connecting to the 39th Parallel triangulation at Parkersburg, Ill.

Of unusual interest were the several very long lines across Lake Superior they were able to observe despite the fact they were theoretically not intervisible. While very rare, 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 1930s Hudson River arc.

In the 1880s, 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 and 1899;
- 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 work in Alaska over several decades, including work on the U.S.-Canada boundary in the 1890s;
- the 1893-97 remonumentation of the U.S.-Mexico border made under the direction of Assistant Alonzo T. Mosman, C&GS; and
- the 1872-85(?) triangulation of the Adirondack Mountains, New York 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. During this period, the quality of the observations was never compromised and the quest for higher accuracies did not end.