DEPARTMENT OF COMMERCE AND LABOR

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THE WORK

OF THE

COAST AND GEODETIC SURVEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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PREFACE.

Leaflets, descriptive of the work of the Coast and Geodetic Survey, were published as separates for distribution at the Louisiana Purchase Exposition, held at St. Louis, Mo., in 1904, and they have been republished in this form for distribution at the Lewis and Clark Centennial Exposition, at Portland, Oregon, in 1905.

It will be seen on inspection that they are intended to present concise statements relating to the origin of the Survey, to the general plan of its operations, to the methods and processes whereby the work is carried on, and to some of the more important results reached in its progress.

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 1

THE COAST AND GEODETIC SURVEY

To all nations whose territory touches the sea or who have any interests in the commerce of the sea, a full and complete knowledge of the coast—its nature and form, the character of the sea bottom near it, the locations of reefs, shoals, and other dangers to navigation, the rise and fall of the tides, the direction and strength of currents, and the character and amount of magnetic disturbance—is of the greatest moment.

To supply this knowledge the governments of the principal maritime nations have in modern times made surveys of their coasts by the most exact methods.

Some idea of the importance to this country of such operations may be formed when it is remembered that the coast line of the United States and Alaska, measured along its general trend, exceeds 10,000 miles in length. To represent the actual shore line which includes all the islands, bays, sounds, and rivers in the littoral or tidal belt, these figures would have to be multiplied many times. To this must be added the shore line of Porto Rico, the Hawaiian Islands and the Philippine Islands. The length of the general shore line of only fourteen of the principal islands of the latter group exceeds 11,000 miles.

On the recommendation of President Thomas Jefferson, Congress in 1807 authorized the establishment of a national Coast Survey as a bureau under the Secretary of the Treasury. No further action was taken until 1811, when preparations were made and field work began in 1816. The work was suspended in 1818 and resumed in 1832. For the purpose of furnishing geographic positions and other data to State surveys, the scope of the Bureau was enlarged in 1871 and in 1878 its designation became the Coast and Geodetic Survey.

In 1903 the Bureau was transferred to the newly created Department of Commerce and Labor.

The plan upon which it is at present organized is based on the broad scientific foundation proposed by Hassler and approved by Jefferson. Its present methods have been perfected as the result of experience gained in the field and office during the century of its existence.

Under the direction of a superintendent there are two great divisions of its work, the field and the office.

In accordance with the plan of reorganization of 1843, the work on shore was divided between civilian assistants and officers of the Army, and the hydrographic work was almost entirely under charge of officers of the Navy.

In 1861 the officers of the Army and Navy were detached, and since that date no officers of the Army have been assigned to duty on the Survey. After the civil war the assignments of officers of the Navy gradually increased in number, so that the hydrographic work was about equally divided between them and the civil assistants during the period which followed until 1898, when the officers of the Navy were finally relieved, and in 1900 Congress authorized the establishment of the Survey on a purely civil basis.

The Survey owns a fleet of eleven steamers and four schooners, and a number of launches.

The personnel of the Survey is at present divided as follows:

1. Field force, composed of 46 assistants, 29 aids, 8 magnetic observers, 4 nautical experts, 6 tide observers, 32 watch officers, engineers, surgeons, deck officers, etc., and 300 enlisted men with such additional employees as are necessary to insure the effective work of field parties on shore.

2. Office force, composed of disbursing agent, chiefs of division, clerks, computers, draftsmen, engravers, instrument makers, printers, etc., numbering 145 persons.

The office is that part of the establishment which receives the records, original sheets, etc., representing the results of field work. They are registered and deposited in the archives until in turn they are taken up for examination, computation, and adjustment, prepared for publication, and finally published. Charts prepared from original surveys are reduced, engraved, electrotyped, and printed.

For the convenience of administration the operations of the main office at Washington are carried on by eight divisions, each having some specified portion of the general work to perform.

There are suboffices at San Francisco and Manila. The latter is practically a branch office in the sense that the officer in charge, representing the Superintendent, has authority to prepare and publish charts and sailing directions and all other information which he decides is necessary or desirable for the use of mariners.

Many of the field operations of the Survey being geodetic in their nature, a system of primary triangulation, together with the determination of geographic positions by means of astronomic methods, must furnish the foundation upon which the whole rests. On the Atlantic coast a chain of triangles begins at the eastern boundary of Maine and stretches to the Gulf of Mexico. An extensive system of triangles extends across the continent along the thirty-ninth parallel of latitude, connecting the surveys of the two coasts and furnishing a basis for the surveys of the thirteen States through which it passes. Another triangulation system is being extended along the ninety-eighth meridian.

In connection with these principal systems, the triangulation has been considerably expanded in the New England States, New York, and several Western States, including California, where some exceptionally large figures were introduced. The longest line so far observed is that from Mount Helena to Mount Shasta, over 190 miles in length.

A tertiary triangulation for topographic and hydrographic purposes has been completed along the entire Atlantic and Gulf coasts and Porto Rico, and practically the whole of the Pacific coast except Alaska. Much progress has been made in the latter Territory and in the Philippines by methods which possess a sufficient degree of accuracy for immediate use and are capable of rapid execution.

In the determination of astronomic positions the exact methods originally developed in the Survey have been adhered to and perfected. The methods of using the zenith telescope for latitude and the telegraph for longitude have been constantly improved.

Incidentally the triangulation and the astronomic observations connected with it furnish the most valuable data for the determination of the figure of the earth that has been contributed by any one nation.

The topographic operations have been mostly restricted to a narrow margin, rarely more than 3 or 4 miles wide, along the coast and surrounding harbors, bays, and rivers to the head of tide water.

The hydrographic operations have extended as far out from the coast as was necessary for the interests of navigation, and have included all harbors, channels, bays, etc., as far as the work has gone.

Deep-sea soundings have been made extensively, especially in and about the Gulf Stream.

Much attention has been given to tides, and continuous series of tidal records have been obtained at important points.

The results of the operations of the Survey in connection with the study of terrestrial magnetism can be found on its charts and in its numerous publications on the subject. In addition to the determination of the magnetic elements at many widely distributed points and their frequent redetermination for secular variation, special observations are also made at certain base stations, with the aid of self-registering instruments, for the purpose of obtaining the record of the numerous variations of the earth's magnetism continually taking place.

The study of the force of gravity as a part of the great geodetic problem has received attention for many years, and the Survey has developed methods and instruments with which the work can be done at a greatly reduced cost, and with a high standard of accuracy.

A network of precise levels covering, in a general way, the eastern half of the United States, connecting the Atlantic Ocean, the Gulf of

Mexico, and the Great Lakes, has been run, and is being extended to the Pacific Ocean.

Throughout its history the Survey has constantly been called upon to determine boundary lines, both State and National.

The principal publications of the Survey consist of about 500 different charts; tide tables for all the principal and many of the minor ports of the world; a monthly edition of 4,350 copies of a circular known as "Notice to mariners," containing notes of all changes along the coast; Coast Pilots, containing minute sailing directions for all navigable waters along our coast; and the Annual Report of the Coast and Geodetic Survey, which contains the report of the Superintendent on the conduct of the work, and special reports upon the various technical and scientific operations of the service.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 2

TRIANGULATION AND RECONNAISSANCE

In any survey it is necessary to know the relative positions of some principal points of reference upon which to base the work. In other words, the distances and directions between certain points must be known.

When the area to be surveyed is small or unimportant, the distances may be measured directly upon the ground, with chain or tape, and the directions may be obtained by the use of a compass or surveyor's transit. But when a survey is to cover an extensive territory, or when great precision is desired, this method is unsatisfactory. Aside from the difficulties and delays experienced in making accurate linear measurements upon even moderately level ground, the natural obstructions, such as bays, rivers, mountains, and forests, frequently render direct measurement impracticable. To overcome these difficulties the method called "triangulation" is employed. It rests upon the geometrical proposition that if one side and the angles of a triangle are known the remaining sides can be determined.

A single line, forming a side of one of the triangles, is measured with extreme care. The angles of each triangle are measured and the distances between the points are then computed, one from another, through the successive triangles, proceeding in regular order from the measured line or *base*. From these fundamental ideas it is evident that the three stations forming each triangle must be intervisible, and it is also desirable that the triangles should be as nearly equilateral as practicable.

Triangulations are usually classified as *primary*, *secondary*, or *tertiary*, in accordance with their relative importance and the size of their individual triangles. Primary triangulation is the basis upon which rests the accuracy of an extended survey, and consists of triangles of maximum size. Tertiary triangulation is usually composed of many small triangles, furnishing the numerous points of reference needed for the detailed survey of any locality, while the term "secondary triangulation" is applied to work of an intermediate character, serving to reduce the long lines of the primary system to more convenient dimensions.

The work of selecting points which shall fulfill these conditions is called *Reconnaissance*, and is the most difficult and exacting task of an extensive survey. No two regions call for the same treatment, but some general considerations can here be briefly outlined.

A reconnaissance may be preliminary to minor triangulation along the seacoast, a river, or an estuary, where but a moderate degree of accuracy is required and the range of selection of points is limited by the purpose for which the triangulation is to be used, namely, the control of a hydrographic or topographic survey along the shore. Or, again, it may have to do with the arrangement of a great triangulation to cover a wide region. In the latter case careful study will be required in order that the resulting project may best satisfy all the conditions. A reconnaissance for triangulation of the largest size is a matter of great complexity and demands great skill, experience, and judgment. Heavily wooded country is the most troublesome, and makes it necessary to climb the tallest trees, or to raise poles taller than the trees, from which the distant horizon can be seen and such observations made as may be practicable.

MOUNTAIN TRIANGULATION STATION.

When the reconnaissance of a region has been completed and the stations of the triangulation have been selected, the three angles of each triangle are carefully measured. Instruments of various sizes and stands or piers of different kinds are employed, according to the character of the country, the size of the triangulation, and the facilities at hand. These conditions also determine the kind of signals or objects to be used at the distant stations. At great distances the only objects which can be used are heliotropes by day and powerful lights by night. The heliotrope is a small mirror so arranged that it reflects the sunlight toward the observer. During the past three years acetylene lamps mounted behind a pair of powerful condensing lenses have been used for night signals.

The theodolites used in primary triangulation are instruments with well-graduated circles from 12 to 24 inches in diameter. The circle is read to a second of arc, or closer, by three micrometer microscopes, the mean of the readings constituting one observation of a direction. Were all the conditions perfect, a single careful observation of each direction would be sufficient. But the most excellent instruments have some defects; the most careful observers are liable to some slight error; and, above all, the line of sight, passing through miles of atmosphere of variable density and temperature, is subject to influences which defy analysis, and which can be neutralized only by making observations under different conditions. In order also to eliminate errors due to irregular graduation, these successive observations are made on different parts of the circle by shifting it through a definite portion of the circumference after each set of observations. The number of such positions may vary widely for primary triangulation.

The present practice is to use sixteen positions on the circle, making one reading with the telescope direct and one with the telescope reversed for each position, giving sixteen measures of each direction.

Triangulation with very long lines is possible only in regions of high mountains, where the curvature of the earth is overcome by the natural elevations. In lower country, heavily wooded, or where mountains of nearly uniform height are closely crowded together, triangulation must have more moderate dimensions, with lines from 10 to 40 miles long. In such country it will often be necessary to elevate the instrument from 20 to 150 feet above the surface, either on some existing building, or upon a structure built for the purpose. Heliotropes and lamps can still be used, and signal poles are also useful in cloudy weather.

In secondary and tertiary triangulation the lines may range downward from 20 miles to less than 1 mile. The same general principles apply as in primary triangulation, but the details of the work will vary with the circumstances. Heliotropes are rarely used, and the angles are often measured with theodolites from 6 to 12 inches in diameter, and a smaller number of measures are required. After measuring the angles the triangle sides are computed. The latitudes and longitudes of all stations are also computed by geodetic formulæ.

The accuracy attained in triangulation may be tested in various ways. The sum of the angles of a plane triangle must equal 180°, and the same condition holds good in a geodetic triangle, after reducing it to a plane triangle by deducting the *spherical excess* due to the figure of the earth. The difference, if any, between 180° and this corrected sum is the *error of closure*, which in the best work will average rather less than 1″. We may also test a triangulation by comparing the computed length of a line obtained through a long chain of triangles with an actual measurement of the same line. In the triangulation between the Maryland and Georgia base lines, 602 miles apart, the discrepancy was scarcely perceptible, being little over half an inch in a 30-mile line. This line was a triangle side halfway between the base lines, and the comparison was made by computing its length from each base line through the triangulation. Equally small discrepancies have been found in other triangulations, and the method may be considered practically exact.

Various improvements made in the methods of primary triangulation by the Coast and Geodetic Survey have resulted in the speed of the work in 1902–3 being more than doubled, as compared with earlier work of the same kind in the United States and the present work in foreign countries.

The cost of the work has also been greatly reduced without perceptible loss of accuracy.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 3

BASE APPARATUS

A *base* in geodesy is a line actually measured upon the ground for the purpose of determining the dimensions of a series of connected triangles, of one of which it forms a side.[a]

In an extended triangulation there will probably be several bases, which serve as checks upon each other when all have been connected by computation through the system of triangles. Their number will depend upon the plan adopted for the work, upon the means available for the measurements, and upon the nature of the country, which may or may not afford suitable sites at convenient places. Very broken ground is unsuitable for base measures, though moderate slopes offer no serious obstacles.

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[a] See leaflet: Triangulation and Reconnaissance.

It is evident that the length of a base should be obtained with a high degree of precision, since any error in its length is multiplied as many times as that length is contained in the whole extent of the work. This demands a degree of care and refinement far surpassing ordinary needs, and for this reason various devices have at different times been contrived for the special purpose of extremely precise measurement. Such arrangements are collectively called *base apparatus.*

The attainment of absolute accuracy in the measurement of a base depends upon certain essentials which must be secured, whatever the form of apparatus used. These are: (1) A knowledge of the length of the apparatus in standard measure at the moment of use; (2) the inclination, or deviation of the apparatus from the horizontal; (3) the measure of the fractional distances which may occur at the end of any section. The alignment of the bars in the direction of the base line can be made sufficiently perfect, and therefore no correction for deviations from the vertical plane of the base needs consideration.

Of the three requisites just mentioned, the first is far the most difficult of attainment and is the only one which needs special consideration in this paper. The length of a bar or tape varies with its temperature. Hence, in order to obtain correct results, that temperature must be known with absolute accuracy throughout the measurement, and that again is very difficult to accomplish.

EARLY FORMS OF APPARATUS.

Among the earlier forms of base apparatus were metallic chains, wooden rods, and glass tubes. Wooden rods have been used, under special circumstances, as late as 1857, and the chain is still frequently used in ordinary land surveying, though long discarded in work of precision. As will be seen a little later, however, metallic tapes and wires, which differ less in principle than in details, have been much used in recent geodetic work and seem likely to be still more frequently employed in the future.

CORRECTIONS FOR TEMPERATURE.

The early forms just mentioned were gradually supplanted by metallic bars, which apparently were first used in 1788, in Italy, and in 1798, in France. With their use, the changes in length of the bars due to variations of temperature at once became a most important subject for consideration.

Two main difficulties present themselves in this connection; first, to determine the precise change in the length of a given bar for a given change of temperature; and second, to determine the exact temperature of the bar at any given time. In practice, the latter requirement is much the more troublesome, since under the conditions of exposure inseparable from base measurement it is practically impossible to determine by thermometers, with absolute accuracy, the actual temperature of a bar unless that temperature is invariable.

Four different methods have at various times been followed in the attempt to avoid the errors due to varying and uncertain temperature.

The first method was to use for the measuring rods materials which were only slightly affected by temperature changes, such as wood or glass, as already mentioned. Other considerations then prevented the success of such systems, but it is probable that in the near future the nearly invariable alloy of steel and nickel, discovered in France and there called "*invar*," may come into use for this purpose. In fact, base bars of this metal have already been made and are undergoing tests as to their qualities.

The second method is to ascertain the temperature of the metallic bar or tape by means of mercurial thermometers suitably applied and then to correct the measured length accordingly by means of the carefully determined coefficient of expansion of the bar or tape. The weak point of this method is the impossibility, noted above, of certainly securing absolute equality of temperature between the bar or tape and the mercurial thermometer.

The third method is to use compound bars, in which parallel rods of two metals possessing quite different rates of expansion, as platinum and copper or steel and brass, for example, replace the single rod of one metal. The ends of the rods being provided with suitable scales or other devices for intercomparison, the relative displacements due to temperature changes may be measured. Such an arrangement, often called the *Borda scale* from the name of its originator, is, of course, a form of thermometer, and from the readings taken at any time the length of the compound bar can be computed. This principle of differential expansion is applied, in different ways, in several of the modern forms of apparatus.

In Borda's apparatus, used by Delambre in 1798, the strips of copper and platinum which formed the measuring bar were firmly connected at one end, while free to expand or contract at the other. In Porro's apparatus, sixty years later, the components of steel and copper were united at the middle, while in the Eimbeck "*duplex*" *apparatus* of the present day the parallel tubes of steel and brass are capable of independent motion.

A somewhat different application of the principle is found in the "compensation apparatus," used by Colby in Ireland, in 1827, and by Borden in Massachusetts, in 1831. Colby's apparatus has also been used in England and in India. In each of these the differential expansion was utilized to produce a bar of invariable length in the following manner: The parallel rods of iron and brass are firmly connected, midway of their length, while near each end a transverse metal strip, the "compensation tongue," pivoted to each rod, projects to one side. The proportions of the rods and their attachments are so arranged that the distance between two points marked upon the projecting ends of the transverse strips remains invariable, or nearly so, whatever the temperature. This apparatus, however, has not been found entirely satisfactory, especially in India, the compensation not being absolutely reliable.

The elaborate apparatus constructed for the United States Coast Survey in 1845 combines the principles of Borda's measuring rods, the Colby compensation tongue, and the *contact lever* introduced by the Russian astronomer, Struve, with marked improvements in their application. The length of the compound bar was supposed to be independent of temperature, but, as in the Colby apparatus, the compensation was not absolutely exact, slightly different results being obtained with rising and with falling temperatures and the bars were therefore standardized under each condition. Much excellent work was done with this apparatus, although it is no longer in use.

The fourth method, and the only perfect solution of the problem, is to eliminate temperature corrections by maintaining the bar at a constant temperature, when its length will, of course, be invariable. The well-known fact that melting ice affords a uniform standard of temperature points the way to the attainment of this end and the application of the principle in the *iced bar apparatus* of the Coast and Geodetic Survey, designed by Woodward, leaves little to be desired on the score of precision.

TYPES OF BASE APPARATUS.

All forms of apparatus may be divided into two principal classes, namely: (1) Those which use but a single measuring unit, whether chain, tape, or metallic bar; and (2) those which employ two or more separate units.

With apparatus of the first type the measurement of the base proceeds by repeated applications of the single unit, the ends of its successive lengths being marked in the case of a tape upon posts or tripods firmly planted in the ground and in the case of a bar by powerful microscopes mounted upon firm supports. Measures of this type are, in general, *line measures*, i. e., their lengths are defined by lines upon their surfaces. In the case of a bar these are microscopic lines engraved upon small polished disks of gold, silver, or platinum inlaid in the bar near its ends.

With apparatus of the second type the measurement proceeds by the alternate application of the several units of measurement, end to end, either in actual contact or separated by a small interval, which is carefully measured by some suitable device. Bars of this type are, in general, *end measure* bars, i. e., their lengths are defined by their ends.

Bars of either type are usually supported upon stable tripods, or even more permanent supports, provided with suitable arrangements for controlling the alignment and the inclination of the bars.

It is obvious that the principle of Borda's device may be applied to apparatus of either type by the simultaneous use of two metals possessing quite different coefficients of expansion. A subdivision into *monometallic* and *bimetallic* forms therefore becomes necessary.

The limits of this paper will not permit even a brief description of the various forms of base apparatus which have been used in the different geodetic surveys, but, speaking generally, it may be stated that most of the European surveys favor the bimetallic forms, that of Porro, for example, of the first or single bar type, or those of Borda, Bessel, and Brunner, of the second or multiple bar type. In Spain, however, while the central base of Madridejos was measured with a compound bar of copper and platinum, on the Porro system, some later bases of verification have been measured with an iron bar designed by General Ibañez, and in Russia the monometallic forms devised by Struve and Tenner were exclusively used for many years. The most recent Russian bases, however, have been measured with the bimetallic apparatus of Jäderin. In this system a wire of steel and another of brass, each 25 meters long and 2 millimeters in diameter, are stretched between tripods under a tension of 10 kilograms. Each wire carries a divided scale near one end for measuring the exact distance to the forward tripod. The tension is measured by a spring balance. Two bases were measured in 1888 with this apparatus and another in 1894. It seems to possess a degree of precision sufficient for geodetic purposes and is at the same time capable of rapid use, as much as 3,500 meters having been easily measured per day. The apparatus is also simple, portable, and inexpensive.

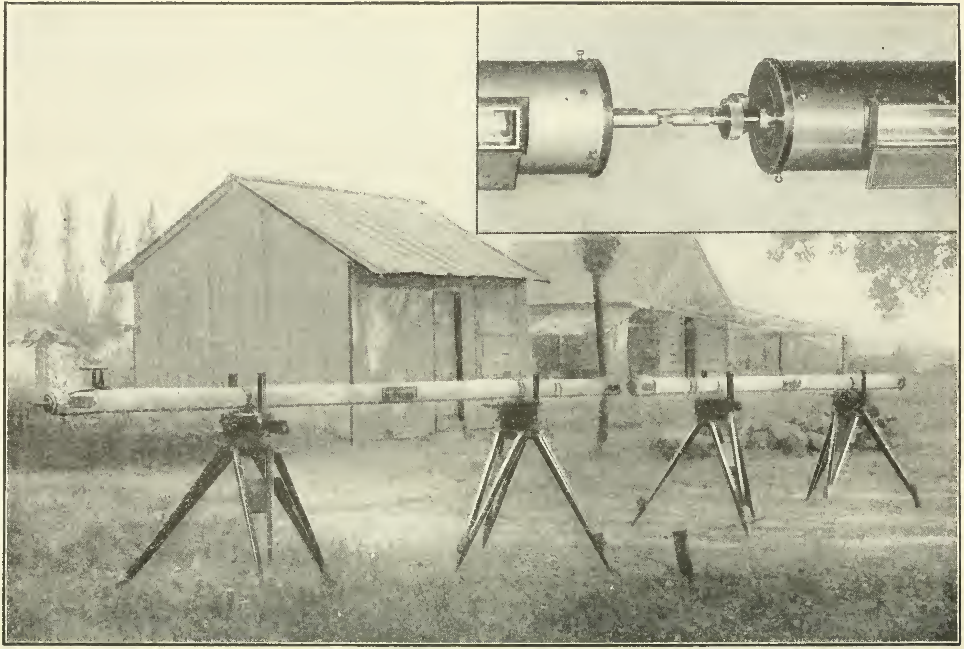
APPARATUS NOW IN USE IN THE COAST AND GEODETIC SURVEY.

The foregoing general observations lead to the main purpose of this paper, the description of the apparatus and methods now employed by the Coast and Geodetic Survey. In the recent work four principal forms have been used, namely:

(1) The so-called iced bar, a monometallic single-bar system.
(2) The duplex apparatus, a bimetallic multiple-bar system.
(3) The secondary apparatus, a monometallic multiple-bar system.
(4) The tape apparatus, a monometallic single-unit system.

ICED BAR APPARATUS.

The measuring unit is a steel bar 5 meters long, that length being defined by microscopic lines engraved upon the polished surfaces of small, inset, platinum-iridium plugs near the ends of the bar and in its neutral axis, to permit which arrangement the upper part of each end is cut away for a short distance. While in use it is supported within a metallic trough filled with melting ice, which keeps the bar at constant temperature. Uncertainties due to varying temperature



DUPLEX BASE APPARATUS.

are therefore entirely avoided. The trough inclosing the bar is supported upon a carriage movable upon a track built for the purpose. The successive positions of the ends of the bar are fixed by powerful microscopes firmly attached to stout posts solidly planted in the ground and such refinements are used at every step of the process of measurement that an extraordinary degree of accuracy is obtained.

Measurements with this apparatus are deemed in the United States too slow and costly, however, to be advisable for an entire base, and the most recent practice of the Coast and Geodetic Survey is to use it for measuring with great precision a distance of 100 meters, near and parallel to the base about to be measured. This distance of 100 meters then becomes a field standard for the careful testing and comparison, under actual field conditions, of the apparatus intended for the actual base measurement. When a number of bases are to be measured in the same season, this field standardization is effected at the first and last bases of the series. For the purpose of establishing these accurate field standards the value of the iced bar apparatus can hardly be overestimated.

DUPLEX APPARATUS.

The *duplex* apparatus, as the name implies, has two separate measuring rods in each compound bar, one being made of steel and the other of brass. These rods are tubular, instead of being solid as usual, and the thickness of their walls is based on the specific heat and conductivity of each metal. To give the tubes equal capacities for absorbing and radiating heat they are plated with nickel. These tubular rods are so arranged that an independent measure is conducted with each, giving for any measured distance two results, one in terms of the steel, the other in terms of the brass component. By means of attached scales direct comparisons between the two may be made whenever desired. The difference between the two measures determines the average temperature of the two rods and, by means of the ratio of the expansions of brass and of steel, the corrections which will reduce the measures to standard, without any reference to mercurial thermometers. Each compound bar is, however, provided with three such thermometers, and a single measurement will therefore yield three results, a duplex and two separate thermometric results.

Though these results are perhaps not absolutely independent, they afford valuable checks upon the reliability of the measurement. It will be seen that the great difference between this and other bimetallic types is that instead of making the comparison between the components for each successive 5-meter bar, in which case the changes are of course minute, the measurement is continued for a considerable distance between comparisons, 500 or 1,000 meters, for example, giving in effect the comparison between steel and brass bars of that length, with a considerable increase of precision in its accomplishment. This apparatus has been used upon ten bases recently measured in the United States, and is an undoubted success, giving results of a high order of precision at a moderate expense.

SECONDARY APPARATUS.

The *secondary* apparatus of the Coast and Geodetic Survey is a simple monometallic type possessing a considerable degree of precision. The rods are of steel and, for the purpose of checking radiation, are inclosed in massive wooden bars, from which they project a little at each end. Temperatures are determined by mercurial thermometers, two for each bar, which are inclosed in the wooden casing, with their bulbs in contact with the steel rod, one near each end. The *contact slide device*, used also on the duplex bars, was first designed for this apparatus. To secure the best results with this apparatus, the measurement should be equally divided between periods of rising and of falling temperature.

TAPE APPARATUS.

Steel tapes have been used with marked success in measuring twelve recent bases in the United States. In each case, however, they have been standardized, under field conditions, by comparison with a test base carefully measured with the iced bar or have been used in connection with the duplex or the secondary apparatus. On the nine most recent bases independent measures were made with four different tapes, two of which were 50 and two 100 meters long. In recent work of precision in the United States, all tape measurements have been made at night, it having been found that mercurial thermometers will not accurately indicate the temperature of the tape in daylight. The steel tapes now used are either 50 meters (164 feet) or

100 meters (328 feet) long. They are 6.34 millimeters (0.25 inch) wide and about 0.47 millimeter (0.019 inch) thick. During the measurements they are supported at intervals of 25 meters (82 feet), the intermediate supports being wire nails driven horizontally into the sides of stakes previously arranged for that purpose. The successive positions of the forward end of the tape are marked upon copper strips secured to the tops of suitable posts, which are previously aligned at the proper distances. In the measurement, a tension of 15 kilograms (33.1 pounds) is applied to the tape by a lever, the amount of the tension being determined by a spring balance. With this tension, the sag of the tape between supports is very slight, and a high degree of accuracy in the measurement of the tension is therefore unnecessary. The temperature of the tape is determined by two mercurial thermometers attached to the tape near its ends.

Mention must here be made of a very promising application of the *thermophone* to the determination of the temperature of a steel tape, suggested by Professor Burton, of the Massachusetts Institute of Technology. By this device the temperature of a tape is obtained by the application of the principle of the differential variations, with varying temperatures, of the electrical resistances of steel and German silver, the tape for this purpose being made one arm of a Wheatstone bridge.

It seems probable that when this apparatus has been further improved, to make it more convenient in use and less liable to injury by accident, it may enable tape measurements of precision to be made by day instead of by night, and thus considerably facilitate such operations. It is also probable that the nearly invariable alloy of steel and nickel, previously mentioned, may play an important part in future measurements, wires of that metal having already been used in the measurement of base lines by the Jäderin system. It seems evident that base measurement by tape apparatus will become more and more common and that by this means the number of geodetic bases will be very greatly increased. The following observations will be interesting in this connection.

PRECISION AND ECONOMY OF MEASUREMENT.

The accuracy attainable with either bars or tapes falls well within the limits required for even the most accurate triangulation. Experience has shown that the judicious use of tapes easily admits of repeating a measurement with no greater discrepancy than about one-twelfth inch per mile, or about 1 part in 760,000, and that the duplex apparatus admits of remeasuring a line with a discrepancy not exceeding about one-sixteenth inch per mile, or about 1 part in 1,000,000. These figures represent average discrepancies for sections of a base, each a mile in length, and, in the case of continuous measurements, these may be assumed to cancel each other, in part at least. Hence the accuracy of a base line several miles in length may be expected to be proportionately still greater than that mentioned.

While steel tapes give nearly the same degree of accuracy as the duplex apparatus, the cost of measuring a base with any good bar apparatus is nearly three times as great as for tape measurements.

In Appendix 3 of the Coast and Geodetic Survey Report for 1901 may be found a detailed statement in regard to the measurement of nine primary base lines by one party in six months, with a high degree of accuracy, showing a very successful application of business methods to the operations of geodesy.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 4

TIME, LATITUDE, LONGITUDE, AND AZIMUTH

Time determinations as made by the Coast and Geodetic Survey are incidental to, and necessary in connection with, observations of latitude, longitude, and azimuth. Astronomic determinations of latitude and longitude are necessary in connection with a survey to place it in its proper position on the earth's surface. Astronomic observations of azimuth serve to determine the true directions of lines fixed by a survey.

TIME.

Time may be determined by observations on the sun or stars with any instrument which will measure their altitude or indicate their meridian passage. For this purpose sextants or altazimuth instruments are generally used for approximate determinations, and a transit adjusted to the meridian for refined work. With the transit, a chronograph is frequently used for recording the observations. The telescope usually has from five to eleven vertical lines, which are placed in the common focus of the eyepiece and object glass, the center line being adjusted to the optical axis of the telescope and set in the meridian.

When ready for observations, the observer sets the telescope at the proper elevation to observe the passage of the star across the meridian, and records on the chronograph the transit over each line by interrupting the circuit with an observing key held in the hand and electrically connected with the chronograph, on which a break-circuit chronometer is making a continuous record. The chronograph sheet is read by means of a scale.

LATITUDE.

Latitudes of an inferior grade may be determined with a sextant or an altazimuth instrument by observations on the sun or stars, but determinations of the first order are usually made by observations on the stars with a zenith telescope. The principle on which this method depends is the measurement, with a micrometer, of small differences of zenith distance of two stars, nearly equidistant from but on opposite sides of the zenith. The telescope is set to the mean zenith distance of the two stars, one of which passes above and the other below the center of the field. These two stars, forming a pair, should culminate within from one to twenty minutes of each other, and they are bisected by the movable micrometer line as they reach the meridian.

In the past the use of from fifteen to twenty-five pairs observed on three nights has been considered necessary for a good determination.

LONGITUDE.

The longitude of a place may be determined by observations of the eclipses of the satellites of Jupiter, of solar eclipses, of moon culminations, of occultations of stars, and by transporting chronometers with varying degrees of accuracy. The most accurate results are obtained by determining the difference of time between the desired positions by the telegraphic method. The local time must be determined in the usual manner at the two places on the same nights (6 nights for work of primary importance) and a comparison of the chronometers must be made on each night by using a telegraph line between the places.

Each station should be supplied with a transit, a break-circuit chronometer, a chronograph, and a set of telegraph instruments. Two time sets must be observed at both stations each night, and between the observations the two chronometers must be compared over the telegraph line by means of chronometer signals, which are arbitrary breaks made by the observers alternately, and recorded on both chronographs. The comparison of chronometers only requires about three minutes. The transmission time of the electric current is derived by sending signals in both directions, and the personal equation of the observers is eliminated by the interchange of observers after half the work is completed, or is obtained by direct observations, if the work is not of primary importance.

In longitude work of the first order, observations should be made each night on twenty stars to determine the local time at the stations. When the transits are equipped with Repsold self-registering micrometer eye pieces, the observations are free from personal equation. In using this micrometer the star is kept constantly bisected by the movable micrometer line during its passage across the field of the telescope, and its position is automatically recorded at regular intervals.

AZIMUTH.

Azimuths are of different grades, according to the purposes for which they are required.

For exploration, reconnaissance or magnetic observations theodolites with horizontal circles from 3 to 6 inches in diameter are used to observe on the sun or the north star.

For tracing meridian lines or for tertiary triangulation theodolites with horizontal circles from 6 to 10 inches in diameter are used in connection with a circumpolar star.

For the principal triangulation, 12 to 20 inch circles, which are read to single seconds by micrometer microscopes, are needed to produce an accuracy commensurate with the requirements of the work. Only circumpolar stars are observed to determine high-grade azimuths.

Accurate time is required for this class of work, except when the observations are made at elongation.

A terrestrial mark is used in connection with all azimuth observations.

For fuller details refer to Chauvenet's Spherical and Practical Astronomy, or to the Report of the United States Coast and Geodetic Survey, 1898, Appendix No. 7.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 5

TERRESTRIAL MAGNETISM

In the "Plan for the reorganization of the survey of the coast, as adopted by a board convened on the 30th of March, 1843, by direction of the President of the United States," explicit provision is made for the making of "all such magnetic observations as circumstances and the state of the annual appropriations may allow," and Congress, in its annual appropriations, distinctly recognizes the importance of this feature of the work of the Coast and Geodetic Survey.

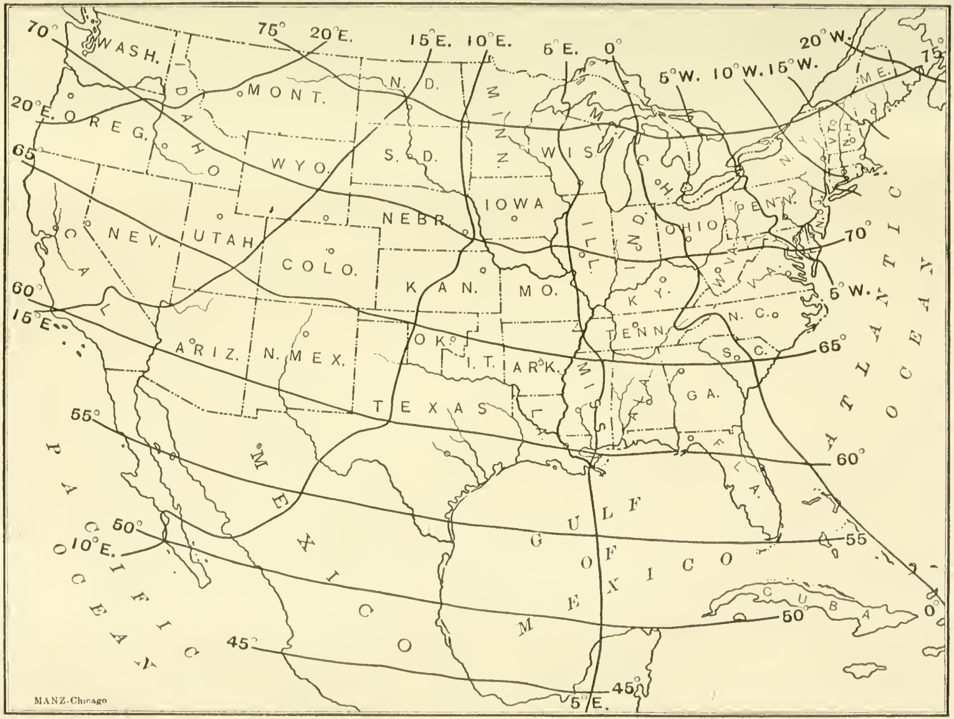
With the advancing years the demands for practical information from surveyors and mariners became so heavy that on July 1, 1899, an inspector was detailed for general charge of the field work and the discussion of results, which had previously been a function of the Computing Division of the Office, was placed in charge of the Division of Terrestrial Magnetism, which was created for that purpose.

A magnetic or compass needle does not point "true to the pole," as the old saying would have it, but instead makes an angle with the true north and south line, as was first discovered by Columbus, this angle varying according to the location of the place where the compass is mounted. Thus, in the United States, in the extreme northeastern part of Maine, the compass needle points 21° west of north, while in the northwestern part of the State of Washington it points 23° east of north, a change of 44° from one end of our country to the other (see Chart of Lines of Equal Magnetic Declination for 1900). There are portions of the earth where the "north" end of the needle points due east or due west, and even, for certain regions between the magnetic north pole and the geographic north pole, due south.

In view, then, of the use of the compass by the surveyor to locate land surveys, by the mariner to guide him over trackless seas, and by the traveler to pilot him in unfrequented regions of the earth, it becomes the *first* object of magnetic surveys to determine the amount by which the compass direction differs from the true direction, and to publish the quantities in such a form that those interested may at a glance be able to extract the desired information. The Chart of Lines of Equal Magnetic Declination for the United States, based on over 5,000 determinations in different parts of the country, is a specimen of the form now generally adopted for giving this information.

Not only does the needle not generally point due north, as already shown, but the amount of its departure therefrom is continually undergoing change from hour to hour, from day to day, and from year to year. At London, for example, the needle changed its direction from 11° east in 1580 to 24° 12′ west in 1812, a change of 35° in 232 years. *A street a mile long laid out in London during the year 1580 in the direction indicated by the compass at that time would have had its northern terminus six-tenths of a mile too far east, according to the compass direction of 1812.* At the present time, at London, the needle points about 16°.5 west.

In this country the rate of change in the compass direction is not as large as at London, nevertheless it is of sufficient magnitude to seriously affect the magnetic bearings of boundary lines. Thus, at Baltimore, the needle pointed in 1670 about 6° 6′ west; in 1802, 39′ west, and in 1900, 5° west: *A street a mile long laid out in Baltimore in*



LINES OF EQUAL MAGNETIC DECLINATION (VARIATION OF THE COMPASS) AND OF EQUAL MAGNETIC DIP FOR THE YEAR 1900.

1670, so as to run in the direction indicated by the compass at that time, would have had its northern terminus one-tenth of a mile too far west in 1802.

At St. Louis, at the time of the Louisiana purchase, the compass needle pointed about $7\frac{1}{2}°$ east, and it now points about 5° east.

Even in the course of a day, from 8 a. m. to 2 p. m., the fickle needle changes its direction by an amount sufficient to be taken into account. This amount, according to the season of the year, may cause a discrepancy at the terminus of a line a mile long run by the compass in the morning and rerun in the afternoon of from 5 to 20 feet.

Again, at times the needle's direction, by some subtile force, is abruptly changed. This is the case during magnetic storms which make their influence felt over a large portion of the globe at practically the same instant of time. Thus, in November, 1882, during the period of maximum sun spot activity, occurred a magnetic storm which caused the needle at Los Angeles, California, to change its direction by more than a degree and a third. At the same time General Greely, at Lady Franklin Bay, in the Arctic region, noted a deflection of 20° 48′. Frequently these magnetic storms are accompanied by brilliant displays of polar lights. There are in addition many minor fluctuations, depending upon the position of the sun and the moon with reference to the earth and to each other.

It is possible to portray the state of the earth's magnetic condition, as represented by magnetic maps, only for a definite moment of time. The tides, the trade winds, while subject to definite, periodic fluctuations, nevertheless will not change their general character for thousands of years, but a few years suffice to materially change and make useless a cartographic representation of the magnetic forces. It is of great importance, therefore, to provide for a continuous record of the countless fluctuations of the magnetic needle. It is then possible always to bring our magnetic charts up to date and to provide the surveyor and mariner with the precise amount of change between any two given dates. This necessitates the establishment of certain base stations, where are mounted sensitive magnetic instruments, which photographically record, day and night, the variations or changes of the magnetic forces.

There are at present five of these stations, situated as follows: At Cheltenham, Maryland; at Baldwin, Kansas; at Sitka, Alaska; at Vieques, Porto Rico, and near Honolulu, Hawaii.

The Coast and Geodetic Survey has made an exhaustive and careful compilation of the available data for the past three centuries as obtained from various sources, and the practical information, which it is in the position to furnish in reply to inquiries from lawyers and surveyors, is regarded as final and authoritative throughout the country. It can thus be of material assistance to landowners in the prevention of costly litigations.

The practical application of magnetic data is, however, not entirely limited to a knowledge of the direction of the compass needle. The mariner with the modern iron ship now in use carries with him a continuous source of disturbance, so that his uncompensated compass will fail to give the true *magnetic* direction for the ship's position. It is therefore necessary to apply correcting devices which to a large extent counteract the ship's magnetic influence. These mechanical devices are not, however, entirely compensatory for all the places a ship is likely to be in, owing to the changing character of the ship's own magnetism, and so the mariner must determine a table of corrections (the so-called deviation table) for different localities and for all positions and directions of the ship's head. For this purpose a knowledge of the dip of the magnetic needle and the intensity of the magnetic force are essential. The electrician, the geologist, and the physicist likewise desire a knowledge of these quantities. They are, furthermore, essential in ascertaining the precise laws underlying the variations of the earth's magnetism.

A complete magnetic survey, therefore, embraces the determinations of the three magnetic elements, declination (variation of the compass), dip, and intensity, and their changes from time to time over land and ocean areas as well. Special magnetic instruments are being used for the magnetic work at sea.

One practical result of a magnetic survey is the establishment of meridian lines near county seats for the purpose of enabling the surveyors to test and verify their compasses.

Washington, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 6

HYDROGRAPHY

Hydrographic surveying is the process of determining the shape of portions of the earth's surface which lie beneath the water and of recording the results of such determinations in form to be utilized in the construction of charts. It delineates with accuracy the submerged contour lines of channels, banks, and shoals. Work along the shore and in harbors and rivers is preceded by other processes of surveying, to which it is closely allied, and upon which depend the accuracy of the final result.

These processes are, first, triangulation, which gives points on land from which to determine the position of the soundings taken; and, second, topography, which provides the delineation of the shore line, or wharf lines, locates the rocks that show above the water; and the limits of dry shoals and banks. These data are placed in their proper relation to each other on paper by means of a suitable *projection*. This projection is prepared by a draftsman on a scale determined by the minuteness with which the submerged features are to be mapped. A scale of $\frac{1}{10000}$ (which means that 10,000 feet in nature are represented by 1 foot on the projection) is well adapted for the survey of most harbors.

This *projection* shows the geographic position of the points which have been determined by triangulation. These points correspond in position on the projection to certain marks on the ground suitable to observe upon in locating the positions of the soundings, such as church spires, chimneys of buildings, peculiarly shaped rocks or trees, and signals built over triangulation stations.

When a sufficient number of signals and objects are available, and a tide gauge or tide staff has been erected at some point in the vicinity of the work, the next step is to "run the lines of soundings." Having decided where a line is to begin, the boat is moved to that point. Two observers, with sextant in hand, the recorder, with a watch or clock and record book, and the leadsman, with his "lead line," take their respective positions. The officer in charge directs the recorder to make a note, say, as follows: "Line begins at angle $\angle$ 1, about 20 meters from shore, south of Fleck's Point; course about east." The observers measure the angles between three signals on shore and read the angles measured; the leadsman gets a cast of the lead and calls out the number of feet or fathoms, and the recorder records all these, with the time when the boat begins to move. The boat starts ahead and does not stop again until the end of the line is reached. Other pairs of angles are taken by the observers at three or four minute intervals, or as frequently as necessary, each set of angles locating the position of the boat at the instant of observation. At the end of the line a final set is taken. The boat is then moved to a position at the beginning of a new line. Where the depths are changing rapidly, the soundings are taken as frequently as possible, and the time of each sounding may be noted to seconds; but where the bottom is comparatively level the soundings are preferably taken at equal intervals of time.

When practicable, the lines of soundings are run on ranges—that is, with the boat in the same straight line with two objects on shore.

While the boat has been running the lines of soundings the water,

SOUNDING PARTY.

in all probability, has not maintained the same level, owing to the rise or fall of the tide. Each sounding must therefore be corrected for the height of the tide at the time it was taken, so as to reduce all to a common plane. The plane of reference adopted by the Survey for its charts of the Atlantic and Gulf coasts is that of "Mean low water," which is, roughly speaking, a mean reading of all the low waters observed on the tide staff for as long a series as practicable, but usually not shorter than one lunar month. The reading of mean low water on the staff being known, and observations of the height of the tide having been made at intervals of five or ten minutes while the boat was sounding, it is easy to apply this tidal correction. In order to preserve the height of the plane of reference, a permanent tidal bench mark is established on shore and the height of this plane is carried to it by leveling. Descriptions of these bench marks are preserved in the archives of the office. In deep-sea work, offshore, the tidal reduction is not applied to the soundings.

The Coast and Geodetic Survey requires that in smooth, shoal water the reduced soundings on lines crossing each other shall not differ more than $1\frac{1}{2}$ per cent of the depth.

At the end of each day's work, the results are graphically transferred to the "projection." Every position of the boat corresponding to any pair of angles measured on any three points on shore is plotted by means of a three-arm protractor. This method of plotting, it will be observed, is merely a graphic solution of the three-point problem.

The successive positions of the sounding boat being plotted, and the number and time intervals of the soundings and their number being shown in the record, it becomes an easy matter to space the soundings accurately between the positions. The result is practically the same as though the boat's position had been instrumentally determined at each sounding.

Hydrographic surveys of the character described develop the slopes of the bottom, but in regions like the coast of Maine and Alaska, where there are many isolated rocks and ledges on the bottom, or like the coast of Florida, Porto Rico, and the Philippines, fringed with coral reefs, and many coral heads, the work has frequently to be supplemented by special examinations where soundings on the regular lines shoaler than the surrounding depths give indications that there may be yet shoaler water. Examinations of this character have been greatly facilitated in late years by the attachment under the vessel of a device designed to give the vessel any draft of water up to 6 fathoms, and now known as the "Channel sweep." This device will find rocks that the lead line has failed to develop. The sweep is also used to verify channels that have been marked out through reefs, or areas of broken ground.

The method used in deep-sea sounding differs from the foregoing. The leadsman is replaced by a sounding machine, and the line by a fine steel piano wire coiled on a drum, the depth being obtained by recording the number of revolutions of the drum while paying out. The "lead" is replaced by a solid spherical shot weighing about 100 pounds, which is detached automatically from the wire on reaching the bottom. While the sounding ship remains in sight of land the method for determining its position is similar to that explained above, but when out of sight of land the position is obtained by astronomic observations and the ship's log.

Great accuracy is demanded of the hydrographer, even in water so deep that there is no possible danger of the largest ship afloat striking bottom, because the hydrography on a mariner's chart has a twofold object: First, to indicate to the navigator the hidden perils which he must avoid; and second, to display the configuration of the bottom so truly that by the use of the lead he may fix his position relative to those perils, or, when offshore, determine his distance from land.

For details of the theory and practice of hydrographic surveying the inquirer is referred to:

Coast and Geodetic Survey reports.

General Instructions for Hydrographic Work, Coast and Geodetic Survey.

Chauvenet's Astronomy.

Jeffer's Surveying.

Howell's Marine Surveying.

Washington, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 7

TOPOGRAPHY

A topographic map is one on which the natural and artificial features of the country are represented in their proper geographic positions by conventional symbols.

The two most important symbols on maps, where they occur, are the *shore line*, or boundary between land and water, and *contour lines*, which are lines of equal elevation above a selected plane, such as the sea level. A contour is in fact a representation of what the shore line would be if the level of the water were to rise to the elevation indicated by the particular contour.

In order to show the undulations of the ground, contour lines are drawn for some constant vertical interval—20 feet, for instance. On large-scale maps they have superseded the representation of heights by hachures or shade lines, which only picture the configuration of the country, without furnishing the means, as the contours do, of stating in terms of some linear unit the difference of elevation.

In reading a map one is able to tell the nature of the country from the various symbols—whether it is high or low, rugged or gently undulating, by the number and arrangement of the contours or hachures—and whether it is marshy or sandy, wooded or rocky, and so on.

A topographic map is particularly valuable for the study of the physical conditions relating to engineering projects in general, such as the preliminary location of railroads and highways, the problems relating to water supply and drainage, etc. It serves as a basis for directing military movements and planning military works of defense. Combined with hydrography, it forms a chart on which is shown the relation of land to water for purposes of navigation and the improvement of harbors and waterways.

Charting the coasts of the United States is the chief function of the Coast and Geodetic Survey, and topography is necessarily included as one of the important features of its work.

A topographic survey has for its object the collection of data for the construction of a topographic map. The character of the map in regard to accuracy, scale, and fullness of detail depends on the purpose which it is intended to serve. Military topographic sketches are frequently made by using a pocket compass, the stride of the observer's horse serving to estimate the distance. More elaborate methods are used where greater accuracy is required and greater detail is desired.

Different topographic methods require the use of various instruments and may, for the purpose of description, be classed under four heads, from the fact that each method is identified with some particular instrument or combination of instruments with which the principal part of the work is done.

1. *With a chain or steel tape and level, by what may be called the checkerboard system.*—The whole area is subdivided into rectangles by a system of distances measured with a chain or steel tape and marked by pegs whose elevations are determined with a level and rod. The positions and elevations of the pegs having been plotted, the contours are drawn on the plan with reference to them, and all other details are located by measurements from them. This method is best adapted

PLANE-TABLE PARTY.

for small areas where work of construction is shortly to follow the survey.

The ordnance survey of Great Britain is made by traversing the country with a network of straight lines measured with a chain, the accuracy of the work being controlled by starting each line from one triangulation point and ending at another. Offsets are measured from the line wherever it is necessary to locate details. The elevations of a number of points on the ground are determined by the level, and the contours are sketched with reference to these after the rest of the details have been plotted. This is the simplest of all instrumental methods in the field, but it is not efficient where there is little detail or where the ground is unsuitable for chaining.

2. *With transit and stadia.*—This method is a development of the preceding one. The country is likewise traversed by lines, but the slow, laborious process of chaining is discarded for the quicker one of reading the distances through the telescope of the transit on the stadia rod held at any desired point, and the lines may have any direction. The level is also dispensed with, as the height of any point can be determined by computation when its distance is known and the vertical angle to it is observed. A vertical circle is attached to the transit for this purpose. All the names of the objects sighted upon, as well as the distances and angles to them, are entered in a notebook, together with sketches of the locality to assist the draftsman to interpret the notes.

3. *With the camera.*—Surveys can be made with an ordinary landscape camera, but there are many advantages in having one especially designed for the purpose. The essential feature of this method consists in occupying a sufficient number of camera stations to fully cover the territory to be mapped, so that every topographic detail of importance may be photographed from at least two stations. This is the most rapid of all instrumental methods in the field, since a great deal of topographic material can be gathered photographically in a short time. It has the serious drawback that for areas abounding in detail the plotting becomes overwhelming.

By the three foregoing methods the map is constructed in the office; by the following method its construction is coincident with the field work.

4. *With the plane table and stadia.*—This is the principal method used for topographic work by the Coast and Geodetic Survey. For this purpose the plane table is a universal instrument. All the necessary operations for producing a map are executed with it in the field from the country as a model. Other instruments may at times be employed as auxiliaries, but in general it alone fulfills all requirements. Owing to the rapidity with which results are obtained by the method of graphic triangulation, and the facility the plane table affords the topographer for determining his position at an unknown point by the graphic solution of the three-point problem, and in the effective use of the stadia, it is an instrument peculiarly fitted for delineating coast topography, which includes such features as outlying islands and ledges, inaccessible rocky bluffs, and large marsh areas intersected by numerous streams.

In the experience of the Coast and Geodetic Survey, derived from surveying operations covering the coast line of the United States and Alaska, over 10,000 miles in length measured along its general trend, the plane table has proved to be the most comprehensive and effective mapping instrument.

Washington, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 8

TIDES AND TIDAL CURRENTS

To one who for the first time visits the seacoast, the continual variation of the water level due to the tides and the tidal currents which accompany this variation possess a novel and unfailing interest. This is especially the case in a region where the tide has a large vertical range, thus producing many curious changes in the aspect of the shore. Broad flats or ragged ledges may be left bare at low water, over which boats sail freely at high tide, and land masses which are peninsulas at one stage of the tide become islands at another. Even to one long accustomed to these phenomena there is an element of the solemn and mysterious in this vast and irresistible pulsation of the waters, coming in from the mighty depths of the great ocean.

Here, too, the mathematician and the physicist find problems of absorbing interest and of far-reaching application. From the time of

Sir Isaac Newton, who in 1687 laid the foundation for the modern researches, the subject has received the attention of many brilliant minds, and Daniel Bernouilli, Euler, Laplace, Whewell, Airy, Kelvin, Ferrel, G. H. Darwin, Harris, and others have investigated the theory of the tides. These investigations have aided in determining the moon's mass and the mutual relations of the earth and the moon and furnish evidence of the motion of the earth's axis of rotation relatively to the geographic poles.

While the disturbing forces of the sun and the moon are universally accepted as causing the tides, there is much to be desired in the way of showing how these forces actually cause the observed motions. These forces, acting horizontally rather than vertically, are the same which deflect the plumb line from the mean vertical. By their repeated action portions of the sea of the proper depth and dimensions are caused to oscillate in a manner analogous to the vibration of a pendulum. A phenomenon of a similar nature is observed in certain lakes, where oscillations known as *seiches* when once started continue for some time, the period of the oscillations depending upon the dimensions of the lake.

Nor are the tides of merely general or theoretical interest. The question of a foot or two in depth on a dangerous shoal may involve both lives and property upon a passing vessel, while the commercial prosperity of a port may depend upon the depth at both high and low water or upon the way in which the scouring effect of the tidal current serves to preserve its channels.

Any investigation of the tides, whether for theoretical or practical application, requires a basis of fact, and this can be furnished only by careful observations of the actual phenomena during considerable periods of time. Long series of observations are necessary because the tides are very complex phenomena, being modified by all influences acting upon the earth from without, as well as by those arising upon the earth itself (such as winds, earthquakes, and variations of the atmospheric pressure), by irregularities in the coast line, by the eccentric distribution of the land masses, and by the varying depth of the sea. A sufficient number of observations is therefore needed to eliminate as far as possible the effects of temporary influences and to permit the external forces to run through one of their great cycles, in order that a harmonic analysis may disclose the various elements which go to make up the tide.

While the vertical motion of the water surface is called the *tide*, the horizontal motion of the water itself is properly called the *tidal current* or *tidal stream*, and is often of even greater practical importance in navigation. While the rise or fall of the tide in a given period may be practically uniform in amount and nearly simultaneous at widely separated points within quite an extensive area, the currents which accompany the change will vary widely within the same region, being modified by every outline of the shore and by every irregularity of the bottom. Further than this, the time at which the tidal current changes its direction, as from flood to ebb or the reverse, by no means necessarily coincides with the time at which the tide begins to fall or to rise. Indeed, it would be more nearly correct to say that these times generally differ, the difference varying from a few minutes to as much as three hours in some localities. Not only does the tidal current vary both in force and in direction in different parts of the same sheet of water, but at any one point of observation wide variations are noted at different stages of the tide, so that a current which at a certain time runs with moderate force along the axis of a channel may perhaps an hour or two later set with great force directly across some dangerous shoal.

It will be readily seen that tidal currents require careful consideration, and that many difficulties present themselves in the way of obtaining and of collating sufficient observations to be able to predict their direction and velocity at any particular time. Fortunately, in the neighborhood of the land, where such currents are most likely to cause disaster, there are usually landmarks or artificial aids to navigation, by careful attention to which a shipmaster or pilot may safely guide his vessel.

The Coast and Geodetic Survey, as an organization charged with the important duties of the preparation of correct charts and coast pilots, has carried on from very early days in its history the observation and discussion of tides and tidal currents.

Observations of the height of the tide are usually made either upon a simple graduated staff or else by a self-registering gauge. The latter, which is always employed in places where a long series of observations is desired, is a simple but ingenious combination of a clock with a recording apparatus, in which a pencil, controlled in lateral position by the elevation of the water, traces an undulatory curve upon a long strip of paper which moves slowly at right angles to the direction of motion of the pencil and is regulated in its progress by the clock, which controls the apparatus.

Washington, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 9

LEVELING

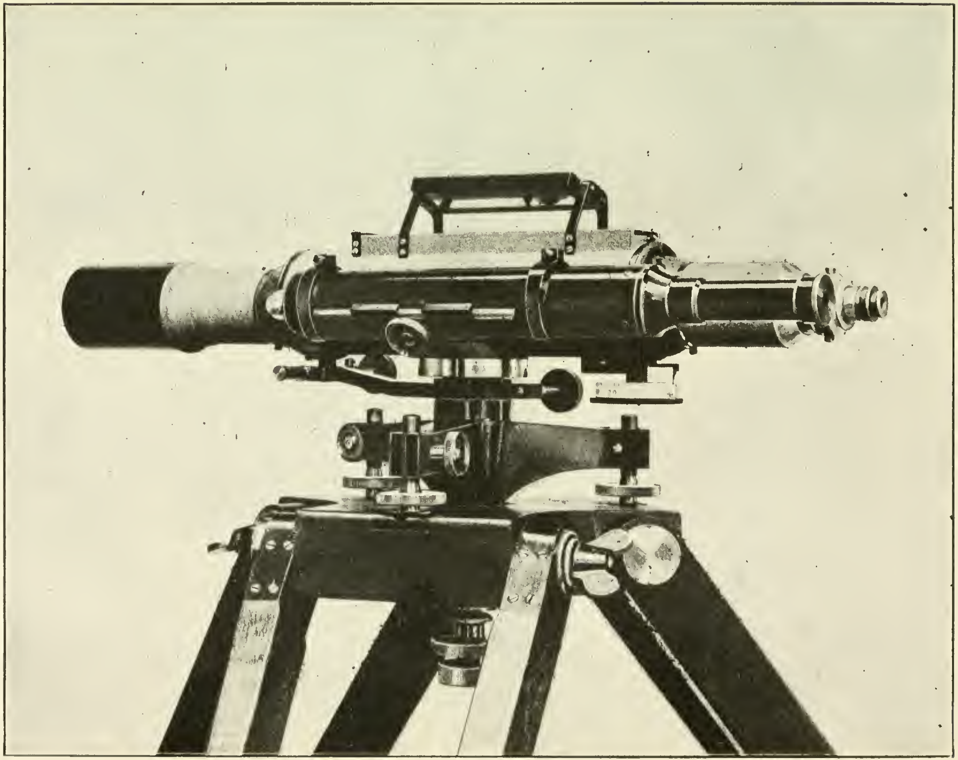
Leveling is the operation of determining differences of elevation between any two points on the surface of the earth. The determination of such differences, or relative elevations, is of primary importance for many of the purposes for which surveys are intended, and from them may readily be obtained so-called "absolute elevations" above any particular point or surface of reference which may be selected. The mean level of the sea is the surface of reference most commonly used for the determination of heights, but others arbitrarily selected are frequently employed for special purposes.

The two principal methods now in use in the Coast and Geodetic Survey for the determination of elevations are by precise spirit leveling and by the measurement of vertical angles. The first is the most accurate method known; the second is of a lower degree of accuracy, but suffices for many purposes.

The instrument used in the first method consists essentially of a telescope suitably mounted on a portable tripod and carrying a delicate spirit level, so that it may be quickly and readily placed in a horizontal position. Graduated rods are held at two points, the instrument being usually placed midway between them. The telescope is sighted first on one rod and then on the other. The difference of the readings of the rods is the difference of height between the two points. The length of sight is usually short and should not exceed 150 meters for accurate work. By repeating the operation at successive stations the difference of elevation of widely separated points may be determined.

Various types of instruments have been used for precise spirit leveling, some of them being nearly like the Y level used extensively by engineers on construction work and others differing widely from it. The principal characteristics which distinguish the form of precise level now in use in the Coast and Geodetic Survey are the irreversibility of the telescope and level, the absence of Y's, the rigid fastening of the level vial to the telescope and its close juxtaposition to the latter, in the barrel of which it is countersunk; the use in the construction of the telescope, and adjacent parts, of a nickel-iron alloy having a very small coefficient of expansion; the protection of the level vial and the middle part of the telescope from sudden and unequal changes of temperature by incasing them in an outer tube; and an arrangement by which, without any change of the observer's position, the level bubble can be clearly seen by his left eye at nearly the same instant in which the distant rod is observed through the telescope by his right eye.

It has been found that one of the principal sources of error in some of the precise leveling of the past was due to unequal changes of temperature in the telescope and parts connecting it with the level vial. The momentary changes in the relative positions of the level vial and telescope produced by these temperature changes, though microscopic in magnitude, were yet sufficient to introduce appreciable errors into the leveling on long lines. The particular nickel-iron alloy used in the construction of the new level expands less than one-fourth as much as brass for a given increase of temperature. This, together with the fact that the level is mounted as close as possible to the line of sight, gives a very high degree of stability to the relation between



LATEST TYPE OF PRECISE LEVEL.

the two, which is quite the most important point to be secured in a precise leveling instrument.

A line of precise levels is always run twice, usually in opposite directions, and in case of disagreement of the results beyond prescribed limits between adjacent bench marks, the leveling is repeated. Permanent points called bench marks are established at short intervals, so that the work may thus be frequently checked. For the leveling done during the last two years the maximum discrepancy allowed between two measurements on a section 1.6 kilometers (1 mile) long is 5 millimeters, or one-fifth of an inch. For sections of other lengths the discrepancy allowed is made proportional to the square root of the length.

A much more severe test of the accuracy of the leveling is obtained from the closures of large circuits, 50, 100, or 1000 miles in circumference. Elevations being carried from one point continuously in one direction around the circuit, the computed elevation for the starting point on closing the circuit should agree with that assumed for it at the start if there are no errors in the leveling.

In the network of precise leveling, which now covers in a general way the eastern half of the United States, there are 50 such circuits, varying in circumference from 100 to 1800 miles. The lines are so interlaced that each line usually forms a part of two circuits. The greatest error indicated by the circuit closures in any line of the whole system, involving nearly 20000 miles of leveling executed by the Coast and Geodetic Survey and other organizations, is 1.8 millimeters per kilometer, or about one-tenth of an inch per mile. On all of the lines run by the method now in use and with such instruments as that shown in the illustration, the greatest error indicated by the circuit closures is 0.074 millimeter per kilometer, or about $\frac{1}{200}$ of an inch per mile. The total length of lines so run is 3400 miles.

With the new instrument and method the leveling has been remarkably rapid and cheap, as well as extremely accurate. The average rate of progress for the first 2400 miles of such leveling was 66 completed miles per month, each mile being leveled at least twice, once in the forward and once in the backward direction. During the month in which the most rapid leveling was done, 105 miles of the line were completed, this being 223 miles of single line, or an average of 8.9

miles of single line per working day. The cost of this leveling has been from $7 to $11 per mile, or from one-fourth to one-half as much as leveling of the same grade of accuracy obtained with any other instrument and method.

Leveling by vertical angles, or, as it is usually called, trigonometric leveling, consists in measuring at any station the angle of elevation or depression of a distant station, and is carried on in connection with triangulation. The sight in this case may be of any length, and in mountainous regions sometimes exceeds 100 miles. The distance to the station sighted being known, the difference of elevation between the observer's station and the distant point is computed. In making the computations of heights from such observations it is necessary to apply large corrections, on account of the refraction of the ray of light coming from the distant point to the observer. This refraction is quite variable, having different values at different hours of the day, on different days and in different seasons. Little is known in regard to the laws controlling the changes, and the accuracy of the trigonometric leveling falls considerably below that of precise spirit leveling. The plan followed for preventing the accumulation of errors and improving the elevations determined by trigonometric leveling is to connect these measures at various points with precise level bench marks and to adjust the trigonometric levels to fit the precise leveling between these points. When this has been done the resulting heights are of sufficient accuracy for mapping purposes. Thousands of points have been so determined in various parts of the United States. The connections with precise leveling work and other tests of the accuracy of the trigonometric leveling indicate that, roughly speaking, it is an even chance that the difference of elevation of two points determined by trigonometric leveling is right within 1 inch to the mile when the computation is made from observations in both directions over a single line on several days at each station.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 10

COAST PILOTS

Coast Pilots are compiled to assist mariners in the navigation of their vessels. They serve to supplement the charts issued for that purpose. The Coast Pilots contain information which is important to the mariner and which is of such a character that it can not be conveniently placed upon a chart. The governments of the principal maritime nations publish works for these purposes.

As early as 1796 a volume known as The American Coast Pilot,[a] by Capt. Lawrence Furlong, was published in Newburyport, Massachusetts, by Edmund M. Blunt, and the first edition met with so ready a sale that a second edition of the same work was published in 1798. Since the latter date numerous compilers have published Coast Pilots of the coast of the United States and its harbors. These works

[a] The first Coast Pilot published in America.

were compiled from charts, from reports by shipmasters published in the newspapers, and from surveys and the personal knowledge of the compilers, some of whom were experienced shipmasters.

The vessels of the Coast and Geodetic Survey, while engaged in surveying the coast and harbors of the United States, collect much information of importance to mariners which can not be shown on the charts or completely given in *Notices to Mariners.* Coast Pilots are published and distributed by the Coast and Geodetic Survey at the cost of the printing and binding. Similar information can not be collected by private enterprise except at great cost and with imperfect means, and at the present time all the private publications containing such information relative to the coast of the United States are compilations from Government publications and are generally based on the work of the Coast and Geodetic Survey.

The compilation of the Coast Pilots necessitates work in the office and in the field. The office work consists of the collection of the latest data from the reports and surveys of hydrographic and topographic parties, from the reports and surveys of the United States engineers engaged in the improvement of harbors and waterways, and from correspondence with local authorities and engineers. This information, in manuscript, is then put in the form which experience has shown to be convenient for the use of the mariner.

For the field work a vessel of the Survey, with the compilers of the Coast Pilot on board, visits every part of the coast which is treated in the volume; the information collected in the office is verified and, if necessary, corrected on the spot; the sailing lines and directions are tested by running over the courses given; such artificial aids and natural landmarks as are of use to the mariner are noted, and hydrographic examinations of reported dangers and changes are made; pilots, shipmasters, and local authorites are interviewed and the latest information is incorporated, together with such notes as can only be obtained by observation and experience in the locality.

On returning to the office from the field, the manuscript, corrected to date, is prepared for the printer, and when issued the volumes contain a supplement or insertion sheet of the changes which have occurred since the date of the preparation of the volume and while the matter was going through the press.

The Coast Pilots published by the Coast and Geodetic Survey contain—

1. A tabular description of lighthouses, light-vessels, and fog signals; lists of life-saving stations, storm-warning display stations, and seacoast telegraph stations, and information regarding tides, tidal currents, variation of the compass, etc.

2. Nautical descriptions of the coast and harbors and general information concerning the several bodies of water and harbors, including notes relative to pilots, depth of water, draft of vessels entering the harbor, supplies, facilities for making repairs, usual or best anchorage, and other matters of practical value. In each case the information of this nature precedes the sailing directions and is printed in smaller type.

3. Sailing directions, with subordinate paragraphs treating of prominent objects, dangers, aids to navigation, etc. The arrangement conforms to the order in which these matters would be considered in practice and be available when wanted promptly. For this purpose, and to afford a ready means of reference from one part to another, the sailing directions, where long, are divided into numbered or lettered paragraphs, printed in large type, each followed by its own subordinate remarks in smaller type.

4. Appendices, containing rules of the road at sea and in inland waters, laws and regulations relative to pilotage, harbor control, national and local quarantine and the Public Health and Marine-Hospital Service, and information regarding storm-warning displays.

5. Views of important points. These are only inserted in volumes which treat of localities which have not yet been surveyed or where the lighthouses and other aids to navigation are not sufficiently numerous to readily locate and navigate a vessel.

6. Sections of charts, covering the coast treated in the volume, to aid in finding the geographic positions of different localities, and index maps showing the limits of the charts covering the localities treated in the volume.

The Coast Pilot publications of the Coast and Geodetic Survey include—

Seven volumes of the United States Coast Pilot, Atlantic Coast, in 8 parts, as follows:

Parts I–II. From St. Croix River to Cape Ann.

Part III. From Cape Ann to Point Judith.

Part IV. From Point Judith to New York.

Part V. From New York to Chesapeake Bay Entrance.

Part VI. Chesapeake Bay and Tributaries.

Part VII. From Chesapeake Bay Entrance to Key West.

Part VIII. Gulf of Mexico, from Key West to the Rio Grande.

One volume of the United States Coast Pilot, Pacific Coast; California, Oregon and Washington.

One volume of the United States Coast Pilot, Pacific Coast; Alaska, Part I, Dixon Entrance to Yakutat Bay, with Inland Passage from Juan de Fuca Strait to Dixon Entrance.

In addition to the above Coast Pilots, bulletins containing the latest information obtainable from all sources about the little-known waters of northwest Alaska and Bering Sea are published for the use of mariners navigating those waters.

It is manifest that publications of this character must be subject to numerous corrections in the details after the lapse of a few years. To maintain the volume in a useful form corrections are issued in Notices to Mariners, insertion sheets, and supplements; and each volume is revised and passed to a new edition when the corrections have assumed proportions that impair its usefulness, or more recent surveys show changes or furnish additions that render the old volume unsatisfactory.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 11

CHART PUBLICATIONS

Charts are designed to assist the navigator and to subserve the interests of commerce. For purposes of navigation they may embrace large areas, like one of the great oceans or seas, delineating the conformation of the shores and outlying dangers, and perhaps indicating the principal currents and winds that may be utilized in determining the most advantageous routes between specified localities. Charts may also embrace much smaller areas, but on larger scales, permitting greater fullness of the detail, and thus presenting graphically the channels that can be followed, with the depths of the water, the positions of lights, beacons, spindles, buoys, and other objects provided to indicate the way to the stranger. Charts of these classes are usually designated "Navigation charts," although they may also be useful for other purposes.

All classes of charts aid in the extension of commerce—one class representing large areas as guides, and the other class delineating limited areas, such as harbors, roadsteads, and anchorages, presenting all the advantages and disadvantages of a locality. These harbor charts or plans may exhibit every important detail of the harbor, and if based upon precise surveys possess an additional value to the engineer for the study of physical conditions with a view to improvements, and for defensive purposes.

Nearly all civilized nations have published charts of their coast lines, in greater or less detail, and the principal maritime nations copy those issued by other nations, and thus maintain for the use of their own seamen charts of all parts of the world to which their commerce may extend. Great Britain maintains the most extensive establishment for the purpose, and issues the most complete series of charts; she has also made the most extensive surveys of uncivilized coasts for cartographic purposes.

In the United States three bureaus of the Government service are authorized to issue charts, but under restrictions intended to clearly define the duties of each and prevent unnecessary duplication—the Coast and Geodetic Survey, in the Department of Commerce and Labor, the Hydrographic Office, in the Navy Department, and the Corps of Engineers, in the War Department. The Coast and Geodetic Survey is charged with surveying the coasts of the United States and the coasts under the jurisdiction of the United States, and with researches to determine the origin and courses of the great ocean currents known as the Gulf Stream and the Japan Stream, and to issue charts from these surveys suitable for the purposes of navigation, commerce, and the public defense; the Hydrographic Office, with the duplication of charts and plans issued by other nations, and the publication of surveys by the Navy on other coasts not under the jurisdiction of the United States; the Corps of Engineers, with survey of the Great Lakes and the issue of the charts necessary for their navigation.

The Coast and Geodetic Survey issues four series of charts on the Atlantic and Gulf coasts of the United States, and three series on the Pacific coast, designed to subserve the purposes for which the Survey was established. The first series includes "Sailing charts," which embrace long stretches of coast, as from the Bay of Fundy to Cape Hatteras, Chesapeake Bay to the Bahamas, etc., and are intended to serve for offshore navigation, or between the greater headlands, as Cape Cod, Cape Hatteras, etc., and between distant harbors, as Boston to Chesapeake Bay, Charleston, etc. They show only the outline of the continent, the seacoast lights, and geographic information that will be useful for the purposes intended. The second series includes "General charts of the coast," also designed for purposes of navigation. They are on a scale three times as large as that of the first series, and embrace more limited areas, as the Gulf of Maine, Gay Head to Cape Henlopen, Galveston to the Rio Grande, etc. These charts serve the navigator in coasting alongshore between headlands, and in approaching harbors. Those of the third series, called "Coast charts," embrace the whole coast on a uniform scale five times as large as that of the second series. Such charts are necessarily confined to comparatively short stretches of coast, as Sandy Hook to Barnegat, the entrance to Chesapeake Bay, Mobile Bay, etc. One inch on the paper represents about $1\frac{1}{4}$ statute miles, a scale sufficiently large to give the features of the topography and hydrography with great clearness, portraying the appearance of the coast and the irregularities of the bottom with a detail quite close enough for the navigation of the principal harbors. The fourth series consists of harbor charts on large scales, intended to meet the needs of local navigation. On the Pacific coast the first series is similar to that on the Atlantic coast, and extends from San Diego, California, to Point Barrow, Alaska. The second series is on a scale about six times as large as the first, and is suitable for alongshore navigation, and the inland passages of southeast Alaska. The third series includes charts on scales like those of the fourth series on the Atlantic coast.

All these series of charts are published from the same original surveys, the details of the original work being generalized or omitted to meet the requirements any particular series is intended to subserve. Various methods are available for producing charts of these classes, but experience has demonstrated that on coasts like large portions of those of the United States, which are subject to frequent changes from natural causes, necessitating extensive corrections, engravings upon copper are the most expedient and economical. The engravings afford the additional advantage of being readily duplicated by the electrotyping process. All the standard charts issued by the bureau are therefore copperplate engravings. Preliminary editions, however, are frequently issued by means of the "photolithograph process," which affords a cheap and ready method for temporary purposes.

The Coast and Geodetic Survey publishes about 500 charts, with an annual issue of 97,000 copies.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 12

GRAVITY

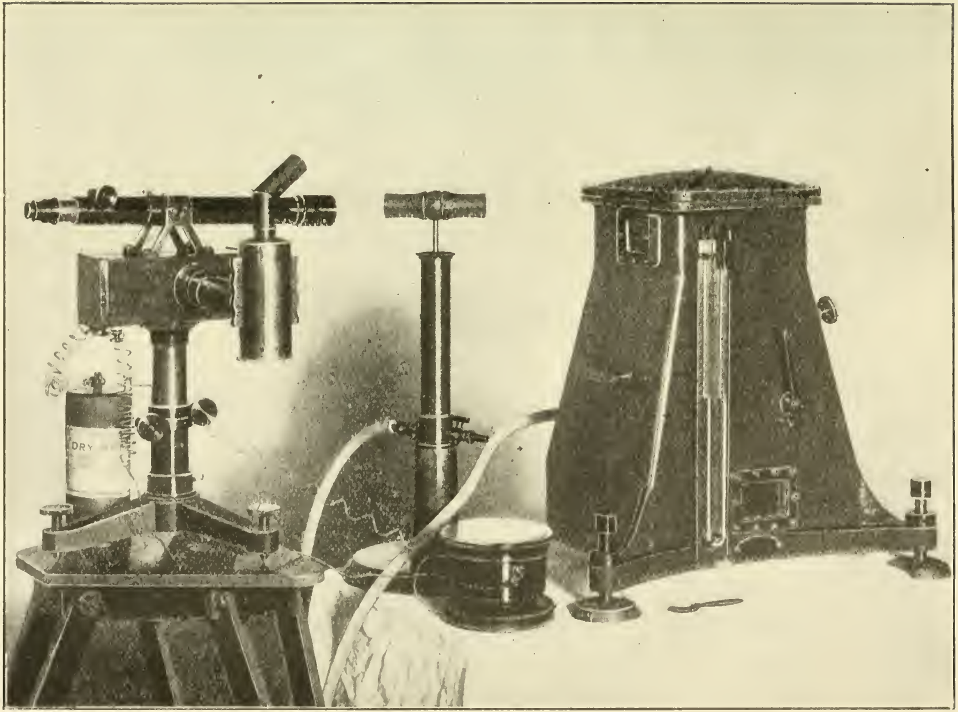
The measurement of the force of gravity is effected by means of a pendulum. Other means have been employed, but the pendulum furnishes the most precise as well as the most convenient way. Ever since Bouguer made his famous experiment at Quito, one hundred and sixty years ago, where a simple piece of brass was suspended by a thread of the aloe, the form of the instrument has undergone successive improvements until we now have a modern type which is compact, very portable, and of the highest degree of precision.

In passing let it be remarked that the first experimental proof of the circumpolar flattening of the earth was obtained by counting the oscillations of a pendulum in different latitudes, and that this operation still holds its supremacy as the best method of determining this important quantity. Not only do the observations accord well with one another, but the results by other methods are coming more and more toward the form set by the pendulum.

Nearly every nation of importance has made gravity work the subject of study, and different shapes have been given to the instrument, according to the object in view and the degree of precision sought. Omitting the earlier experiments, the most prominent types are the invariable pendulums used by the English, French, and Russians for measuring differences in the force of gravity and the reversible ones used by the Germans for absolute determinations. The short forms, which have as yet only been employed for relative work, have been adopted by the Coast and Geodetic Survey and are employed by the Austrians.

The following is a brief statement of the characteristics of the different types.

The Repsold reversible pendulum is designed to measure the absolute force of gravity and at the same time may be used differentially. It is made of brass, and consists of a hollow tube supporting a bob at each end. The distance between the two points of suspension is one meter, and the distribution of matter in the instrument is such that the time of oscillation is the same whether the pendulum is supported at one point or at the other. The supporting parts consist of a steel plane upon which the instrument rests, and a beveled piece, also of steel, firmly attached to the pendulum. These beveled pieces are called the "knives," and are, of course, similiar in construction for both points of suspension. Indeed, they are so made that they may be used interchangeably, and thus eliminate sources of error. The external form of the pendulum is perfectly symmetrical with reference to the center of figure, so that the resistance offered by the air is the same for either position. This is one of the strong points of this form of instrument, as the atmospheric correction is a very important quantity, and one that has given considerable trouble in dealing with absolute measures of gravity. The most prominent defect of the Repsold apparatus is that the tripod is weak and is set in vibration by the movement of the pendulum; moreover, the shape of the latter is such that the air resistance, although the same for both positions, is too great. The accuracy of the determination of the time of one oscillation depends partly on the length of time that the pendulum will swing before coming to rest, and in this respect Repsold's pendulum attains a precision less than half that given by other forms. Part of this apparatus consists of a comparator used in getting the dis-



HALF-SECOND PENDULUM APPARATUS.

tance between the knives in terms of a meter supported vertically near by. To calculate the absolute force of gravity it is of course necessary to know this distance, and it must be determined with an accuracy equal to that attained in the determination of the time of oscillation of the pendulum.

The Repsold pendulum was supplanted in the Coast and Geodetic Survey practice by another pattern, due to C. S. Peirce, Assistant, Coast and Geodetic Survey. This instrument was also intended for absolute measures, but embodied several improvements on the Repsold type. As in the Repsold, the material was brass and the stem was a hollow cylinder, but the external form was less complicated and its greater weight and freedom from irregularities enabled it to swing four or five hours before coming to rest. Two lengths of this instrument were made—one in which the distance between the knives was a meter and the other in which it was a yard. This supplied a new method of comparing the meter and yard through a comparison of the times of oscillation of the two pendulums, and a subsequent comparison of the length of the pendulums with the respective standards.

In 1890 a complete departure was made in the Survey regarding the form of instrument and the method of observation. A small pendulum, one-fourth of the length of those previously used, was constructed as designed by Dr. T. C. Mendenhall, then Superintendent of the Coast and Geodetic Survey, and an elegant method of making the observations, also suggested by him, permits the work to be done with ease and accuracy.

The metal used is a composition of copper and aluminum. The form is that of a flat stem supporting a lenticular bob. The supporting parts are of agate; in one form the beveled piece attached to the pendulum rests on a plane; in another the plane is attached to the pendulum and rests on the beveled piece below. The pendulum swings in a brass chamber from which the air can be exhausted to any pressure desired. The observations are made by noting the time of a coincidence between the beat of the pendulum and that of a chronometer, and the observation of two such coincidences enables one to deduce the period of the pendulum in terms of that of the chronometer. The pendulum is so made that its period is nearly, but not quite, equal to a half second, so that a coincidence occurs every five or six minutes. By an ingenious mechanical device a beam of light is thrown every second into the pendulum receiver, and there falls upon two mirrors, one on the pendulum and the other permanently fixed by its side. When the pendulum is hanging vertically, the two illuminated slits, as seen through the observing telescope, coincide, but in any other position of the pendulum only the one reflected from the fixed mirror is seen, that from the pendulum mirror being thrown up and down, according as the pendulum is on one side or the other of its equilibrium point. When the pendulum from continued swinging has lost or gained a whole vibration on the chronometer, a recurrence of the coincidence takes place and is observed as before. The advantages of this new apparatus are numerous. The support is nearly free from flexure, and the swinging is done in a closed chamber protected from currents of air and rapid changes of temperature. The observations are moreover easily made, the pendulums are very portable, and the accuracy attained is far superior to any hitherto reached.

In order to determine the force of gravity at stations difficult of access it is desirable to reduce the dimensions of the apparatus, as far as this can be done without impairing the accuracy of the results. This led to the construction, some years ago, of pendulums similar to those just described, but having a period of oscillation of one-fourth of a second. Their virtual length was, therefore, one-sixteenth of a meter, or, say, $2\frac{1}{2}$ inches. The transportation of an instrument of this size, with necessary accessories, is an easy matter, and such a pendulum has been swung on the summit of several high mountains, including Pikes Peak. The deduced force of gravity agrees well with that obtained by means of the larger apparatus.

Consult: Volume VII, Mem. Royal Astronomical Society.
Sabine, Pendulum Experiments.
Great Trigonometrical Survey of India, Vol. V.
Clarke's Geodesy.
Bessel's Pendeluntersuchungen.
Reports Coast and Geodetic Survey.
Comptes-rendus de l'Association Géodésique Internationale.

WASHINGTON, D. C., *April 30, 1904.*

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DEPARTMENT OF COMMERCE AND LABOR

COAST AND GEODETIC SURVEY

O. H. TITTMANN, Superintendent

No. 13

GEODESY OR MEASUREMENT OF THE EARTH

It is natural that from the earliest times man should have inquired and speculated about matters concerning the earth upon which he walks and on which he spends his life, but his first crude ideas about its shape and magnitude were not developed up to the point of a fair resemblance to the facts until the civilization of the race had already grown old.

Geodesy is a natural development of the simpler operations of land surveying, which may be carried on without knowing that the earth is a sphere. Land surveying was practiced from a very ancient date. Thus, in a papyrus of a date earlier than 1700 B. C. the author stated that his work was a compilation from older manuscripts. The notion that the earth's surface could not be a plane, but must be curved like the surface of an immense ball, should have been apparent to dwellers upon the seashore; yet the fact that the earth is, roughly speaking, spherical was not appreciated for many centuries after civilization had developed to such an extent that land surveying was practiced. The step from plane to spherical surveying was an important one, and when it was made, geodesy, allied to practical astronomy, became an independent branch of science.

It is the glory of the famous School of Alexandria to have produced, shortly before the beginning of the second century before Christ, the first measure, and a little later a second measure of the earth's curvature—that is, of the radius of the sphere. It is also remarkable that the principle then employed is the same that has been used ever since, although in its application the accuracy has been greatly increased at the expense of the addition of a great mass of details in the methods. Essentially it consists of measuring a long north and south line in feet, miles, meters, or some other unit of length, and of observing the altitude of the sun or of some star as seen from the two ends of the measured line. The difference of the measured altitudes gives the curvature of this arc of the great earth-sphere expressed, say, in degrees. This being known, as well as the length of the arc, the circumference or the radius of the sphere can be computed. After these first measures by the School of Alexandria a thousand years passed before a similar attempt was made—this time by the Arabs in Mesopotamia, about 825. This in turn was followed, after another long lapse of eight centuries extending through the middle ages, by several measures executed by different nations. The principle of triangulation which is used in the refined modern measures was introduced in 1617.

Modern geodesy, as it now exists, began with the discovery of the law of gravitation by Newton late in the seventeenth century, when he proved that the earth, as a revolving and not wholly rigid body subject to its own attraction, must take the form of a slightly flattened sphere. The form thus indicated by theory was apparently contradicted by the measure of an arc in France between 1683 and 1716, which indicated the earth to be an elongated sphere. To settle the matter two memorable expeditions were sent out—one to the equatorial region of Peru (1735–1741) and the other to the polar region of Lapland (1736–1737). Their work proved Newton's theory to be correct, since they found the length of one degree to be greater, or, in other words, the arc flatter, near the pole than near the equator. Since then, in theory and in practice, geodesy has advanced on sure ground and with ever-increasing precision in its results.

Though the early measures of the earth's curvature were made along meridians only, the modern methods of measures and computations are such that the measures made along parallels of latitude, or in an oblique direction, as well as those along a meridian, may be utilized in the determination of the size and figure of the earth.

The same instruments and methods of observing are employed in a triangulation designed primarily as a basis for accurate map making as are used in measuring an arc for the purpose of determining the earth's size and figure. Nearly all geodetic arcs have been obtained incidentally during the progress of surveys made chiefly for practical purposes.

Since the revival and spread of science many surveys of countries, made primarily for mapping purposes and yielding incidentally geodetic arcs, have been carried out in different parts of the world. In making these measures France, Great Britain, Germany, Russia, and the United States have taken leading parts. Among the more recent measures there may be mentioned the Anglo-French arc, extending from the northern part of the British Isles southward into Africa; the great Russian arc, extending from the Arctic Ocean to the northern boundary of Turkey; the great Indian arc, extending from the southern point of India to the Himalayas; the European arc of a parallel, extending from southern Ireland eastward to central Russia; and in the United States, the transcontinental arc, extending along the thirty-ninth parallel from the Atlantic to the Pacific oceans, and the eastern oblique arc, extending parallel to the Atlantic coast from Maine to Louisiana. These six arcs joined end to end would reach about two-fifths of the way around the earth.

The form of the earth as given by the modern precise measurement is found to be such that with considerable exactness any section of it parallel to the equator is a circle and any section passing through both poles is an ellipse. The dimensions and form of this spheroid, or ellipsoid of revolution, as it may be called more accurately, are usually stated by giving its equatorial and polar radii or diameters. The two most notable computations of the dimensions of the ellipsoid are that made by Bessel in 1841 and that made by Clarke in 1866. The latter is used in all the computations of the Coast and Geodetic Survey.

The dimensions of the earth as given by these computations are as follows:

	Bessel. (Meters.)	Clarke. (Meters.)	Bessel. (English statute miles.)	Clarke. (English statute miles.)
a. Equatorial radius	6377397	6378206	3962.72	3963.23
b. Semipolar axis	6356079	6356584	3949.48	3949.79
Difference a–b	21318	21622	13.25	13.44
Compression $\frac{a-b}{a}$	$\frac{1}{299.12}$	$\frac{1}{295.0}$	1 statute mile = 5280 feet = 1609.347 meters.	

More recent measures are not yet sufficiently numerous to make it certain which of the two sets of dimensions given above is most nearly correct. It is probable that the truth lies between them. To appreciate correctly the small amount of flattening at the poles indicated by the above figures it should be noted that if a globe approximately 5 feet in diameter were constructed to scale to represent the earth its equatorial diameter would be but one-fifth of an inch longer than its polar diameter. To the eye unaided by the use of calipers or other measuring instruments this globe would appear to be a perfect sphere.

The following brief statement gives some of the most important facts in regard to the two arcs already completed in the United States. That crossing the country along the thirty-ninth parallel from Cape May, New Jersey, to Point Arena, California, is 2625 statute miles (4225 kilometers) long. The ten base lines in this triangulation have an aggregate length of 53½ miles, one of them being nearly 11 miles in length. Many of the triangle sides in the Rocky Mountain region are over 100 miles long and there is one line of 183 miles over which observations were made in both directions. Some of the triangulation stations were more than 14000 feet above the sea (4300 meters). Many astronomic observations were necessary to fix the position of this arc upon the earth and to determine the true direction of the lines of the triangulation. The latitude was determined accurately at 109 stations, the longitude at 29, and the azimuth or true direction at 73.

The eastern oblique arc extends from Calais, Maine, to New Orleans, Louisiana, a distance of 1623 miles (2612 kilometers). The triangulation contains six base lines. The latitude was determined at 71 stations, the longitude at 17, and the azimuth at 56.

A powerful stimulus to progress in geodesy was given by the formation of the International Geodetic Association, which was founded in 1861 and made international in character in 1886, and of which the United States became a member in 1889. Nearly all the civilized countries are now members of this association. General meetings are held at least once in three years, and the proceedings and publications are widely disseminated.

WASHINGTON, D. C., *April 30, 1904.*

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