SCIENCE

FRIDAY, MARCH 3, 1899.

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson N. Y.

*GEODETIC OPERATIONS IN THE UNITED STATES.**

THE geodetic operations in the United States, as executed by the Coast and Geodetic Survey, may be grouped into three distinct periods of time. The work was authorized by Congress in 1807, but a quarter of a century elapsed before anything was done in the field worthy of the name of Geodesy. This closed the first period, which may be characterized as the era of preparation and education of public sentiment. In 1832 operations were begun with vigor, and the foundation was laid for a great national work. The Survey was conducted on the same general lines of policy for eleven years, when the reorganization of 1843 established its permanent status. No great deviation has since been made from this plan, which has now held for fifty-five years. If we eliminate the Civil War period of five years, during which work was suspended, and regard operations before the reorganization as of a preliminary nature, we have half a century of geodesy. During its comparatively short existence the Survey has been three times under the control of the Treasury Department, twice under the Navy, and once under law requiring its personnel to be army or navy officers. The direction of the work has, however, remained throughout

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in the hands of a civilian, and civilian methods have been applied in the administration. At the present time it has been continuously under the Treasury for a period of sixty-two years. Although statistics do not always give an adequate conception of the work to which they are supposed to bear testimony, a general idea of the activity displayed may be had from the following statement of work done:

350,000 square miles (906,500 sq. kilo.) of triangulation, embracing
15,000 stations for horizontal measures, and determining
28,500 geographical positions at which
1,000 astronomical coordinates have been observed.

38,500 square miles (99,710 sq. kilo.) of topography, embracing
11,600 miles (18,670 kilometers) of general coast line and more than
100,000 miles (160,900 kilometers) of shore line (rivers, etc.), also including
51,000 miles (82,080 kilometers) of roadways.

545,000 miles (877,100 kilometers) of sounding, covering
164,000 square miles (424,800 sq. kilo) of area, besides
93,000 miles (149,700 kilometers) of deep sea sounding, in which
14,000 bottom specimens were obtained.

4,600 original topographic and hydrographic sheets, from which
1,300,000 charts have been made and distributed;
30,000 original volumes of observations, including magnetic records from
1,100 stations.

BASE LINES.

Two hundred and three base lines have been measured, of which nineteen, on account of their accuracy, length and geodetic connection, are classed as primary. The average length of these is 9,892 meters. The probable error, which includes both that of measurement and the comparison with the standard, is 22.2 millimeters, or about 1/445,000 of the length stated. Speaking of the three types of apparatus used in the Survey, and referring now to errors of measurement purely, it may be said that with the different forms of metallic bars, compensating and otherwise, the error is one-millionth part of the length measured. With the tape line the accuracy may be increased to 1/2,000,000, while with a rod in melting ice 1/5,000,000 is easily attainable. In the first form the contacts are material; in the last, optical; with the tape they are linear. The cost is greatest for the rod in melting ice, and least with metallic bars.

Attention may here be called to a new form of base apparatus named the Duplex and designed by Assistant William Eimbeck. It consists of two bars, brass and steel, five meters in length, so arranged that the measure may be made with each component separately and simultaneously. It may also be employed as a Borda scale, or the temperature may be directly observed. Some unique features, which need not here be described, are employed in its manipulation. The Salt Lake base, measured in 1896, gave results with either component having a probable error of less than 1/5,000,000 part of the measured length.

TRIANGULATION AND ARCS.

The shore line of the United States, exclusive of Alaska, is 5,452 miles (8,774 kilometers). This has been covered by triangulation, with the exception of a few hundred miles on the northwest coast. An oblique arc of 22° has been measured from the northeast boundary in Maine, to the southwest limit of Alabama, on the Gulf of Mexico, and an arc of 49° on the 39th parallel of latitude has been completed, from the Atlantic to the Pacific. All of the New England States, a large part of the Middle ones, and considerable areas in the South and West, have been covered with triangulation. Adjacent regions have had careful reconnaissance. The work in this direction has been executed on a large and accurate

scale. The greatest triangle has sides of 133, 167 and 190 miles (214,269, and 306 kilometers). The highest station is over 14,000 feet (4,267 meters). Operations of such magnitude justify the introduction of refinements not usually employed. The latitudes are corrected for elevation, and the horizontal directions are changed, to reduce them to the sea level of the observed station. A distinctive feature in the final adjustment is the application of weights depending on both the station errors and those arising from the closing of figures. These are treated separately, but the final weights consist of two parts, one resulting from local conditions and varying with each direction, and the other deduced from the formation of triangles and remaining constant for the network under consideration In the California work the probable error of a direction at any station was 0″.081 while that from the closing of triangles was about twice as much. The latter necessarily includes the former. The two are separated by means of the formula

$$e_c = \sqrt{e_t^2 - e_s^2}$$

which gives the resulting combination error as ± 0″.169. e_t is the probable error of a direction from the closing of triangles, and e_s is the average probable error of an observed direction from station adjustment. Each direction, therefore, enters the final adjustment with a weight derived from measures at its own station, added to the above value, which represents the constant part for the entire figure. The cost of the transcontinental arc from Cape May to San Francisco was two hundred dollars per linear mile ($124 per kilometer), three and a half dollars per square mile ($1.35 per sq. kilo.), and two thousand dollars per station.

A fine example of rapid expansion from the base to a fully developed net of triangulation is found in the vicinity of Salt Lake, and is a characteristic specimen of primary work as carried out in the Rocky Mountain region of the United States. The average height of the thirteen stations composing the main scheme is 11,256 feet (3,431 meters), while the average length of the lines connecting them is 159,734 kilometers (99¼ miles). The distance between Mt. Ellen and Uncompagre is 294,104 kilometers (182¾ miles). This remains to the present day the longest line observed from both ends and forming an integral part of a regular system of triangulation executed by any trigonometric survey in existence. Indeed, the entire chain from the Sierra Nevada on the west to the Mississippi plateau on the east is without a parallel in similar work, when we consider the magnitude of the geometrical figures, the elevation of the stations and the refinement of the individual measures.

Referring to a part of this work—the base net at Salt Lake, Utah—the following details are of interest:

The elevation of the base above sea level is about 4,224 feet, while the mean height of the stations composing the quadrilateral is 11,088 feet. In only five steps we pass from a base 11.2 kilometers in length to a line 237,765 kilometers long (Pilot Peak, Mt. Nebo). This involves an average multiplication of 4¼ times for each step of expansion, which is within the limit set for development in well conditioned triangulation. The resulting quadrilateral in which the base line expansion culminates and on which the transcontinental extension rests contains nearly 10,500 square miles and is the largest yet realized. The base net including this figure (Ogden, Mt. Nebo, Ibepah and Pilot) was adjusted separately and brought out the following criteria of accuracy:

FROM STATION ADJUSTMENT.

Average probable error of a single observation of a direction	= 0″.71
Average probable error of an adjusted direction	= 0 .10

FROM FIGURE ADJUSTMENT.

The largest correction is.....0″.84
And 55 per cent. of the corrections are less than..0 .25

The probable error of the side Ibepah-Nebo, depending on angular measures only, is 1/280,000 of its length.

Heliotropes were continually employed, and the angles were measured with a theodolite having a horizontal circle of 20″ diameter and a magnifying power of 83.

ASTRONOMICAL WORK.

Aside from the work in practical astronomy incident and necessary to the operations of every trigonometrical survey, attention has been given to various other phases of the subject. It has not alone sufficed to point out and demonstrate the utility of the method of equal zenith distances for latitude, and of the application of the telegraph to longitudes. The Coast and Geodetic Survey feeling the necessity of better star places, arising from the use of the methods just mentioned, has devoted some of its energy to the perfection of star catalogues. It is probably no exageration to say that the declinations given in our field lists are the best attainable anywhere. More than fifty of the best modern catalogues are corrected for their systematic errors, and each is given weight depending on the value of the work and number of observations. A collection of all these data, and their consolidation into one homogeneous result, eliminates as far as possible all known sources of inaccuracy, and gives us finally the most reliable positions. A list so constructed of several thousand stars has been already published, many of which are especially adapted to southern work. The average probable error of a declination may be given as rather less than $\frac{1}{4}$ of a second; a degree of precision, which enables an observer to determine his latitude from 20 pairs, in one evening, with an uncertainty of only $\pm$ 10 feet. This is sufficient for the purposes of geodesy. Incidental to regular astronomic work, the Survey has equipped and sent out no less than 35 parties for the observation of solar eclipses and transits of the inferior planets, which work has required the occupation of stations in every continent and Polynesia. The variations of latitude have been determined at three stations, each one having been occupied more than a year.

MISCELLANEOUS OPERATIONS.

The legitimate field of investigation in a geodetic service embraces many subjects outside of those already specified. In the execution of the task before us a free interpretation has been given to the law authorizing the work, and the kindred subjects of Hypsometry, Magnetism, Gravity and Physical Hydrography have been pursued along with others more strictly within our province.

Five thousand miles (8,047 kilometers) of precise levelling have been executed, including four independent determinations of the height of St. Louis. Two have been made from the Atlantic at Sandy Hook, and two from the Gulf of Mexico at Biloxi.

A comparison indicates that the surface of the Gulf is somewhat higher than the sea level at New York, and this has been verified in character, although not precisely in amount, by a line across the peninsula of Florida, three times repeated. Other subsidiary lines have been observed. The limit of error has been that usually adopted in similar work, viz., 5 mm. $\sqrt{K}$. The heights by spirit level have been supplemented and controlled by micrometric measurements of zenith distances. In the determination of elevations necessary to reduce the base lines along the transcontinental arc to sea level the latter method has been employed across the Allegheny and Rocky Mountains. The spirit levels are continuous from Sandy Hook to Denver and Colorado Springs.

They are checked by zenith distances from the Chesapeake Bay to the Ohio River, and supplemented by the same method from Denver to the Pacific coast, where the spirit levels are not yet completed.

Permanent magnetic observations have been in operation at Philadelphia, Key West, Madison, Los Angeles, and each one has furnished records for five consecutive years; with one exception a self-registering apparatus has been continuously and exclusively employed in each locality. These data added to records from 1,100 widely distant points, many of which are secular variation stations, furnish precious material for the study of the earth's magnetism. The work of the Survey in the investigation of the force of gravity has been carried on both within and without the limits of the United States. Twenty-eight foreign stations have been occupied, including points in Europe, Asia, Africa, Australia and many islands in both the Atlantic and Pacific. New light on the subject of volcanic formation, as well as on the constitution of the earth's crust, has come from this work. Fifty nine-stations have been observed at home, including a line across the continent. Half-second pendulums are now exclusively employed, and the determinations are purely differential. The period of oscillation is usually known to within a few millionths of a second.

In the field of Physical Hydrography most comprehensive studies have been made.

The exploration of the Gulf Stream, including a study of its density, temperature and currents, the geology of the sea bottom, the establishment of cotidal lines, the determination of the ocean depth from earthquake waves and other specialties in the domain of hydrography, have been made a part of the regular work. The hydrography of the coast, to the head of tidewater, has been developed side by side with the triangulation and topography.

The practical results of the Survey are shown in the publication of the annual reports, the issue of charts, notice to mariners (corrected monthly), coast pilots for Atlantic, Pacific and Alaskan waters, tide tables (now extended to foreign ports) and various miscellaneous publications in special lines of research.

PRESENT AND FUTURE OPERATIONS.

A resurvey of Chesapeake Bay, the measurement of an arc through the United States on the 98th meridian, and the development of Alaskan geography, are among the projects of Dr. Pritchett, the present superintendent of the organization. All these have been carried on during the last two years. The line of transcontinental precise levels is being pushed westward with all available means. Primary triangulation on the Pacific coast has been resumed, and will soon be completed from San Francisco to the Mexican boundary. Hydrographic surveys are in progress along the Atlantic seaboard, on the Pacific, and at the mouth of the Yukon in Alaska. Numerous topographic, astronomic and magnetic parties, are employed in the interior.

An extension of the great arcs of the United States into Mexico and the British possessions has been proposed by Dr. Pritchett, and diplomatic representations between the interested governments looking towards concerted action in the near future have already been made. This will give to North America an additional meridian arc of about 55° and an oblique one of 33°. Together with existing arcs, the proposed material will practically exhaust our contribution to the determination of the earth's figure.

In the ordinary prosecution of the field work since 1895 about fifty parties have been employed during the course of each

year. Added to this, the purely hydrographic work has been carried on by a fleet of sixteen vessels, of which ten are steamers. The operations have been widely distributed, extending as far as the Pribilof Islands in the Bering Sea. A longitude determination was made from Sitka, of Kadiak and Unalaska, in which twenty-one chronometers were carried on four successive trips. The probable error of the resulting longitudes was $0^s.20$ for the former and $0^s.21$ for the latter. A tidal indicator, similar to the one in New York, has been erected at Philadelphia, and one is in process of construction at San Francisco. The mechanism, actuated by the tide, furnishes the navigator at any moment, at a distance of one mile, with necessary information as to the character and amount of the tide.

Among the auxiliary duties of the service may be mentioned the establishment of trial speed courses for ships of the Navy (a number of which have been recently laid out); the exploration of oyster beds; the fauna of the Gulf Stream; the administration of an Office of Standard Weights and Measures, from which prototypes are issued to the different States; meteorological researches for the use of the coast pilot; the study of astronomical refraction; mathematical investigations on the theory of projections, on the equations of steady motion, on errors of observations; and finally, in experimental researches in engraving, electrotyping and lithography; all of which knowledge finds application in the various fields of activity now covered by the Coast and Geodetic Survey.

WORK OF THE UNITED STATES ENGINEERS.

Geodetic surveys have also been carried on by the Corps of Engineers of the United States Army. That of the Great Lakes was completed in 1882. The work was reorganized in 1892, and resurveys and extensions thereto are now in progress. Changes in the original plan have been introduced, chiefly in the direction of rapidity of execution. Fewer positions on the circle are now used for horizontal angles, and adjustment is effected by separate small figures, rather than through any extended scheme. In the measure of the Mackinaw base three tapes were used, each a kilometer in length. Each section of the tape was compared with a standard length of 100 meters established on the ground. This standard length was determined by means of an 8-meter bar packed in ice, which in turn was compared with the Repsold meter, R 1878.

The Engineer Corps of the Army has also had charge of the Mexican boundary survey, and of the work done by the Missouri and Mississippi River Commissions. The report on the Mexican boundary is already in type, but is not ready for distribution.

The Missouri River Commission has completed a triangulation from St. Louis to Three Forks, in Montana, a distance of 2,551 miles. The work follows the river and covers the valley from bluff to bluff. Precise levels have been run over 807 miles of it, and ordinary levels cover the remainder. Ten base lines have been measured with a standardized steel tape.

The Mississippi River Commission, utilizing some work already done by the Lake Survey and the Coast and Geodetic Survey, has now a complete connection from the Gulf of Mexico to St. Paul, in Minnesota. The total distance is about 1,600 miles. Twenty-seven bases have been used, of which eighteen have been measured by the Commission with a steel tape 300 feet long. The work has been adjusted by quadrilaterals employing the method of least squares.

E. D. Preston.

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