happier form of immortality than this—to have added something to the world's store of fact and of law!

Many then are the inspirations of research, and many the satisfactions of the teacher and the investigator. If we keep our view point clear, recognize the many ways in which new facts and new thoughts are garnered, avoid the spirit of pride and intolerance—we can be assured that from our university faculties there will come a spirit of research and of helpfulness that will act as a powerful factor in moving civilization onward and we hope upward.

Ray Lyman Wilbur
Stanford University

CONTRIBUTIONS OF THE UNITED STATES COAST AND GEODETIC SURVEY TO GEODESY[1]

In the earlier days of the Coast Survey, whose centennial is now being commemorated, the geodetic function, as such, was little in evidence. It was then simply an aid in carrying on the work outlined in the Act of 1807, which provided for a survey of the coasts of the United States, in order to provide accurate charts of every part of the coast and adjacent waters.

Upon the reorganization of the Survey in 1843, the cornerstone was laid for that fine system of geodetic works which the Survey has at present. In this reorganization two very prominent features, from a geodetic standpoint, are to be noted. The first is the man who was the dominant figure in the board of reorganization, and the second is the principles he advocated. Probably no other man has had the influence upon the geodetic operations of the Survey as had Superintendent F. R. Hassler, and probably no one thing has been of such importance to these operations as the scientific methods proposed by him. To him belongs the credit that to-day the operations of the Survey are bound together by a trigonometric survey with long lines, and executed by the most accurate instruments, and the most refined methods, rather than being correlated by purely astronomical observations. Due to his far-sightedness, the best of foundations was thus laid for geodetic operations, and from this time geodesy became an important part of the Survey's work.

A further impetus was given to the work when, shortly after the close of the Civil War, Congress authorized a geodetic connection between the Atlantic and Pacific coasts of the United States. The result of this was the great transcontinental arc of triangulation along the 39th parallel of latitude, one of the most famous arcs in the history of geodesy, and one which has helped to place the United States in the front rank of the nations carrying on geodetic operations. One of the immediate results was the recognition of the geodetic function as an important part of the Coast Survey's work, and in 1879 the Survey's title officially became "The Coast and Geodetic Survey."

THE TRANSCONTINENTAL ARC

The great triangulation system along the 39th parallel was probably the greatest single contribution to the world's geodesy that had been made by any one country. It marks an epoch in the scientific history of the United States and in that of the world. The results of the work are most important and far-reaching to geodesy, geography, geology, and the other earth sciences.

It is the longest arc of a parallel ever undertaken by a single nation, being more than 48° of longitude between its extremities, or about one-eighth of the earth's circuit, and is more than half the length of the combined arcs (measured by various

[1] Address given at the celebration of the centennial of the U. S. Coast and Geodetic Survey.

nations), used by Clarke in deriving the figure of the earth in 1880.

The nature of the country traversed by the arc developed new ideas in reconnoissance, signal building, triangulation and methods of computing, which have had an important bearing on all subsequent work. By means of it unity and consistency have been secured in the geodetic work of the Survey. It has proved a bond between the many separate parts of the Survey's work. These, at first, existed as a number of detached portions, in each of which the datum was necessarily dependent upon the astronomic observations. The transcontinental triangulations joined these detached portions and made them into one continuous system dependent upon the same geodetic and astronomic data.

From a higher scientific standpoint this arc is a great contribution to geodesy in giving data for the determination of the earth's shape and size, but like any other arc of a parallel, it must be combined with an arc in the north and south direction to obtain its full power in this respect.

THE EASTERN OBLIQUE ARC

In the Eastern Oblique arc the United States has another arc of note, which covers some 22°, and extends from the Bay of Fundy to the Gulf of Mexico at New Orleans. This was the direct result of Hassler's plans, was the scene of his last labors, and had for its main object the binding together of the detached surveys of the harbors of the Atlantic Coast.

Unlike the transcontinental arc, it has all the elements necessary for the determination of the figure of the earth. It is the first arc which made use, on a large scale, of measurements oblique to the meridian. One of its great effects on the geodesy of the United States was that, through it, came the rejection in 1880 of Bessel's spheroid of reference, and the adoption of the Clarke spheroid of 1866 as the reference spheroid to be used in this country.

ASSISTANT CHARLES A. SCHOTT

Many men took part in furnishing the data for these two arcs, and in the resulting computations, but no name stands forth so prominently as that of Assistant Charles A. Schott, the "Grand Old Man," who for more than fifty years was identified with the work of the Survey. His labors in the field and office did much to bring this work to a most successful finish, and it is fitting that credit be given him for the two monumental volumes of results which it was his privilege to see completed before death came. For this work, and for the work done in many other lines of the Survey's activities, I do not hesitate to mention the work of Mr. Schott as one of the great contributions made by the Coast and Geodetic Survey to the geodesy of the world.

The Survey was particularly fortunate in having such a man in charge of geodetic work; one who could see the full wisdom in the plans of Mr. Hassler, who consistently worked for their fulfilment, and who was able to have these plans transmitted to his successors, Assistant John F. Hayford and Assistant William Bowie. This furnished a continuity of plan which probably stands unrivaled in the scientific history of the world, and has been one of the big factors in the great success attendant upon the geodetic operations of the Survey.

RECENT TRIANGULATION

Since the completion of the arcs mentioned, the Coast and Geodetic Survey has added many more arcs to its system, until the total length of the combined arcs is more than 150° of a great circle of the earth, or about three sevenths of the circuit of the globe. Incorporated into the system

and placed on one datum are also the many miles of coast triangulation of the Survey and much of the triangulation executed by the Lake Survey and by the U. S. Engineers, until now the system stands without an equal in any nation.

In the closing years of the last century a new era in geodetic operations by the Coast and Geodetic Survey was begun. The work of the past was searched for the best in instruments and methods, field and office methods were standardized, limits of accuracy were set, and where it seemed advisable new methods and instruments were devised to meet the changing conditions of the work. This era may be characterized as a period of great speed and low costs.

Never before had triangulation been executed with such rapidity and with such economy in operations. It is significant that this was attained without a reduction in accuracy, and in fact had the effect of an ultimate increase in accuracy, for, owing to the speed, many more circuits could be added to the network, thus strengthening the whole system.

As an example of the speed and economy of operation in this last period the Texas-California arc of about 20° is cited. The reconnoissance on this arc was done by two men in 145 days and the primary observations in a total of 183 days at a cost of $400 per station and of $32 per mile of progress. Nearly 50 years were spent on the transcontinental arc of 48° with a cost of $2000 per station and $200 per mile of progress. This comparison is not intended to be derogatory to the latter arc, for the work on that arc was the best of any up to that date, and it was only through its work that the economy and speed of the later work was made possible. It is believed that no extensive arc in any other country equals the Texas-California arc or some of the other recent arcs of the United States, in these respects.

Since about 1900, practically all of the reconnoissance and signal building has been in the hands of one man, Signalman Jasper S. Bilby, who as an expert along these lines probably stands unrivaled in the world to-day.

THE UNITED STATES STANDARD DATUM

A direct and far-reaching geodetic movement of influence, not only to the United States, but also one of great importance to the North American continent, and also to the whole world, was initiated in the adoption by the Survey (in 1901) of the United States Standard Datum. It placed the geodetic work of the Survey on one datum for the correct coordination of the geographic latitudes, longitudes, distances and azimuths. From the scientist's standpoint it furnished accurate correlation of data for a study of the figure of the earth, of isostasy, and for other related sciences.

By its adoption, as the Standard Datum for geodetic operations in Canada and Mexico, it became a matter of international importance and consequently its designation was changed by the Survey in 1913 to that of the "North American Datum." Plans are now under way for carrying the primary triangulation of the United States and Canada to the Yukon, and the prediction is here made, that eventually the fifty miles which separate Alaska from Siberia will be spanned, and a junction be effected with the great systems of Asia, Europe and Africa. Then with the extension from Mexico through Central and South America, the data will be available for a "World Datum," and the final word will have been said in the geodetic work of the earth.

BASE LINE MEASUREMENTS

Closely related to, and forming an integral part of the triangulation executed by the Coast and Geodetic Survey, is the meas-

urement of the base lines for controlling the lengths in triangulation. In this work the Survey has furnished much of interest and of value to the geodesist. Ever has it kept keenly before it the necessity for refined measurements, and many valuable devices to accomplish this desired result have been added by members of the force.

BASE BARS

The Duplex bars, invented by Assistant William Eimbeck, are probably the best form of base bars ever devised and gave a very high degree of precision. But they were soon replaced by the tape as a form of base apparatus.

The only bar used in the United States, and probably in the world, which gives entire satisfaction, so far as accuracy is concerned, is the iced bar, designed by President R. S. Woodward of the Carnegie Institution when an assistant in the Survey. Owing to the great cost per kilometer of base of using this form of apparatus for field work, when compared with the cost of using tapes, the iced bar is now used only for standardizing other apparatus, and for this purpose it remains unexcelled.

STEEL TAPES

In the Coast and Geodetic Survey the tape has supplanted the other forms of base apparatus. Credit for the introduction of steel wires and tapes for this purpose must be given to Professor Jaderin of Sweden, but it was the accurate and extensive investigations made by Assistant Woodward in 1891 which caused the adoption of tapes by the Survey. He proved that steel tapes, when used at night, and standardized under the same conditions that prevail during the base measures, gave essentially the same high degree of accuracy as the Duplex bars, with about one third of the cost and with far greater rapidity. It is practically certain that no more base lines will be measured by base bars, at least in the United States, except when it is necessary to standardize the tapes.

The remarkable measurement of nine base lines in one season, in 1900, by a single party constitutes a noteworthy achievement. The nine bases had a total length of 43 miles and furnished a control of over 1,000 miles of triangulation. In order to eliminate constant errors five different sets of apparatus were used, and an average accuracy corresponding to a probable error of 1 part in 1,200,000 was secured. With this work a new epoch in base line measurement was introduced, for it proved, through the most rigid of tests, that the tape had no superior for speed, economy and ease of manipulation.

INVAR TAPES

In the use of invar tapes, base measuring took another long step forward. Many severe tests have fully proved their excellence. They are found to possess practically all of the good features of the steel tapes, but have the added advantage that they enable bases to be measured in the daytime and even in the sunny days, a fact due to the small coefficient of expansion of invar, which is only about one thirtieth that of the steel tapes.

Recently the plan has been adopted of having the bases measured by the triangulation party. By it base measurement has become simply an incident to the triangulation, and the cost has been reduced to about $60 per kilometer, a sum which is in great contrast to about $300 per kilometer with the Duplex bars.

PRECISE LEVELING

Practically all of the great nations of the earth have been actively engaged upon the difficult problem of determining the cor-

rect elevation of points far from their coast. It is a work which demands the highest degree of accurate observing and painstaking endeavor. It calls for especially designed instruments and methods of observation. These accurate elevations are needed for the reduction of base lines to mean sea-level, for engineering operations of wide extent, and for the solution of scientific problems concerning gravity, the tides and other work.

In this leveling of precision, the Coast and Geodetic Survey has added much to the world's work by attainments in field operations, methods of reduction and scientific study of errors involved. In its great precise level net (greater than that of any other nation) there are more than 15,000 bench marks, of which the elevations have all been accurately fixed through a single least square adjustment of more than 80 circuits with a total length of more than 25,000 miles.

THE COAST SURVEY LEVEL

Among the instruments of precision employed by the nations for precise level work, it may be truly said that none holds a higher rank than the type which has been in use in the Coast and Geodetic Survey since 1900. This level was designed and built within the Survey, and after more than fifteen years of constant service, in all parts of the United States, has shown itself to be indeed a superior instrument for accurate and rapid leveling.

Before the introduction of this level, the average rate of progress was less than 60 miles a month. Recent work, which is of much higher grade of accuracy, shows an average of nearly 80 miles; and one observer with a party of six men, last season completed 120 miles of progress, or more than 250 miles of single line in one month, which constitutes a world record.

Although precise leveling has been brought to the highest perfection in France, the Coast and Geodetic Survey, by the very magnitude of its operations, by the instruments employed, and by the economy in speed and cost, is certainly without an equal in the geodetic world.

ASTRONOMIC DETERMINATIONS

Considering astronomy as a definite part of its geodetic function, the Survey has added to the work done by the various nations many hundreds of astronomic latitude, longitude and azimuth determinations, mostly at stations connected directly with the great triangulation system. While no great changes have been introduced in latitude and azimuth work as far as instruments are concerned, there has been a decided change in speed and economy. Methods of observing and of computing have been standardized and this has greatly aided the work.

Since about 1904 all of the primary azimuths, in so far as was practicable, have been observed by the triangulation party during the progress of the work. It is believed that this plan gives the highest degree of accuracy, for the measurements are made under exactly the same conditions as the triangulation with which they are concerned, and the cost is very materially reduced.

TELEGRAPHIC LONGITUDES

The formation of the great telegraphic longitude net of the Coast and Geodetic Survey is a geodetic feat worthy of special note. No less than four transatlantic determinations have been made which serve to connect the longitudes of the United States with Greenwich and Paris, and more than 50 stations are included in the net which covers this country. Finally, through a transpacific determination made by the Survey, supplemented by a similar one

made by Canada, the last link in the telegraphic longitude circuit of the globe was completed, and thus nearly all of the longitude observations made in the world are united into one great single system, accurately correlated through this circuit.

THE TRANSIT MICROMETER

Among improvements made by the Survey to the instrumental equipment used in astronomic work only one will be mentioned. This is the transit micrometer used in the determination of time by stars at meridian passage. Although the transit micrometer had been in use at fixed observatories, it was not until the investigations made at the Coast and Geodetic Survey, in 1904, that its adaptability to portable transits was thoroughly proved. The many tests it has had in actual field work have shown for it many features of excellence. With its use, the relative personal equation between two observers is so small as to be masked by the accidental errors of observation and is certainly not more than one tenth as large as the average using the key. No interchange of observers is necessary, and the time of the determination of a difference of longitude is about one half the time taken by the older method.

THE FIGURE OF THE EARTH

The very important problem of determining the shape and size of the earth is probably the climax, from the scientific point of view, in the geodetic work of the Survey.

Reference has already been made to the use of the arcs of triangulation in determining the figure of the earth. When many arcs, both meridional and latitudinal, are all joined together on the same trigonometric and astronomic basis, the area method, developed in the Coast and Geodetic Survey since about 1901, is, without doubt, far superior to the arc method. In it are all of the features of the arc method, to which many important new features are added. Using the great system of triangulation in the United States to furnish the area factor and the many astronomical measures connected with the system to furnish the curvature factors, a value for the figure of the earth was derived which is of a very high degree of accuracy. The investigations and results obtained in this work are noteworthy contributions to geodesy. Some of the prominent features of this investigation are shown in the wide area treated, the large number of astronomic observations involved, and the unusual methods of computation used. Topographic irregularities within 4,000 kilometers of each astronomic station were considered, and account was taken of possible distribution of density beneath the surface of the earth. These features, together with the actual results obtained, make this a monumental work.

By a study of the station errors, or deflections in the verticals, which were developed when the astronomical and geodetic measures were compared, evidence was brought forth which established the fact that the condition of isostasy exists in the earth—a fact which is of interest and value to geodesy and geology.

These studies of the figure of the earth and isostasy have attracted the attention of the scientific world. Dr. Woodward, the distinguished geodesist, is authority for the statement that the work done by the Coast and Geodetic Survey on isostasy is the greatest contribution to geodesy since the time of Bessel and Gauss.

GRAVITY MEASURES

Another method of attacking this important problem of the earth's shape and size is by the use of the pendulum in the determination of gravity. The contribution of

the Coast and Geodetic Survey to this field of geodesy are given in the results of more than 30 foreign stations and of nearly 200 stations in the United States.

Happily the gravity conference held in 1882 endorsed the plan of using the invariable pendulum, and of employing the differential method of carrying on gravity work, and the Survey's present excellent equipment and methods are the direct results. In its present type of apparatus, known as the Mendenhall pendulums, the Survey has a form which for compactness, portability, precision and ease of operation ranks well among the highest in this field of endeavor.

Two features in recent gravity work are worthy of note. One is the application of the interferometer to the measurement of the flexure of the pendulum support, thus giving a direct measurement of this small quantity in terms of a wave-length of light. It is believed that the resulting corrections to the period of the pendulum are more accurate than those by the older static method where the corrections were derived under exaggerated conditions. The interferometer has been in use for about 8 years as a field instrument, and determinations of the flexure have been made at about 140 gravity stations, through a very wide range of conditions in piers and external vibrations.

The second feature worthy of note in recent gravity work is the deriving of the rate of the chronometers by Western Union time signals at noon—a distinct advantage over the older method. By it the local time observations are dispensed with, the time of occupation of a station is decreased and the labor of preparing the station greatly lessened, all of which contribute to a lowering of the cost per station occupied. In connection with this it is interesting to note that Assistant Schott in 1882 made the statement that

> Time furnished telegraphically by an observatory whose clock is protected from changes of temperature and pressure will be preferable to any local determination at a field station.

FIELD AND OFFICE FORCE

Little has been said of the men who have composed and do now compose the field and office force of the Coast and Geodetic Survey. What the Survey is and accomplishes is due to these men, and to the spirit which influences them. To them must be given the credit for much that the Survey has contributed to geodesy. It would be difficult to find a body of men of greater enthusiasm for, or a higher scientific attitude toward their work. They have a careful devotion, to duty and an interest in the success of the Survey and its work, a fact which has developed a corps of workers of unrivalled excellence.

They have ever been most alert to adapt new discoveries, made in the various fields of science, to the needs of the Survey, and to plan new and improved instruments; while to the theoretical work of geodesy they have added much by critical discussion and extensive study of results.

Workers must have tools, and this fine body of skilled observers would be seriously handicapped in their work if suitable equipment were not furnished them. The Survey is particularly fortunate in having a body of skilled artisans in the Instrument Division, under the supervision of a most highly efficient officer. In this division there have been designed or built nearly all of the instruments of precision which have helped so materially to place the Coast and Geodetic Survey in its present high position.

Of the relation of the geodetic work of the Survey to that of the world, as shown by its share in the operations of the International Geodetic Conference, only slight reference is here made, for this subject is dealt with in another address by the former

Superintendent Tittman who is much more capable of addressing you on this subject.

In the foregoing, the endeavor has been made to give some idea of the contributions which the Coast and Geodetic Survey has made to geodesy. Of necessity much has been omitted, but what has been given will bear witness that the world's geodesy has been greatly enriched by the work of the Survey.

A test of the greatness of the geodetic work of the Survey may be had in a review of the comments made by prominent men in other organizations and countries, by men who are well qualified to judge. They all accord to the geodetic work of the Survey a very high place in the geodesy of the world. One comment only will be here given as a fitting close to this brief review of the contributions made by the Coast and Geodetic Survey to geodesy.

Commandant Perrier, the French geodesist, in speaking of the work of the Survey, says:

> There is no example in the history of geodesy of a comparable collection of measurements, made with so much decision, such rapidity and such powerful means of action, and guided by such an exact comprehension of the end to be attained.

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PITTSBURGH'S FIRST CHEMICAL SOCIETY[1]

IN *The Commonwealth,* a Pittsburgh weekly newspaper, of November 4, 1811, there was an advertisement to the effect that Dr. Aigster would deliver an introductory lecture on chemistry, Wednesday, November 6, at 3 P.M. in the grand jury room at the Court House. The advertisement concluded with this striking sentence:

> All friends of science will be gratuitously admitted.

The Pittsburgh Gazette, of December 20, 1811, carried the following advertisement:

> The subscribers to Dr. Aigster's Chemical Lectures are informed that the regular lectures will begin on Monday, the 16th of December, at the Laboratory, corner of Smithfield and Second Streets, at 3 o'clock P.M., to be continued from that time every Monday, Friday and Saturday at the same hour and at the same place. Further subscription will be received at the Laboratory.

That Dr. Aigster was not unlike many modern lecturers on scientific subjects is seen from an announcement in the *Gazette* of December 27, 1811, that Cramer, Spear and Eichbaum had just published a discourse, introductory to a course of lectures on chemistry, which included "a view of the subject and the utility of that science, delivered at Pittsburgh on the 6th of November by F. Aigster, M.D."

There is a copy of this discourse bound with Cramer's Pittsburgh Magazine Almanacks for 1816 and 1817 in the Carnegie Library of Pittsburgh. The lecture discusses in the words of Dr. Aigster, "the application of chemical knowledge in private and social life." It describes the applications of chemistry to agriculture, mining, cloth making, glass making, brewing, tanning, paper making and, last but not least, to cookery.

Some of Dr. Aigster's statements sound as if his lecture were delivered yesterday. Witness this:

> The time is come when America can shake off the yoke of foreign dependency for a number of the most necessary wants, whose first material, bountiful nature has scattered with lavish hands over this country.

And this:

> A laudable beginning has been made in the wool, flax and cotton manufactures. But it can never be expected that they will attain any high degree of improvement as long as the art of dyeing, which is altogether chemical, is not attended to.

[1] This paper was read before the Historical Society of Western Pennsylvania on January 25, 1916.