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*THE WORK OF THE COAST AND GEODETIC SURVEY.**

IT is a high privilege to address you today on the work of the oldest bureau of applied science under the government, a bureau which invokes the aid of science in its intensely practical work, where theory and practice go hand in hand. It seems reasonable to hope that some inspiration may be drawn from an account of its work, by young men who are about to take up the pleasures and burdens of a share in the world's work after going forth from an educational institution which announces as the underlying principle which controls its method, the advance of the practical, side by side with the scientific. It is particularly pleasant to speak of the survey in a locality where such familiar names as Lovering, Bowditch and Pierce will be recognized as among those who helped it in its earlier struggles for recognition, and that of a statesman like Charles Sumner as one of its staunch supporters, those of Louis and Alexander Agassiz, who utilized the opportunities afforded by the survey to further the aims of science and to add luster to the fame of its work by their association with it, and where it will be remembered that if Massachusetts gave a Peirce to the survey, the survey gave a Mendenhall and a Pritchett to Massachusetts.

* Commencement address delivered before the Worcester Polytechnic Institute.

THE SURVEY'S PLACE UNDER THE GOVERNMENT.

On the first day of next month the Coast and Geodetic Survey will be transferred from the Treasury Department, of which it has been a bureau since 1836, to the newly created Department of Commerce and Labor. This is in accordance with the logic of events. As long as the fiscal department of the government was charged with matters pertaining to commerce the survey found a proper place there, but when the new department was created with functions especially designed to care for the interests of commerce, the survey, being primarily devoted to the interests of commerce, necessarily became a part of it.

The Coast and Geodetic Survey is charged with the survey of the coasts of the United States, including Alaska, and all coasts under the jurisdiction of the United States; the survey of rivers to the head of tide-water ship navigation; deep-sea soundings; temperature and current observations throughout the Gulf Stream and Japan Stream flowing off these coasts; tidal observations, magnetic observations and gravity research; determinations of heights by geodetic leveling, and of geographical positions by lines of transcontinental triangulation which, with other connecting triangulations and observations for latitude, longitude and azimuth, furnish points of reference for state surveys and connect the work on the Atlantic with that on the Pacific coast.

The results of the survey are published in the form of annual reports, which include professional papers of value; bulletins, which give information deemed important for immediate publication; notices to mariners showing changes on charts and reported dangers affecting them; tide tables issued annually in advance; charts upon various scales, including harbor charts, general charts of the coasts and sailing charts, chart catalogues and coast pilots.

ITS GEOGRAPHICAL DOMAIN.

Such in general are its present duties, but when the survey was first planned the coasts under contemplation extended only from the eastern boundary of Maine to the northern boundary of Florida, and on the Gulf coast the shores of the Louisiana Purchase marked the limits of the survey's authority; later on its duties were extended to keep pace with the expansion of the country to the Floridas and the whole of our present Gulf coast, to Oregon and California, to Alaska, and still more recently to the Hawaiian Islands, to Porto Rico and to the Philippines. With the acquisition of Oregon and California and the prosecution of surveys of their coasts arose the necessity for a trigonometric connection between the work on the Atlantic and Pacific coasts, and Congress authorized the extension of the triangulation inland for that purpose, and for the purpose of aiding topographic and state surveys.

The acquisition of the vast territory of Alaska added greatly to the duties of the survey. Beginning at the historical parallel of fifty-four forty, which the popular cry of 'fifty-four forty or fight' demanded as the northern limit of our Pacific coast possessions, the coast of Alaska stretches northward, including the great archipelago which ends at Cape Spencer. Northward of that is Yakutat Bay and Prince William Sound. The latter is assuming commercial importance and is, therefore, now the locality in which the survey is especially active. Farther north is Cook's Inlet, a great bay where the phenomenal rise of the tide, which yet remains to be investigated, rivals or exceeds that of the Bay of Fundy.

North of the Alaskan peninsula the Kuskowim River empties into the Bering

Sea. This large river has its head waters at the base of Mt. McKinley, the highest mountain on our continent, and among Alaskan rivers is second only to the mighty Yukon, whose desolate delta the survey has already charted. No matter how inhospitable the shores, how rugged and forbidding, they will not challenge in vain the skill and daring of our surveyors, as was foretold by Charles Sumner in his speech in favor of the acquisition of Alaska, in which he alluded to the Coast Survey as follows: "An object of immediate practical interest will be the survey of the extended and indented coast by our officers, bringing it all within the domain of science, and assuring to navigation much needed assistance, while the republic is honored by a continuation of national charts, where execution vies with science and the art of engraving is the beautiful handmaid."

The Aleutian Islands, with their towering volcanoes and rugged and bold coasts, stretch westward for twelve hundred miles from the Alaskan peninsula and need yet to be accurately charted. This chain of islands lies along the shortest route from Puget Sound to the Philippines, a route which has already been followed by a ship of the survey in transferring its activities from the sub-arctic waters of Bering Sea to the tropical waters of the Philippines.

In this new domain the survey has another extensive field of operations. For in general the surveys which were made prior to the coming of the Americans are lacking in accuracy and reliability, and are not at all suited to meet the wants of an active commerce. The Philippine archipelago stretches northward from about latitude 5° to 21° and through about ten degrees of longitude, and the intricate shore line of its islands surpasses in length that of the United States proper. Our Samoan island possessions and Guam remain to be surveyed, but in the Hawaiian Islands the most needful work has been accomplished. The size of the Philippines will be better understood by comparison with an island with which we are reasonably familiar. Five islands in the Philippines are as large or larger than Porto Rico, and two of these each about ten times as large.

To Porto Rico the survey promptly extended its work, for, almost before the smoke of battle had cleared away, Admiral Sampson called for accurate surveys of the coasts of Porto Rico in a telegram addressed to the Secretary of the Navy, who requested the survey to begin the charting of its coasts. The work was at once inaugurated, with surprising results. Harbors which had been unknown to the cartographer were discovered, surveyed and mapped. A triangulation was extended around the island and as far eastward as the Danish island of St. Thomas, across the Virgin Passage, famous as the principal entrance into the Caribbean Sea, and near which lies the winter rendezvous of our navy. All the principal harbors have been charted and the results given to the world. One of the interesting results of these surveys is that cartographically the northern shore of the island was moved southward half a mile and the southern shore northward by the same amount. The cause of this is that the visible island of Porto Rico is really the summit of a mountain whose slopes extend to great depths below the adjacent seas. The results of observations for latitude made on the north and south sides of this summit are affected by local attractions of mountain masses which cause deflections of the plumb line and which must be taken into account in charting the island.

ITS GEODETIC FUNCTION.

When the inauguration of the survey was under discussion at the beginning of the

century it was held an open question by some whether the work should be coordinated by purely astronomical observations or whether it should be based on a trigonometric survey, and happily the latter method was chosen and prescribed.

From carefully measured bases chains of triangles were to be extended along the coasts. Their direction and geographical location were to be determined by astronomical observations. The skeleton of triangles was to be clothed by the topographer, who should delineate the topographic features as far as might be necessary for commerce and defense. By making proper use of the trigonometric and topographic features thus determined the hydrographer would follow and sound the depths of the waters, develop the channels fit for safe navigation, discover all hidden dangers, measure the tides and the currents, and thus furnish what was needful for a safe chart. As a matter of fact, this sequence of work, though it is of necessity observed in local surveys, was never followed when the Coast Survey as a whole is considered. The rapid commercial development of this country made it necessary to meet particular demands in some localities at once, leaving others of lesser urgency to be dealt with later on, but the general scheme of proper coordination by a principal triangulation was never lost sight of, though the latter oftentimes followed long after the local surveys had been made. This experience is being repeated in Alaska and particularly in the Philippine Islands, where the survey is constrained by the needs of commerce to make surveys here and there, wherever routes of travel or anchorages have to be developed, leaving it to the future progress of the survey to coordinate all this work.

The distances of the stars, the sun and the moon from the earth as we know them have all been measured, to use the language of a former astronomer royal of England, by means of a yard-stick. For the purpose of this illustration it is immaterial that the particular yard-stick of this survey is the meter. The point is that with a short bar we measure a relatively long base, from this we extend a triangulation over relatively much longer distances, from these distances we deduce the size of the earth and its diameters and thus have found the basis of all dimensional astronomy. The triangulation of the Coast and Geodetic Survey, therefore, subserved not only its immediate purpose of serving as a basis for accurate charting of the coasts, but contributed by its great extension to a knowledge of the earth's dimensions and figure, a problem which has occupied the mind of man since Eratosthenes, 300 B.C., to the present time. For the survey has completed a triangulation from Eastport, Maine, to New Orleans, Louisiana, a distance of 2,400 kilometers, and another from Cape May to San Francisco along the 39th parallel, a distance of over 4,000 kilometers. It is just now engaged in extending another great chain of triangles, which has been measured between the southern boundary of California and a point beyond San Francisco, towards Puget Sound, where in turn it will be connected with our northern boundary. Along the 98th meridian also a chain of triangles is being measured, and it is hoped that the Republic of Mexico on the south and Canada on the north will prolong its measurement through their respective domains. Branching from this meridian a line will cross to the eastward to connect with the admirable triangulation of the Lake Survey which has already been connected with the primary triangulation of the Coast and Geodetic Survey in other places.

The great triangulation already com-

pleted has been adopted as a standard of reference for all future trigonometric work of the survey in so far as purely geographic and topographic purposes are concerned and this great country will soon have a homogeneous system of geographical coordinates which will serve, it may be confidently believed, for all times to come, the manifold uses to which it can be put by the national government, by the states and municipalities and by engineers and surveyors.

Intimately connected with the question of the dimension of the earth is that of its figure, and here the pendulum will play an important part. The earlier work of the survey with the pendulum has its chief value in showing the limitations of the methods and appliances used. Much simpler and more reliable apparatus was introduced some years ago and has given satisfactory results. The apparatus was used not only in relative gravity observations in this country but for the purpose of connecting our own base station with the English and continental ones, a work which was rendered possible by a subvention from the International Geodetic Association. At the present time no gravity work is being done, it being deemed advisable to study the deflections of the plumb line as brought out by a reduction of the triangulation to a common system. When that has been done the pendulum may perhaps serve to indicate relations between any anomalies that may develop in particular localities and the force of gravity in the same regions.

Closely related to these geodetic features of the work of the Coast Survey are the astronomical determinations and especially the determinations of telegraphic longitudes. Long ago the survey determined the difference of longitude between Europe and this country by means of the Atlantic cable. It has covered this country with a well-adjusted network of stations and is now stretching its determinations westward across the Pacific. The longitude between San Francisco and Honolulu is being determined while we are gathered in this hall, and the observers are getting ready to meet the new cable at Guam within a few weeks in order to extend the work to Manila. Manila has been the base station for our observers in the Philippines, who have been for two years busily engaged in utilizing the local cables and land telegraph lines for similar purposes. The geographic explorations in Alaska, the boundary question and the surveys in that territory call for further and immediate extension of this work there. But it requires no great stretch of the imagination to believe that the wireless method of sending signals will at no distant day make us independent of cable or telegraph lines as far as longitude work is concerned, and for this purpose the method would be an ideal one. Last summer, as an experiment and with short-distance instruments, a chronometer on one of the survey vessels transmitted automatically its half-second beats to a shore station over sixty miles away, where they were received and automatically recorded on a moving tape.

In the leveling of precision we have still another class of work belonging to the geodetic function of the survey. Here the aim of the survey is to furnish a series of primary bench marks properly related to the mean sea level of the Atlantic, Gulf and Pacific coasts which shall serve to correlate the thousands of miles of levels which have been and are being run by the railways, the canal enterprises, the Geological Survey and the engineers of the United States Army for many different purposes, but all for the common good. It is pleasant to record that through the cooperation

of the other government surveys concerned, their results are all being placed at the disposal of this bureau for the purpose of including them in a general adjustment by which a homogeneous system of vertical coordinates for the whole country can be established which shall stand side by side with geographical coordinates before referred to.

THE DATA FOR A CHART.

The geodetic functions of the survey have been dwelt upon in this address at some length because their precise nature and great usefulness are not commonly understood, but the administration of the survey has always remembered that the survey owes its existence to the urgent need for reliable charts of the coasts. Their importance to commerce is apparent. The vast sums which every civilized nation is expending in improving its facilities for commercial intercourse are sufficient evidence that everything which can be done to promote the safety of navigation must be done. Every civilized nation also recognizes the fact that this is a duty which it owes not only to its own citizens, but to the world. As an evidence of this consider the lighthouses which flash their friendly warnings or guiding welcome to ships in all parts of the world, the buoys which mark dangers along channels, the sounding sirens which cry their caution through the fogs, the storm signals which are displayed, the sturdy life-savers who patrol the coasts and the guiding charts with which this survey is mainly concerned.

On the open ocean the chart has its least value, for the dangers to which the mariner is there exposed are not such as can be remedied by a chart. Storms, fogs and collision with other ships in the lanes of travel are dangers to be apprehended, but the knowledge that there is deep water under the keel of the ship is a source of comfort to the mariner, however risky it may appear to the landsman. The story of the darky who compared the dangers of a sea voyage with the safety of railway travel is familiar to all: "If the ship sinks whar is yo, but if the train gits smashed dar yo is," illustrates one point of view, but that of the sailor is told in rhyme which the refined muse of the Worcester Polytechnic may not know and is therefore cited here:

> Foolhardy chaps as lives in towns,
> What danger they are all in,
> And now lie quaking in their beds
> For fear the roof should fall in.
>
> Poor creatures, how they envies us,
> And wishes, I've a notion,
> For our good luck, on such a night
> To be upon the ocean.
>
> * * * * * * *
>
> While you and I, Bill, on the deck
> Are comfortably lying,
> My eyes! what tiles and chimney-pots
> About their heads are flying.

But when the ship nears the coast a burden of great responsibility rests upon the navigator, for on his skill, experience and knowledge the safety of life and property entrusted to his care depends. He turns to the chart and follows the path marked out for him by the skill of the surveyor. When the depth of water is great as compared with the draft of vessels, the problem of the hydrographer is comparatively simple, but where it decreases so as to exceed not very much the draft of vessels, the problem of finding every hidden rock, every coral pinnacle or shoal, requires an immense amount of work and minute accuracy in the soundings and locations. Imagine to yourselves a totally submerged city and solve the problem of finding every chimney, every steeple, every house top and every street by means of a sounding lead, and you will have a good illustration, even though it be a slightly exaggerated one,

of the difficulty of making an accurate hydrographic survey in regions where the coral rocks rise in pinnacles from relatively great depths with appalling suddenness. As a concrete example take a small area about 400 square miles lying between Porto Rico and St. Thomas, a region used by our fleet for its maneuvers, and consider what it means to find with the lead every hidden coral rock or reef which might cause the destruction of a seven-million-dollar battleship.

Not only must the depths be correctly shown, but as a further aid to navigation the characteristics of the bottom must be indicated, and there are places on the Atlantic coast where the nature of the bottom, as disclosed by the material which is brought up by the sounding-lead, is so characteristic of the particular locality that it tells the navigator the exact position of his ship.

When the triangulation and topography are complete, and the channels and general configuration of the bottom have been developed and charted in their true relation to the natural or artificial objects on shore which guide the navigator, yet is the chart not complete. The rise and fall of the tide as affecting the indications of the chart must be known at any time in present and future. To the difficult problem of the tides the survey has also addressed itself, and permanent stations are maintained which record automatically the stages of the tide. The information furnished by them is supplemented by shorter series of observations made at intermediate places by our own surveying parties or by others. The commerce of this country, however, knows no geographical boundaries, and the survey collects and publishes annually in advance a volume giving predictions for nearly all the ports of the world.

Another branch of the survey which covers a broad field of observation and research is that of terrestrial magnetism, represented on the chart by compass diagrams. In order to draw them correctly and by means of them to show the amount of the variation of the needle at given localities, the magnetic elements have been investigated from the earliest days of the survey. At first these investigations were inaugurated in the interests of the mariner alone, and confined to the neighborhood of the coasts, but as years passed the demands made on the survey for more information required their extension to the whole area of the United States and beyond. The intimate relation of the compass to property surveys is the chief case in point. The rerunning of the boundaries of old estates, the interpretation of old deeds in litigation, require a knowledge of the amount of the needle's variation in the present time and the means of computing its direction in the past. In the more delicate work of the electrical engineer the earth's magnetic elements have also to be taken into consideration. Side by side with the practical requirements the scientific phase of the subject has been kept in view, with full faith in the belief, which is based on the history of science, that the things which to-day are speculative and abstruse will to-morrow belong to the commonplace applications of science to the daily wants of the community. The survey now maintains a small magnetic observatory in Porto Rico; a complete and modern one at Cheltenham, Maryland; another at Baldwin, Kansas; one at Sitka, Alaska; and yet another near Honolulu in the Hawaiian Islands. We may hope, therefore, that the United States will contribute no small share towards finding the mysterious cause of the earth's magnetism, or at least in furnishing the data necessary for a more

perfect understanding of the laws which govern its manifestations.

How the information gathered by the various branches of the field work is utilized in the office and prepared for publication belongs to another chapter which can not be read to-day. Nor will time permit a reference to the mechanism of its organization. What the survey is and does is due to the men who composed its working force in the past and who compose it in the present, and, therefore, this fragmentary account may be fitly closed with a brief reference to the men who carry out its field work.

While there is a proper amount of specialization which leads to excellence in particular branches of work, the field officers hold themselves in readiness to perform any kind of duty which may be required of them. It may be to pack a mule train or to command a ship, to pitch a camp or outfit a vessel, to sound along the edge of resistless breakers, to climb glaciers or to break through tropical jungles, to guide vessels through uncharted dangers or men along a mountain trail, to look after the health of their men in all climates, to provide months in advance for supplying them with food in regions where none can be purchased, to build structures which shall tower over tall trees of the western forests in order to see distant stations, to observe the stars by night, to watch the swinging pendulum for the determination of gravity, to measure the forces of the earth's magnetism, to note the tides and currents, to sound the waters of the ocean, to map the topography of the land, to trace international or state boundaries, to cover the land with a network of triangulation, or to join their no less zealous co-workers in the office in the reduction and discussion of results. Long as this recital of their occupation may seem, it is but a tithe of what might be said. Surely the merest contemplation of these duties shows how high the calling of the men who must perform them, and if high thinking and plain living and a life of deeds are things which deserve admiration, they earn it day and night, year in and year out.

Perhaps the zeal and devotion to duty is born in part of the difficulties which men must overcome in the accomplishment of a great purpose. But to whatever it is due, it appears to be common to the craft, as appears from the tribute paid to the British surveyors by the historian of the Great Trigonometrical Survey of India, a tribute which is cited here for the glory of the engineering profession.

"It is and has been a very noble band, that body of surveyors who have been trained and have worked under Lambton, Everest, Waugh and Walker. It is no small honor to be at their head. These men must combine the knowledge and habits of thought of a Cambridge wrangler with the energy, resource and presence of mind of an explorer or backwoodsman, and they must add to this the gallantry and devotion which inspire the leaders of a forlorn hope. The danger of service in the jungles and swamps of India, with the attendant anxiety and incessant work, is greater than that encountered on a battle-field; the percentage of deaths is larger, while the sort of courage that is required is of a far higher order. The story of the Great Trigonometric Survey when fitly told will form one of the proudest pages in the history of English domination in the East."

Is there anything which can stir the blood more than this reference to the fierce conquest of great difficulties in order to achieve a high purpose, or anything more ennobling than the contemplation of unselfish devotion to duty?

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